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SUPPORT OF ENERGY PROGRAM PLANNING

Richard A. Schmidt

Stanford Research Institute

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13. ABSTRACT

Principal energy problem areas of importance to the Department of Defense were identified and possible approaches to advanced research projects directed toward solutions of these problems were suggested to provide partial source material in support of ARPA's research program planning. Topics regarding sources and application of energy, energy transformation, storage, and distribution, and energy utilization were included. For each topic, information was organized according to statement of the problem, state of the art, present activities and organization, implications for the DoD, and recommendations for further studies.

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STANFORD RESEARCH INSTITUTE
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SUPPORT OF ENERGY PROGRAM PLANNING

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Prepared for:

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I INTRODUCTION

In mid-July 1972, Stanford Research Institute began a series of discussions with representatives of the Defense Advanced Research Project Agency (ARPA) that resulted in this effort to provide technical support to ARPA's energy program planning activities. The objectives of the effort were to identify selected principal energy problem areas of importance to the Department of Defense (DoD) and to suggest possible approaches to advanced research projects directed toward solutions for these problems. In the short time available, the Institute could not, and did not, attempt to perform a comprehensive review of the entire energy field of interest to the DoD. Rather, within the general framework discussed below, the staff selected topics of interest which it could review expeditiously because of its background and experience. This effort is intended to provide partial source material to assist ARPA in formulating its research program strategy, together with recommendations for prospective research projects addressed to present or potential energy topics.

In organizing the study team effort, the Institute adopted a tentative program structure based on the several stages of energy resource development and utilization. In particular, the team attempted to bear in mind that

> "... energy resources must be discovered, brought from the ground, processed, stored, and delivered to the ultimate consumer ... (this) implies a complex physical network that, even under the

1

best of circumstances, requires a great deal of attention to ensure its proper functioning."*

In accompishing this assignment, Stanford Research Institute assembled an interdisciplinary team of professional staff members knowledgeable in energy and resources development, economics, materials science, and technology, energy engineering, transportation, fossil fuel conversion, and systems analysis to provide background material and topic descriptions relative to energy problems of concern to the DoD. Each member prepared a brief paper on energy-related topics (according to the tentative structure) from the standpoint of his own experience and expertise. For each topic considered, information was organized as follows: statement of the problem, state of the art, present activities and organizations, implications for DoD, and recommendations for further studies.

The short time available for the study did not permit analysis of each topic in equal manner, and as a result, the depth and breadth of coverage will vary among the several chapters that follow. In some cases, it was possible only to indicate the outline of problems and to sketch prospective approaches, while in other cases more complete and detailed treatment of problems were realized and more definite approaches to their solution were prepared. It is obvious that far greater time than was available for this study is required to develop logical research programs to deal with several of the complex problems identified. Nevertheless, inclusion of even brief, outline descriptions of such problem areas in this report is believed justifiable in that it serves to place such matters on the agenda for future attention. In short, the fact that some topics are discussed at length and others only briefly is

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* Vansant, Carl, Strategic Energy Supply and National Security, 135 pp. (Praeger Publishers, New York, 1971).

not in itself necessarily an indicator of relative importance or the amount of effort expended in their preparation.

The study team has endeavored to identify, in gross terms, recommendations for research priorities consistent with the tentative structures. In presenting these recommendations, the team makes no determination as to which organizations (public or private) should perform the work. Instead, we have attempted to recognize energy research areas of importance to the DoD as an aid in its ongoing planning process, regardless of the ultimate sources of the data.

Stanford Research Institute welcomed the opportunity to undertake a task of such importance for the Defense Advanced Research Projects Agency. It is hoped that the information included in this report will facilitate ARPA's planning task and lead the way to progress in addressing energy requirements related to national defense.

The Stanford Research Institute staff who contributed directly to this report include:

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II SUMMARY AND RECOMMENDATIONS

A. Overview

Abundant domestic supplies of low-cost energy can no longer be taken for granted in the United States to meet projected demands, and the range of choice regarding energy sources is narrowing. Increased demand for energy in many respects is incompatible with growing public concern over environmental impacts of the sequences of operations leading to energy production. Yet, it is apparent that conflict between goals relative to energy and environmental quality must be reconciled if the nation is to achieve progress in its pursuit of an improved style of living that offers each individual opportunities to realize his potential, and participate fully in a dynamic society.

In large measure, the present energy situation and the projected range of energy crises are well-illustrated on a national scale by the activities of the Department of Defense. Although responsible for only about 5 percent of the total national energy consumption, DoD is supported by an extensive industrial base that also is an important energy consumer, estimated to be as much as that used by the DoD itself. Clearly, any energy shortage that impairs the ability of defense-related work to be carried out would result in far-reaching effects on the security posture of the nation, but the diversity of the defense establishment and the complex manner in which it uses energy necessitates great care in analysis to avoid facile but misleading oversimplified conclusions pro or con. In accomplishing its mission in an energy shortage situation, the DoD will require accurate information to assess the energy consequences of its present operations (and conversely), as well as to develop new programs to deal with both energy and mission-related problems.*

The role of advanced research in addressing energy problems will become increasingly important for the DoD and for the nation at large. Through such work, coordinated attacks can be made on problems of energy sources of supply, transformation, storage, distribution, and utilization to provide the capability to meet prospective future conditions that may result from a variety of causes. A number of energy problem areas are discussed in this report, and recommendations for further work are presented in support of the energy program planning activity of the Defense Advanced Research Projects Agency (ARPA). Although the short time available for this study did not permit treatment of each problem area in comparable depth, nor ranking of their relative importance, tentative conclusions regarding the significance of these topics were derived. Finally, some research priorities are suggested in gross terms to aid in ARPA's preparation of a comprehensive energy research program plan.

B. Sources and Applications of Energy

Available information indicates that the nation's conventional energy resources base and the industries that have exploited it no longer have the ability to meet forecast requirements that will be placed on them. The real meaning of the present and prospective energy crisis is that the range of energy options available to individuals, government, industry, and the nation as a whole is becoming limited to an unprecedented degree. To counter this situation, the thrust of advanced research into sources and applications of energy should be to provide the technical data

* The same is true for other public and private agencies, indicating a need for effective cooperation and coordination among them.

and institutional information necessary to arrest the trend toward fewer energy options and to realize new options for satisfying future energy needs.

The solid fossil fuels (coal, lignite, oil shale, and tar sands) provide a vast strategic reserve of hydrocarbons in the North American continent. One way to provide greater options in energy supply is to accelerate the development of advanced technology for conversion of these solid fuels to liquid hydrocarbons and fuel gas. In particular, it would be appropriate for the DoD to take an active role in development of shale oil production from the Naval reserve in the Piceance Basin of Colorado so as to fulfill its responsibility for management of this important resource. A similar argument may be applied to the important but imperfectly defined known coal deposits that occur (together with petroleum) in Naval Petroleum Reserve Number 4.

Additionally, advanced technology can improve recovery of more conventional fuels such as petroleum and natural gas. Present production techniques achieve recovery of only about one-third of petroleum resources, and the potential for adding to the supply of oil through perfection of secondary or tertiary recovery techniques warrants serious attention. Again, the DoD can logically conduct or sponsor this work to discharge its resource management functions.

Among possible other naturally occurring energy sources that might be developed to contribute to the overall energy supply are the apparently widespread but imperfectly known geothermal resources of the nation. Although present geothermal developments are limited to areas of recent volcanic activity in which high-enthalpy waters occur, there are large quantities of low-enthalpy geothermal waters in deep sedimentary basins such as along the Gulf Coast. This heat is probably two orders of magnitude greater than that of localized hydrothermal systems and could be used if adequate heat exchange technology and use for low grade heat were available.

Potentials for development of solid fossil fuels for conversion purposes would be enhanced if high capacity rapid excavation technology could be used to supply the enormous quantities of materials required by conversion processes.

The application of energy to uses of the DoD and defense related industries represents a significant portion of total U.S. energy use. Changes made in DoD material and equipment specifications to reduce internal energy use and extend the current supply could be used as guidelines for much larger energy use reduction, thus providing a much needed option. The energy required on a unit basis to produce the materials used in DoD activities was developed for 18 materials. The data indicate that in general low energy materials such as glass and plastics should replace the greater energy level materials such as steel, aluminum, or copper whenever this is possible. Exceptions exist where a change to a low energy material in one part of a system results in a larger energy consumption in another part of the system, or where changes in materials would degrade performance. Recycled materials in most instances represent a benefit in energy consumption.

The extent to which materials are substitutable to achieve net energy decreases can be treated in a general way only until the full complement of DoD requirements are analyzed. It will be necessary to describe comprehensively the energy requirements for all major material requirements of DoD so as to guide possible revisions to design or material specifications to minimize overall energy consumption.

To obtain an adequate evaluation of energy relationships to materials requirements, it will be necessary to determine the principal materials and equipment required in major DoD activities, the potential substitutions by material involved, and the related energy requirements for each substitution. This could be a huge undertaking.

C. Transformation, Storage, and Distribution

Achievement of a wider range of options regarding energy supply will be of limited value unless complementary progress is made in the means by which energy sources are transformed, stored, and distributed. Improvements in the processes of energy production are needed to achieve optimum efficiency of recovery and minimum losses in furnishing this energy to the point of its use.

Reliable long term operation of advanced energy conversion systems requires materials properties that in some cases exceed current capabilities and in other cases imply a cost premium that is unacceptable under current conditions. Major materials problem areas related to energy transformation include: (1) structural materials of improved strength and toughness, (2) high temperature materials with improved mechanical properties and resistance to physical and chemical degradation, (3) environment resistant materials that withstand stress for long term service, (4) improved conductors, and (5) improved primary and secondary fabrication techniques.

These materials can be of value in enabling greater progress in the development of alternative chemical fuels that may in part be used to compensate for more conventional fuels in particularly favorable applications. Among the chemical fuels that would be candidates for further research using advanced materials technology are hydrogen, ammonia, carbon monoxide, methanol, and alkali metals.

Much work needs to be done regarding energy transformation. As one aspect of most energy transformation processes, it will become increasingly important to control wastes of all types. Wastes may be considered hazardous from the standpoint of their potential environmental impact, but their primary disadvantage is as an indicator that energy transformation is inefficient. The conservation or storage of rejected energy, as well as the recycling and use of waste materials could aid measurably in extending the lifetime of limited conventional fuel supplies. At present, the disposal of wastes requires the expenditure of further amounts of energy and exacerbates the energy problem.

One way in which the waste disposal problem might be dealt with to accomplish energy conservation is an integrated plant concept. A possible approach to using liquefied natural gas (LNG) to provide heat, electricity, water supply, and waste water or sewage treatment at domestic or foreign defense installations is outlined. Basically, the approach uses the energy required in regasification of LNG to manufacture liquid oxygen (plus liquid nitrogen and liquid argon) which can be further used in generation of ozone for water treatment.

Distribution of energy may take many forms. In this study, we have focused on the problems related to transportation of fuels to meet DoD mission requirements and have not considered the set of problems related to energy transmission as such. Among problems of fuel transportation of concern to DoD are (1) sealift capability and escort vessel requirements in the event of greatly increased fuel imports, (2) security of sources of DoD-required petroleum products by locations, and (3) the role of prepositioned fuel storage facilities in meeting DoD operational needs.

The possible effect of nuclear attacks on energy systems is an important factor in assessing the feasibility of national survival and recovery from a heavy nuclear attack. Previous work has shown that, since petroleum refineries are so important to national survival and recovery and so vulnerable to attack, it would be desirable to make plans for dealing with an extreme shortage of refining capacity. Indeed, the present situation is of extremely short capacity now. The feasibility of improvising simple refining equipment to meet potential emergency conditions (of whatever course) should be examined.

D. Utilization

Increased sources of energy-bearing fuels and improved means of energy transformation and distribution will represent additions to overall supply only to the extent that complementary progress is made in enhancing the efficiency by which available energy is employed to perform useful work. In short, the range of options for efficient energy use also needs to be expanded. The primary use of energy for DoD purposes has been to provide mobility, but energy is also required to operate and maintain fixed installations.

It is conceivable that the energy shortage could become so severe that agencies of the federal government including DoD could be restricted to an "energy budget" requiring strict energy accountability, conservation, and management. Should such a situation take place, it will be vital to know the degree to which efficient energy conservation could be practiced without impairing operational mission effectiveness. Improvements in energy conversion efficiency could be accomplished by alternative equipment designs, changes in materials, or improvements in fuels. At present, however, the relative priority of equipment or operations in terms of their energy requirements is not well established (either for the DoD or supporting industries). To design prospective programs for energy conservation by the DoD, it is necessary to determine the scope and character of present energy uses by category of activity, priority, and efficiency of energy use. Particular constraints on energy conservation practices indicated by mission responsibilities of the individual services need to be identified and analyzed, and criteria to guide the assessment of energy-efficient activities consistent with operational performance requirements should be developed.

The present energy situation is in a state of considerable flux, and it will be important to compile and maintain up-to-date information about energy technology, economics, and institutions so as to provide for rational energy data use and management. In view of the large number of public and private organizations active in the energy field, the need for some systematic means to establish a data base regarding energy is of particular importance.

It is clear that energy development and use represent perturbation to the natural environment. The DoD is exposed to pressures regarding the environmental impact of its energy programs because it is a fuel user, a priority consumer of a commodity in short supply, and a holder of fuel reserves whose development can lead to at least temporary degradation of environmental quality. However, DoD has an opportunity to serve as an environmental problem-solver relative to energy utilization by taking account of adverse environmental effects in the design and implementation of its energy use and conservation activities.

In order to conserve energy and minimize environmental impacts at fixed facilities of the DoD, it will become increasingly important to apply "total energy concepts" in which multiple-purpose energy generating and distribution systems are employed. As part of this approach, the potentials for use of apparently significant but undeveloped geothermal resources to supply the energy needs of DoD installations in favorable areas such as the Gulf Coast needs to be assessed.

E. Conclusions

The data summarized above lead to the general conclusion that the increasing levels of public discussion about an impending "energy crisis" are entirely warranted and could even be understated. It is apparent that the present energy situation faced by the United States is one in which the options available to alleviate a potential inbalance in the ability of domestic supplies to meet demands are severely restricted. Unless a coordinated and comprehensive effort is initiated shortly to provide new options for meeting the nation's energy needs, the possibility will loom greater that one or more of the severe energy crisis scenarios could become reality.

It is clear that advanced research is required into a number of problems related to energy. This work will have to include all parts of the sequence of steps by which energy is produced and used. The work will doubtless concern cognizant public and private organizations; however, the DoD can provide the impetus for such work related to its mission or responsibilities. The character of necessary R&D work relative to energy requires attention, since it can influence the degree to which energy options may be effected. A balance will need to be struck between basic and applied research. Although the need for basic research on aspects of the energy situation is acknowledged, a more pressing need appears to be in applied research to demonstrate the operational feasibility of new techniques or processes. In many cases, problems identified during applied research may well require basic research to realize their solution. For example, a number of processes for coal gasification have been developed and tested on a bench or pilot scale, but operational scale demonstrations of modern technology are lacking.

Conclusions regarding research problem areas are presented below, according to a rough ranking as to degree of the problem:

- Items that present no problem: We believe that the energy situation is such that it would be inappropriate to consider that no aspect of the situation is without a problem.

- Problems for which some solution may be anticipated from work already under way: These are areas in which considerable work has already been done, serving as the basis for operational contributions to the energy scene. In large degree, these problems require applied research to resolve particular application or scale factor problems. Among the areas included in this category are:

- Coal gasification and liquefaction
- Oil shale and tar sand recovery
- Secondary and tertiary petroleum recovery
- Liquid fuel transportation and storage
- Energy data management
- Vulnerability of energy systems
- Energy conversion by nuclear reactors

• Problems that require new research to achieve better understanding of directions leading to possible solutions: These are areas that are relatively unknown, requiring a greater degree of research--basic and applied--to define them more fully so as to indicate possible solutions (or at least to identify the blocking problems). Among the areas included in this category are:

- Environmental impacts of energy development and use
- Geothermal resources
- Oil shale recovery
- Materials properties
- Energy relationships to materials production
- Chemical fuels
- Integrated LNG usage.
- Waste heat from energy production processes

• Problems that are technical in nature but constrained by nontechnical factors: These are areas in which nontechnical factors--e.g., institutional, political--constrain technical progress. Among the areas included in this category are:

- Energy conservation in the DoD and supporting industries
- Energy data management
- Relationships among domestic public and private institutions carrying out work in the energy field
- Conceivable international conditions that may influence domestic energy supply.

F. Implications for Research Priorities; Recommendations

The conclusions expressed in the previous section indicate that conventional ideas regarding research priorities--constituting simple listing of things to be done in order of their apparent importance--do not make sufficient allowance for the types of problems existing in the energy field and especially for the urgency of the situation. Instead, the importance of each problem area is such that research priorities can and should be established individually by category, enabling a coordinated and wide-ranging effort in energy R&D to proceed along a number of directions simultaneously, but that the interrelationships among such work need to be recognized. The listing of topics under each problem area in the preceding section is a first attempt to suggest, in gross terms, possible priority rankings.

This approach to identification of research priorities implies recommendations for specific research topics to resolve particular classes of problems identified. Each research topic comprises a number of specific problems requiring attention to permit continued progress in the energy field; these specific research items are contained in individual chapters of this report and are summarized in Table II-1. No attempt is made to identify organizations that could or should perform such work, although the close cooperation of all organizations concerned will be essential. However, before a final listing is attempted, it will be necessary to bear in mind the interrelationships among the stages of energy production and use, as well as the interchangeability among candidate fuels, so as to realize the full benefit of related research work to address the overall national energy problem as well as that relative to the DoD.

Table II-1

SUMMARY OF SPECIFIC RESEARCH TOPICS RECOMMENDED FOR CONSIDERATION BY ARPA IN ENERGY PROGRAM PLANNING

I. Problems for which the solution may be anticipated from work already under way:

A. The need for advanced energy technology in fuel production and processing

1. Coal mining methods for increased productivity with improved health and safety

2. Reclamation of mined lands

3. Secondary and tertiary petroleum recovery

4. Petroleum recovery from the outer continental shelf

5. Coal gasification and liquefaction

6. Control of SO_x and NO_x emissions from fuel use

7. Oil shale and tar sand processing and control of environmental effects

8. Deep drilling for natural gas

9. Production of substitute natural gas (SNG) from coal or oil

10. In-situ processes for solid fuel conversion

11. Advanced power cycles systems for increased efficiency in electric generation with minimal environmental impact

12. Improved home heating and automobile designs to conserve energy

B. Energy fuel transportation

1. New vehicles for fuel transportation (e.g., air cushion vehicles, cargo aircraft, surface vessels, and submarines)

2. Extensions of the capacity of present transportation systems to remote fuel supplies with minimal environmental impact

3. Analysis of effects of fuel discharge into special environments (e.g., oil spills in polar regions).

4. Slurry pipelines for transport of solid fuels, especially flow characteristics of slurries of various types of coal relative to quality

5. Control of large power losses in long distance electrical transmission

C. Vulnerability of energy systems to nuclear attack

1. Analysis of refining, generating, and transportation systems

2. Feasibility of improvising simple refining equipment to meet emergency situations

3. Feasibility of rerouting electricity (or fuel transportation) from surviving supplies to meet needs in areas of attack.

II. Problems that require new research to achieve better understanding of directions leading to possible solutions

A. Environmental aspects of energy development and use

1. Impacts associated with fuel production (e.g., coal mine reclamation, processed oil shale disposal)

2. Processing effects (e.g., air quality, water quality, solid waste disposal)

3. Transportation effects (e.g., oil spills, pipelines)

4. Utilization effects (e.g., waste heat, particulates)

B. Potentials for geothermal resource development

1. Quantify descriptions of geothermal resources

2. Derive criteria for evaluation of sites

3. Assess technology and economics for geothermal resource development

4. Identify needed R&D efforts

C. Advanced research in rapid excavation for oil shale recovery

1. Oil shale weakening or cutting methods
2. Handling of mined shale
3. Advance geological exploration
4. Improved procedures for water control
5. Systems analysis of excavation operations
6. Environmental aspects of oil shale development

D. Energy relationships to materials requirements

1. Comprehensive analysis of energy required for material production
2. Materials substitutability relative to DoD requirements
3. Recycling as an energy conservation measure

E. Materials requirements in advanced energy conversion systems

1. Structural materials of improved strength and toughness
2. High temperature materials of improved mechanical properties
3. Environmental resistant materials
4. Conductors, insulators, and magnetic materials
5. Improved primary and secondary fabrication techniques

F. Production and utilization of non-hydrocarbon chemical fuels

1. Methods for hydrogen storability
2. Combustion characteristics of special fuel mixtures
3. Automatic dual-fuel internal combustion engines
4. Storage of combustion heat by dissociation of hydrides
5. Development of inexpensive and more effective catalysts for fuel cells

6. Reduction in heat generation and reducing cathode irreversibility of existing refuelable battery systems

7. Development of large scale reversible hydrogen fuel cells for use as peak electrical energy storage devices in conjunction with advanced generating systems.

G. Integrated LNG usage

1. Experimental work in ozone generators

2. Compare fuel and cryogenics requirements of DoD facilities

3. Determine applicability of LNG regasification energy to provide for integrated energy and waste treatment

4. Analyze costs and benefits from such operations in terms of fiscal and energy budgets

H. Waste heat from energy production processes

1. Economic and thermodynamic analysis of utilization of power plant waste heat for liquefaction

2. Feasibility studies of LNG stock piling in underground reservoirs

3. R&D in advanced power boiler cycles utilizing oxygen rather than air for the combustion of coal or synthesis gas to control NO_x emissions

4. Interactions of sodium or potassium vapors with advanced turbine materials

5. Feasibility of a closed-co-op energy cycle using an LNG/oxygen boiler for steam operation and an air liquefaction plant for waste heat utilization

III Problems that are technical in nature but constrained by non-technical factors.

A. Energy conservation in the DoD and supporting industries

1. Scope and character of present energy uses by category of activity, priority, and efficiency of energy use

2. Energy substitutionality for priority uses

3. Constraints upon energy conservation practices due to mission responsibilities

4. Assessment of technological and institutional implications of energy conservation

5. Criteria for evaluation of energy consumption relative to operational performance to derive guidelines and specifications for energy-efficient equipment

B. Energy data management

1. Assessment of data system applicability to energy management

2. Determination of DoD energy information needs

3. Design of energy data system to organize and analyze energy data

C. Relationships among domestic public and private institutions carrying out work in the energy field

1. Compilation of practices and procedures of cognizant agencies relative to energy

2. Analysis of patterns of institutional transactions among agencies and organizations to identify constraints to energy supply

3. Assessment of effects of alternative approaches to key institutional modes in the energy field

SOURCES AND APPLICATIONS OF ENERGY

III THE NEED FOR ADVANCED ENERGY TECHNOLOGY FOR FUEL RECOVERY

III THE NEED FOR ADVANCED TECHNOLOGY FOR FUEL RECOVERY AND UTILIZATION

A. Introduction

To provide a general perspective for energy research opportunities, SRI has investigated the U.S. energy picture. The year 1970, for which the latest reliable data were available, was selected as a basis from which an extrapolation to 1980 might be made. Compared with past history, this decade already has shown that unusual events will occur as the nation reaches the limit of its domestic energy supply, which is constrained by the limitation of environmental pollution.

Within a relatively short time and in an unexpected manner, several circumstances are coincidentally occurring that are increasing the uncertainty of meeting future energy requirements in the United States. Much of the dilemma centers around the need for substantially increased environmental purification and protection. The following factors are intended to briefly summarize the situation:

(1) Clean air, particularly with respect to sulfur dioxide content, is the primary incentive for using low sulfur fuels. Use of gas and low sulfur fuel oils has begun to accelerate. Meanwhile, part of the abundant coal reserves has been limited in use because of high sulfur contents and the lack of economic desulfurization technology.

(2) The inability to obtain approval for new plant sites is causing delays in refinery planning and construction. Needed refinery capacity to meet energy requirements probably will not be built in time to avert shortages of refinery products.

(3) Environmental concerns regarding the land and the sea are delaying the use of domestic energy resources.

Relatively large reserves of oil in Alaska cannot be used because of anxieties regarding the use of a pipeline. Oil in the Santa Barbara Channel is shut in because of possible damage to beaches, wildlife, and marine life. The concept of drilling for oil and gas on the Continental Shelf is causing great concern. Plant siting along the Eastern Seaboard has been made extremely difficult. Power generation from nuclear sources may not reach projected capacity because of environmental worries.

(4) Oil production rate in the lower 48 states is projected to begin declining within the decade. Recently it has become clear that forecasts of the supply of natural gas and associated liquids have been overestimated.

(5) The need for substantially greater quantities of imported oils, combined with the difficulty in obtaining plant sites and oil import allocations, is forcing the export of important refinery capacity to foreign countries.

(6) Progress in the development of technology to use U.S. energy resources such as coal, oil shale, and uranium (breeder reactor and U-238 isotope conversion), may not occur in time to allow commercialization in quantities required to avert an energy shortage.

These events are producing a great deal of uncertainty and a need for careful planning that shows comprehension of the entire social and economic structure of the United States. The future security of the United States will depend on the rapid implementation of new energy developments and the continued innovative search for new ideas.

B. The U.S. Energy Situation, 1970-1980

Before examining the U.S. energy balance, a brief review of energy sources and their interrelationships will be useful in obtaining an overall view.

1. Petroleum

The United States is faced with an increasing shortage of domestic petroleum. Estimates of known oil for 1971 in the United States (including the North Slope of Alaska) may be categorized as follows:

	Billions of Barrels	Percent of Total
Cumulative past production	96	22.6%
Recoverable reserves	38	9.0
Potentially recoverable oil	61	14.4
Unrecoverable oil	230	54.0
Total oil discovered	425	100.0%

Crude oil recovery efficiency has increased over the last two decades despite decreasing crude oil prices, as shown in Figure III-1.

The lower 48 states' production is expected to begin a decline within this decade. Alaskan oil will provide an important addition to domestic production, but it will not be enough. U.S. imports of foreign oil are expected to rise as shown below:

	1970		1980	
	Thousands of B/cd	Percent	Thousands of B/cd	Percent
Domestic production	11,312	76.8%	12,780	50.5%
Imports	3,418	23.2	12,520	49.5
Total supply	14,730	100.0%	25,300	100.0%

Refinery processing schemes are expected to change considerably. The removal of lead from gasoline will require the production of higher clear octane number gasolines. Refineries are expected to be producing considerably greater amounts of low-sulfur fuel oils to balance the

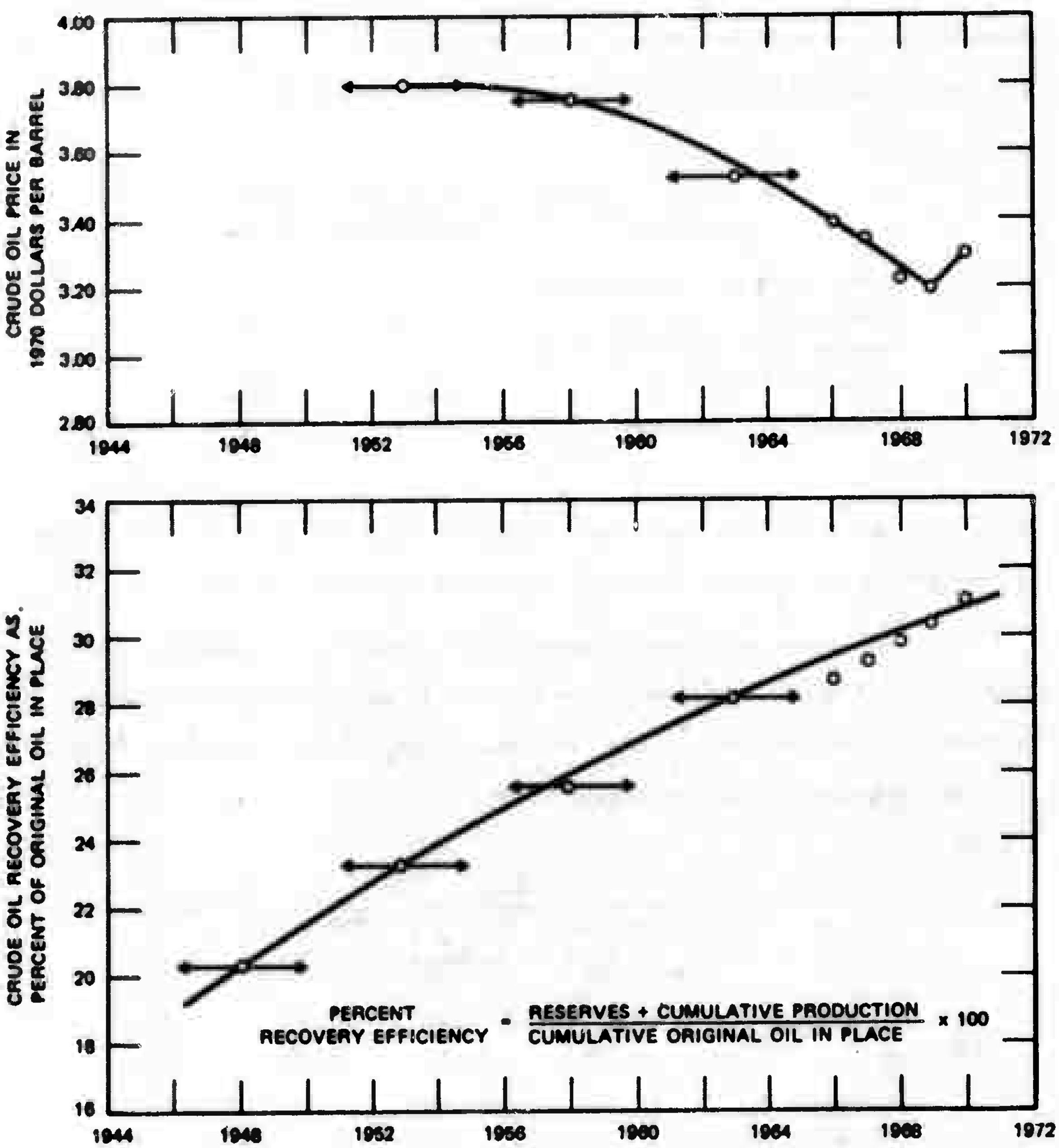


FIGURE III-1 HISTORICAL PATTERN OF U.S. CRUDE OIL RECOVERY EFFICIENCY AND PRICE energy shortfall caused by insufficient gas. The gas oil portion of fuel oil will command a premium value, because it is relatively easy to desulfurize compared with the residuum. Future refineries also will be more complex because of the requirements for octane improvement and fuel oil desulfurization.

2. Gas

At existing price levels, the supply of natural gas in the United States has become limited. The recent regulation of prices by the Federal Power Commission below parity with other low-sulfur fuels is stimulating an excessive demand for gas. Furthermore, the lower prices for gas have reduced the incentive for exploration and development of new gas reserves. The dependence on gas and the shortage of supply are forcing the conversion of oil to gas. It is expected that by 1980 about 700,000 barrels per calendar day of liquid hydrocarbons (primarily naphtha) will be converted to substitute natural gas. The natural gas suppliers and gas transmission companies have already announced several planned installations. These companies will be bidding for light hydrocarbon feedstocks in direct competition with the petrochemical manufacturers. The utility companies, for the most part, may be able to outbid the petrochemical companies, because the utility has considerably less risk in an FPC-approved project.

Supplemental supplies of gas are expected from Alaska, Canada, and via liquified natural gas (LNG) imports. Additionally, by 1980, coal gasification is expected to begin a relatively long period of gas production.

In the future, the shortage of gas will force a system of rationing to be established, with priorities set for its use if gas prices are controlled below parity with other fuels.

3. Coal

The United States has abundant potentially usable reserves of coal. These are optimistically estimated at 800 billion tons, or the equivalent, if liquefied, of 2,500 billion barrels of synthetic crude oil. These figures leave little doubt that coal will become the dominant future source of oil and gas. However, during this decade the direct use of coal as an energy source is expected to remain nearly constant in the range of 6,500 to 7,000 thousands of barrels per calendar day of oil heating value equivalent. The use of coal in the form of substitute natural gas (SNG) is expected to emerge by the end of this decade. By 1980 only 0.4 trillion cubic feet per year of SNG is anticipated. After 1980, the trend of coal gasification should accelerate.

4. Oil Shale

The deposits of oil shale in the United States are a potential source of future energy supply. However, commercialization in significant quantities is not expected during the coming decade. Estimates of potential oil from shale vary widely, depending on the concentration of Kerogen (hydrocarbon source) in the various deposits. Deposits of oil shale with a concentration of 35 gallons per ton or greater are estimated to have a potential for production of 75 billion barrels of oil.

5. Athabasca Tar Sands

These tar sands deposits in Alberta are estimated to have the enormous potential equivalent of 600 to 1,000 billion barrels of synthetic crude oil. This is more than the world's entire proven reserves of conventional crude oil. The exploitation of this energy source has already been commercialized by Great Canadian Oil Sands, Ltd. (GCOS) at the rate of 45,000 barrels per stream day. A second project is currently planned by Syncrude Canada Ltd. to produce 125,000 barrels per stream day with an initial investment of about $500 million. The plant is expected to be completed in 1977. However, because a manufacturing facility of this nature is extremely capital intensive and requires greater than average risks, only production from one additional plant of about 100,000 to 150,000 barrels per stream day can be expected in this decade, giving a total of about 300,000 barrels per stream day of synthetic crude oil.

6. Nuclear Energy

Projections of U.S. energy supply have assumed an important contribution from nuclear energy sources. It is anticipated that the power generated from nuclear plants in 1980 will be equivalent to having converted 6 million barrels per calendar day of oil, gas, or coal at 31 percent efficiency into electrical energy. If these plants cannot be installed, the major alternative to meeting the forecasted energy demand will be the importation of greater amounts of oil, primarily from the Eastern Hemisphere.

7. Petrochemicals

The major problem that petrochemical manufacturers are facing is the limited supply of low-cost hydrocarbon feedstock. Cheap foreign naphtha is expected to become less available because of the demand for this material for gasification in the United States. One proposed SNG plant in the United States has already contracted for 75,000 barrels per day of imported naphtha at 8.3 cents per gallon, which is about 30 percent higher than foreign naphtha has been in recent years.

The limitation of natural gas supply will also limit the production of natural gas liquids. The production of hydrocarbon chemicals has been based on the use of low-cost natural gas liquids and equivalent refinery streams. It is clear that future hydrocarbon feedstocks for petrochemicals will emanate from petroleum. It is probable that the gas oil will be used increasingly for the production of olefins despite the increased value of gas oil in low-sulfur fuel oil. This is especially true as long as gasoline remains leaded. The removal of lead will liberate naphtha-type hydrocarbons that may become petrochemical feedstock. Most of this naphtha will remain in gasoline even at low lead levels. Most of the low octane naphtha will not become available until lead is eliminated. Sources of petrochemical feedstocks are estimated below.

	1970		1980	
	Thousands of B/cd	Percent	Thousands of B/cd	Percent
Gas (oil equivalent)	242	25.2%	395	20.9%
Natural gas liquids and equivalent refinery streams	620	64.4	592	31.4
Imported naphtha	100	10.4	200	10.6
Other liquid hydrocarbons	—	—	700	37.1
Total	962	100.0%	1,887	100.0%

Thus, petrochemical feedstocks will become less available at past prices because of (1) the growing shortage of natural gas and an attendant upward pressure on gas and LPG prices, making the alternative use of natural gas liquids for LPG more attractive; (2) the increasing use of naphtha for gasification; and (3) the increasing necessity of using gas oil in low-sulfur fuel oil to make up the energy shortfall.

In an effort to simplify the complex mixture of energy supply types and their innumerable uses, energy balances for 1970 and 1980 were made by converting all energy forms to acceptable oil heating value equivalents. The oil figures, however, were not modified. Poetic license was taken with respect to the C_2, C_3, and C_4, which are in actual barrels per calendar day (B/cd). Assumed energy equivalence factors are shown below.

Gas	1,035 Btu/scf
Oil	5.85 million Btu/bbl
Coal	25.2 million Btu/st
Power generation efficiency	
1970	30.3%
1980	31.0%
Hydroelectric and nuclear	9,500 Btu/kWh

8. U.S. Energy Balance--1970

The 1970 U.S. energy balance diagram in Figure III-2 shows the demand for the various energy forms and how they were supplied. The most striking fact with regard to energy input is that the United States supplied 88.4 percent of total energy (including hydrocarbons for chemicals) from domestic sources as shown in Table III-1. Compared with Western Europe and Japan, each of whom depends almost wholly on imported energy requirements, the United States was virtually self-sufficient.

Table III-1 shows that petroleum supplied almost one-half the energy needs in 1970. Domestic oil accounted for the bulk of the oil supply. Residual oil from the Caribbean and Western Hemisphere crude oil primarily from Canada and Venezuela accounted for a major portion of the imported oil. Eastern Hemisphere crude oil imports primarily from the Middle East and Africa were only 2.5 percent of the total petroleum supply or about 10.6 percent of total oil imports. The U.S. strategy for imported oil clearly was to minimize dependence on geographically distant and politically unreliable sources.

Domestic production of gas of 22 trillion cubic feet in 1970 (equivalent in heating value to over 10 million barrels per calendar day of oil) supplied about one-third of total energy requirements. Additionally, 0.8 trillion cubic feet were obtained from Canada in 1970.

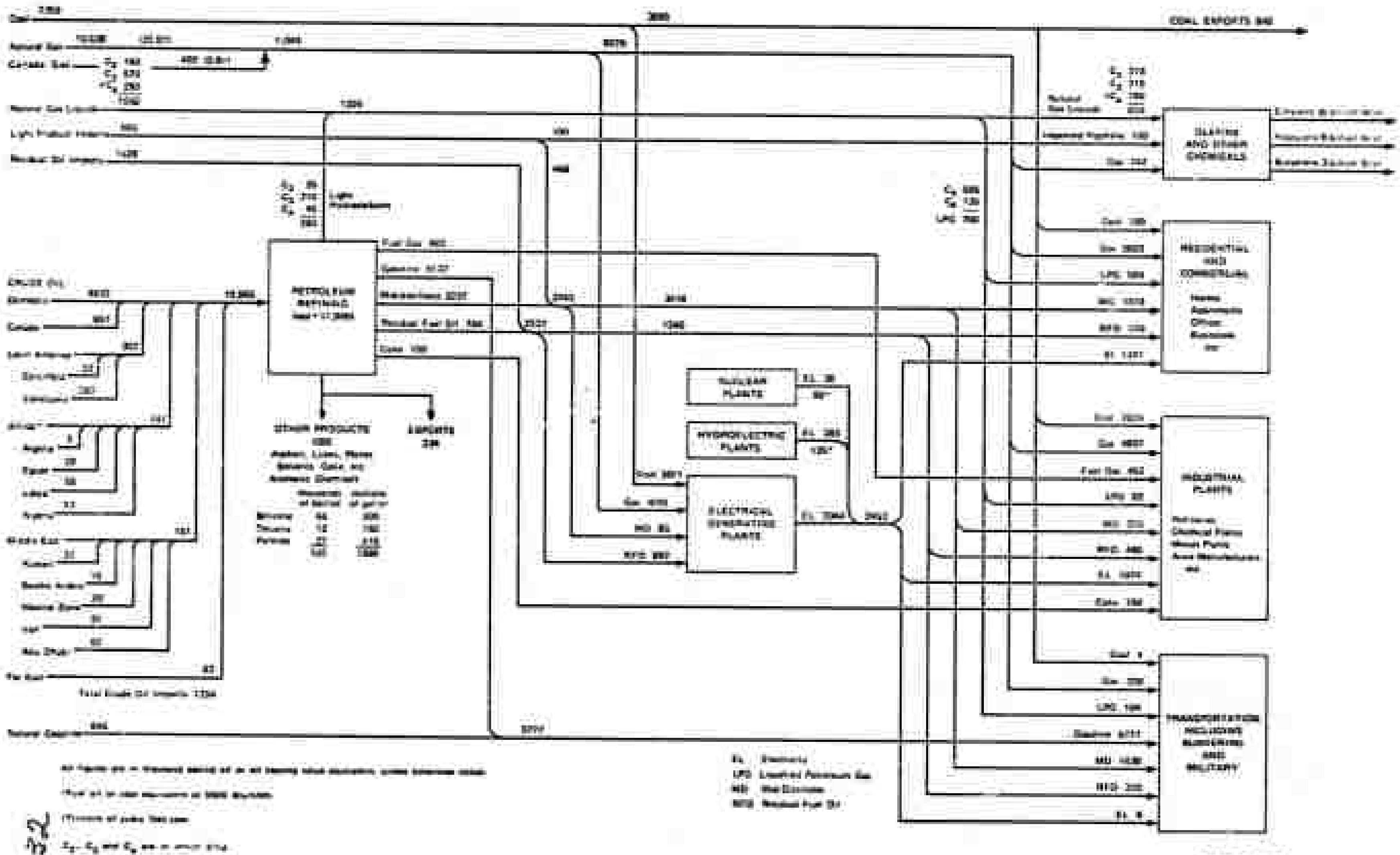


FIGURE III-2
U.S. ENERGY BALANCE, 1970

Table III-1

U.S. ENERGY SUPPLY

	1970		1980	
	Thousands of B/cd*	Percentage of Total	Thousands of B/cd*	Percentage of Total
Coal				
Solid	6,508	19.2%	6,700	12.9%
Gas			276	0.5
Subtotal	6,508	19.2%	6,976	13.4%
Gas				
Domestic	10,638	31.3	10,186	19.7
Imports	402	1.2	1,350	2.6
Subtotal	11,040	32.5%	11,536	22.3%
Oil				
Domestic	11,312	33.2	12,780	24.7
Western hemisphere crude imports	959	2.8	2,700	5.2
Eastern hemisphere crude imports	365	1.1	6,418	12.4
Light products imports	566	1.7	1,102	2.1
Residual oil imports	1,528	4.5	2,300	4.4
Total imports	3,413	10.1	12,520	24.2
Refinery gains	324	1.0	555	1.1
Subtotal	15,054	44.3%	25,855	50.0%
Hydroelectric	1,250	3.7	1,370	2.6
Nuclear	100	0.3	6,050	11.7
Total energy supply	33,952	100.0%	51,787	100.0%

* Oil or oil heating value equivalent.

The U.S. energy supply picture is essentially complete when coal is considered. This source accounted for about 20 percent of total supply and was used primarily for the generation of electricity and as fuel for industrial operations.

The demand for energy and hydrocarbons for chemicals may be conveniently divided into several basic categories. This allows one to quantitatively comprehend the magnitude of energy consumed in these sectors as shown below.

Demand Sector	Percent of Total 1970 Energy Supply
Residential and commercial	19.3%
Industrial plants	27.4
Transportation	24.7
Electric generation	20.4
Hydroelectric (supply)	1.2
Nuclear (supply)	0.1
Chemicals	2.9
Other petroleum products	4.0
Total	100.0%

These figures leave little doubt that the U.S. society is truly industrialized and strongly dependent on automotive transportation. The unparalleled success of achieving a highly industrialized economy and the accompanying increases in standard of living in the United States may be attributed in part to the abundance of domestic energy sources. However, the United States is now facing a situation that indicates a much greater dependence on foreign energy supplies.

9. U.S. Energy Balance--1980

The assumptions made for the 1980 U.S. energy balance are based on what currently seems to be the most probable situation for the future. Events not totally unexpected, such as wars and financial crises, were not assumed because of the relatively short period of the projection.

The 1980 U.S. energy balance in this study is one of a multitude of balances that can be made by varying the input assumptions. The significant assumptions made for the 1980 energy balance as shown in Figure III-3 are as follows:

(1) The projected total energy demand as described above will be satisfied.

(2) Energy must be supplied in a form that is acceptable with regard to environmental care considerations. Emissions of SO_2 will be limited to those derived from the equivalent of 0.3 weight percent sulfur fuel oil.

(3) The use of coal will be limited because of its sulfur content that would emit excessive SO_2 on combustion.

(4) Stack gas scrubbing of SO_2 will be uneconomic for high-sulfur coal and for high-sulfur oil relative to the cost of either coal gasification or low-sulfur oil. Furthermore, the technical problems associated with stack gas scrubbing will not be overcome in sufficient time to allow greater coal utilization than in 1970.

(5) Coal will be gasified into both low and high Btu gas at the rate of one billion cubic feet per day or 0.4 trillion cubic feet per year. The low Btu gas will be used in power plants, and the high Btu gas will enter the pipeline system.

(6) Even with anticipated future price increases for natural gas at the wellhead, the total production of natural gas in the lower 48 states will increase only modestly.

(7) Natural gas from Alaska will be transported to the Chicago area via a pipeline to be constructed along the MacKenzie Valley.

(8) The increase in natural gas prices will bring forth additional Canadian gas for use in the United States. Total gas imports from Canada will be 1.5 trillion cubic feet per year.

(9) Liquefied natural gas (LNG) will be imported at the rate of 1.5 trillion cubic feet per year. LNG imports will be limited by the ability to build tankers and to implement projects from a political viewpoint.

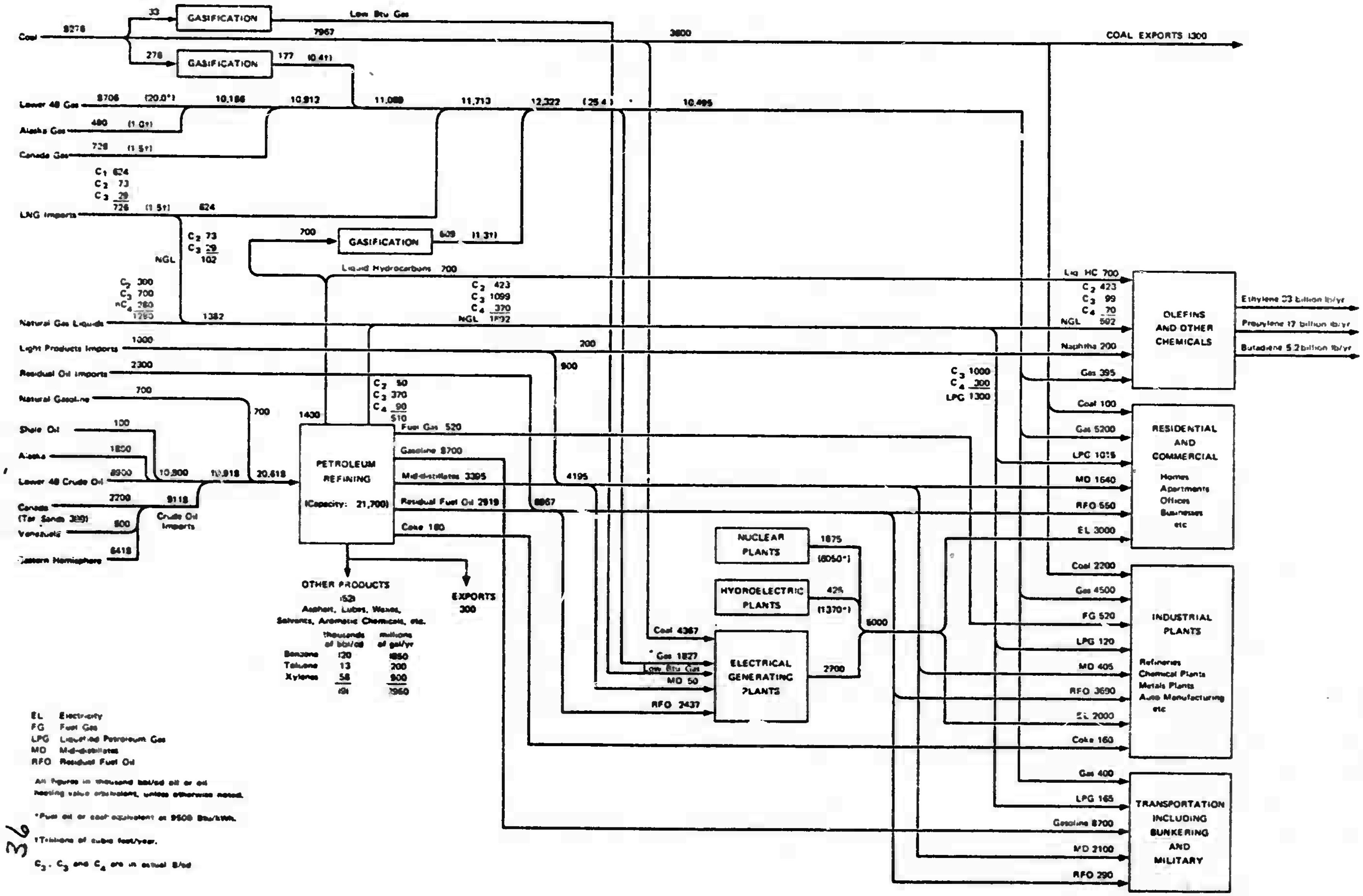


FIGURE III-3
U.S. ENERGY BALANCE, 1980

(10) Natural gas liquids (NGL) supply will increase only modestly and will be related to the production of natural gas in the lower 48 states and Alaska. Natural gas liquids will be separated from LNG imports and will add to the NGL supply.

(11) Imports of light products--naphtha for petrochemicals and middle distillates--will increase to a total of one million barrels per calendar day.

(12) Residual oil imports will reach 2.3 million barrels per calendar day of low sulfur fuel oil derived from the Caribbean area. This quantity is based on the limited availability of Venezuelan oil to supply Caribbean refineries for the production of the residual fuel oil. It was assumed that 3.0 million barrels per calendar day of crude oil from Venezuela would be the limiting amount available to these Caribbean refineries for this purpose. It was further assumed that the Caribbean refineries would not be operated using Eastern Hemisphere crude oil; if crude oil from the Eastern Hemisphere were required, it would enter the U.S. mainland directly via an imported crude oil processing (ICOP) facility or fuel oil-gas (FOG) refinery.

(13) Despite price increases for domestic crude oil, the lower 48 states' production of crude oil will have reached a maximum and have begun declining. U.S. Government policy regarding leasing of government lands for hydrocarbon exploration and development will be modified slowly to allow increased activity.

(14) Crude oil from Alaska will reach the lower 48 states via a trans-Alaskan pipeline with further transshipment by tanker. This rate will be 1.8 million barrels per calendar day.

(15) Canada will supply substantially greater amounts of crude oil to the United States. This rate will be 2.2 million barrels per calendar day.

(16) Venezuela will not be able to supply more than 0.5 million barrels per calendar day of crude oil to the United States, since a great deal of their oil will be going to Caribbean refineries for the production of low-sulfur oil that will enter the United States.

(17) Eastern Hemisphere crude oil necessary to make the energy balance will rise dramatically to 6.42 million barrels per calendar day. Therefore, the United States will become increasingly dependent on Africa and the Middle East for crude oil. The increased competition with Western Europe and Japan for crude oil from the Oil Producing and Exporting Countries (OPEC) will result in increased crude oil prices and increased royalty and tax payments to the host countries.

(18) New refining facilities will be constructed rapidly once penetration is made into the environmental siting problems.

(19) Nuclear plants constructed in the United States will generate electricity at a rate corresponding to the one that would be achieved in conventional power plants running 6.05 million barrels per calendar day of oil. If nuclear plants do not achieve this capacity, oil requirements to make up the shortfall will increase the requirements of crude oil from the Eastern Hemisphere.

(20) Gasoline used in the United States will be lead-free and will have a research octane number (RON) of 93. The internal combustion engine will remain the primary method of automotive propulsion. However, the rotary engine will have made a modest penetration into the market.

(21) Oil gasification processes will effect the conversion of 700,000 barrels per calendar day of naphtha to produce 1.3 trillion cubic feet per year of substitute natural gas or SNG. This quantity will represent about 20 percent of the incremental gas supplied over that supplied in 1970.

(22) The total gas supply of 25.4 trillion cubic feet is less than the potential demand of about 34 trillion cubic feet. It was assumed that the available gas would be allocated on the basis of first satisfying to the full extent the demands in the residential and commercial sector. Any remaining gas was then allocated to industrial plants and electrical generating plants in proportion to their consumption of gas in 1970.

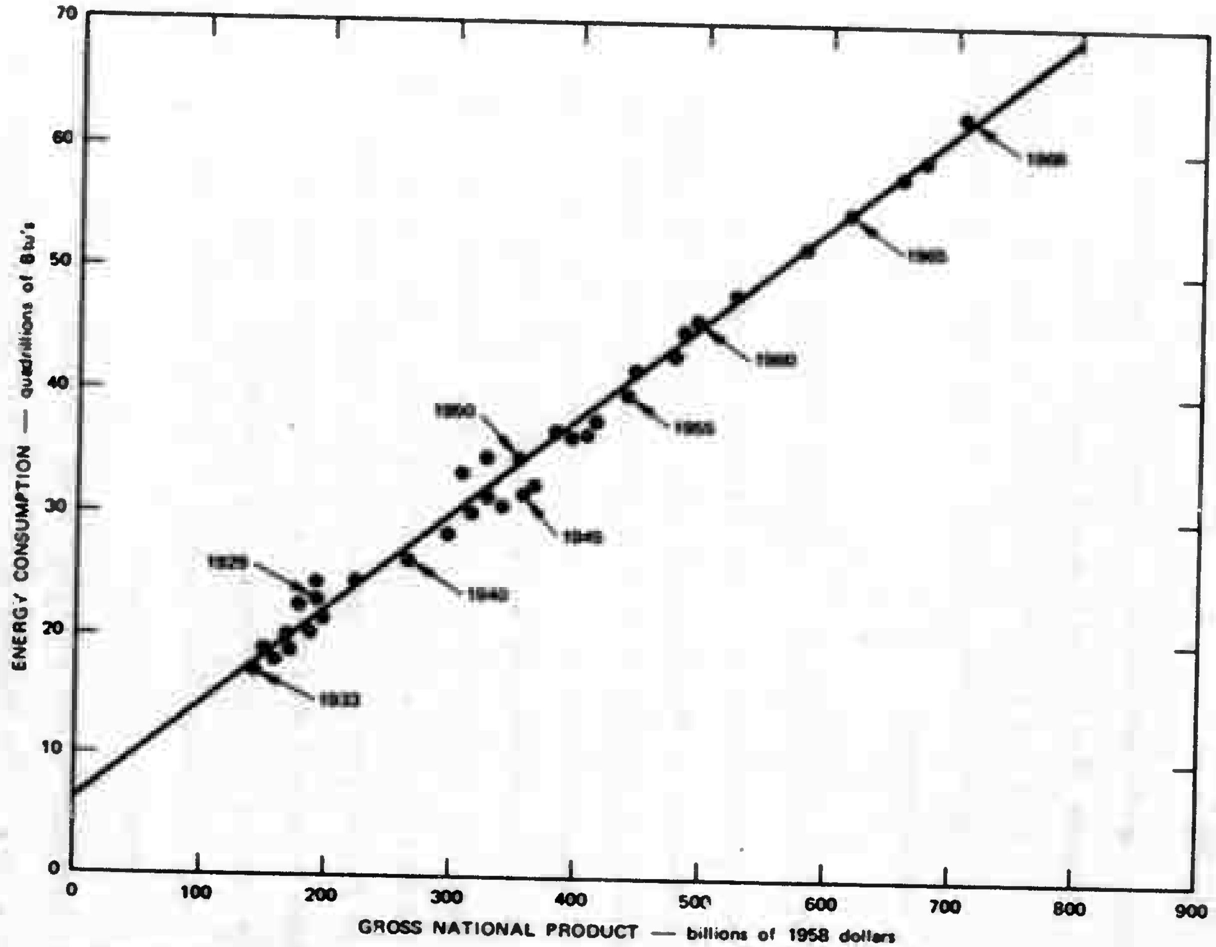
Since industrial and electrical generating sectors did not receive the gas that was demanded and because their ability to burn additional coal was assumed to be hindered both technically and economically, the burden of meeting energy demands was placed on oil. Thus, the demand for oil in electrical generation plants is expected to be double that of 1970, while oil demand for industrial use shows an ominous three-fold increase over 1970.

Clearly, the United States will crave substantial increases of imported oils to supply the forecast energy demand. A great deal of the needed energy will be in the form of low-sulfur oils and SNG. The proportions of each from a given amount of crude oil will depend on both economic and political considerations.

10. Energy Consumption and Gross National Product

One may question the basic premise that requires the satisfaction of total energy demands in the United States. In view of the predicted increasing dependence on foreign sources of energy and the questionable availability of these supplies on a long term basis, it is imperative that the United States detect and reduce nonproductive uses of energy. However, over the last 40 years, it is clear that increased energy consumption was productive as measured by the Gross National Product (GNP) and as shown in Figure III-4. An extrapolation of the trend shown to zero GNP appears to have a positive intercept of energy consumption, which may be an amount of energy that is nonproductive, if, in fact, the intercept is real. Although this subject is worthy of investigation, it is beyond the scope of this study.

On the basis of the extremely good correlation between energy consumption and GNP, it is reasonable to conclude that the GNP will increase only if greater quantities of energy are supplied and consumed within the framework of the U.S. society as it now exists.



NOTE: Redrawn from publication "The Outlook For Fossil Fuels" by Warren B. Davis, Director-Economics, Gulf Oil Corporation

FIGURE III-4 U.S. ENERGY CONSUMPTION AND GROSS NATIONAL PRODUCT, 1929-1968

C. Technology Status for Future Resource Recovery and Utilization

1. Introduction

From the preceeding discussion, it is clear that the need exists for research and development for utilization of fuels and their recovery from the earth. The United States is at a critical crossroads in its industrial development pattern. No longer is the United States self-sufficient in resources; in fact, the pattern of resource recovery and utilization grows more difficult each year. Much research is being conducted by energy-associated industry, but it is becoming increasingly clear that the time and money expenditures associated with such activity are not sufficient to bring research efforts to fruition fast enough to avoid major problems with fuel supply.

In view of the seriousness of the U.S. energy crisis, massive support is needed for research and development programs in the fields of fuel production, processing, power generation, energy transportation, and energy utilization. The energy crisis in the near term (until about 1980) can be eased only by large expenditures for existing development programs. It should be recognized, however, that little fundamental research has been done in many areas pertaining to energy. The ultimate technical and economic success of many U.S. energy-related projects in the 1980s and beyond may well depend on research programs begun now. The following specific research areas are regarded as the most urgent. However, no detailed critique of these research areas was possible within the limited scope of this study.

2. Coal Mining

Coal mining has historically been an industry in which little has been spent on research and development, considering the economic and social importance of the industry. Coal research and development has been funded primarily by the Department of the Interior, coal and gas industry associations, and a few petroleum and chemical companies. Moreover, the work done on coal research and development pales in significance when compared with that for petroleum exploration and refining.

Coal mining is a labor intensive industry. The work in an underground mine is dangerous, uncomfortable, and unhealthy. As such, mining does not attract a sufficient number of trainable personnel. The health and safety record of underground coal mining is poor in spite of postwar technological improvements. The Mine Health and Safety Act of 1969 provides many costly solutions for health and safety problems. It is doubtful that mining companies will be able to sponsor the necessary research and development programs necessary to economically meet the objectives of the Mine Health and Safety Act.

Two specific projects that would be of great benefit would be:

(1) The development of life support systems for underground miners to allow them to work comfortably and to avoid dust inhalation.

(2) The investigation of rugged, sensitive, and reliable gas analyzers to detect the presence of dangerous concentrations of methane gas that often causes mine explosions.

It is likely that the DoD (or NASA) has already funded work in these two areas for aerospace life support applications.

The major problem of surface coal mining is land disturbance and reclamation. In general this problem has not been systematically studied to realize improvements. However, land reclamation research concerning arid stripped land is needed so that many prospective western coal fields may be mined. Cheap soil stabilization and revegetation methods should be studied.

3. Petroleum and Gas Recovery

a. Petroleum

Vast amounts of oil remain to be discovered in the United States. In addition, conventional oil recovery techniques show that only 40 to 50 percent of the oil is produced from an oil deposit. This means that secondary and tertiary recovery techniques could bring forth a large supply of onshore petroleum should sufficient economic incentives exist for such development. Industry is knowledgeable in secondary and tertiary recovery methods, but these are applied in only a few locations throughout the United States. The role of the DoD in oil recovery methods is not clear. It is clear, however, that in the interest of national defense, methods must be used to ensure that domestic petroleum reserves are available in time of emergency. This may require increased government expenditures or incentives to industry to ensure that technology for secondary and tertiary recovery of oil reserves be advanced as far as possible.

It is well-known that substantial oil reserves exist offshore in both U.S. waters and in waters that fall in regions where national boundaries are in question. Recovery of these reserves from the oceans, however, entails sophisticated techniques, many of which exist but for which new methods could be developed to increase the economic attractiveness of such schemes. In addition, environmental considerations have held up development of these resources to a large extent. Should such delays persist, the United States will become increasingly dependent on imported petroleum.

The U.S. petroleum companies have considerable knowledge in offshore recovery techniques. However, there appears to be incentives to develop methods to recover oil by installing recovery facilities directly on the ocean floor itself. It is known that a number of companies are considering such developments, but the exact status of the research has not been determined.

The recovery of petroleum-type liquids from coal and oil shale merits serious consideration. The United States has potentially more than 100 times the crude oil reserves in coal compared with conventional petroleum. As mentioned earlier, our oil shale reserves are estimated at 75 billion barrels for shale containing more than 30 gallons per ton of liquids. Lower grade shales increase these reserves by several orders of magnitude.

Both the government and some petroleum companies are conducting research on methods for producing synthetic crude oil from coal. A number of processes are at the pilot plant stage of development--most with funding by the Office of Coal Research of the Department of Interior. Under the current scale of research expenditures, such technology will not be available for commerical development before the early 1980s.

The size of a synthetic crude oil plant from the coal industry may well be limited by the ability of the United States to recover its coal reserves for such an operation. For a 100,000 barrel per day synthetic crude oil plant, roughly 35,000 to 50,000 tons per day of coal are needed. The United States is not used to handling such vast amounts of solid materials, and this may well limit the development of a significant resource base of petroleum from coal.

The principal technological problems for converting coal to oil lie in two areas: development of hydrotreating catalysts for all stages of processing and development of materials that withstand the high pressures and high temperatures and can handle the abrasive characteristics of coal/oil mixtures.

In addition to these two problem areas, methods to produce cheap hydrogen are needed for any coal-upgrading process scheme. In some processes, since oxygen requirements are large, an improvement in oxygen production economics would be of significant value.

In an environmentally concerned society, any fuel that has the potential of emitting the oxides of sulfur or nitrogen to the atmosphere would be closely regulated. Although crude oil derived from coal can be desulfurized, at the sulfur level competitive with conventional crude oil, large amounts of nitrogen remain. For example, a 0.3 percent sulfur coal-derived crude oil contains nearly 1.0 percent nitrogen; a 0.3 percent sulfur conventional petroleum low-sulfur oil contains virtually no nitrogen. Therefore, the coal liquid must be denitrogenated to be competitive--at a serious cost disadvantage. Processes for removal of nitrogen from coal-derived crude oil must ultimately be developed for effective marketing of these materials.

A shale oil industry should be considered to be in the national interest, since it provides a petroleum back-up reserve of over 75 billion barrels of oil--nearly three times the reported Alaskan resource. This size is estimated from deposits that are believed to be marginally attractive at today's prices. Should the United States go after all the oil shale deposits for oil recovery, the reserves would be significantly larger than this. The process development problems associated with an oil shale industry are primarily those associated with environmental protection--disposal of the spent shale, control of nitrogen oxide emissions from burning shale oil, control of nitrogen and other odorants from a shale retort, and, the most important, mining the oil shale without damaging the Colorado and Utah countrysides. Retort development has been funded principally by industry, although some of the earliest and most extensive work was done under sponsorship of the Bureau of Mines. Most of the Bureau's activities today are devoted to in-situ recovery of shale oil--a very fertile area for research. Both extraction and combustion methods are in very early stages of development and merit a close examination for recovering the vast shale oil reserves on government property. Industry is conducting little or no work in recovering shale oil in place.

b. Gas

As pointed out earlier, the U.S. gas supply is on a serious decline at a time when demand is increasing because of its attractiveness as a nonpolluting fuel. Since much of the problem of gas supply and demand is due to overregulation, it is imperative that policies be set to provide the maximum incentives to find this premium fuel. Currently, the low wellhead price for natural gas has discouraged producers to seek new supplies in unconventional regions. It is hoped, however, that this problem will be faced and solved in the near future.

A higher price for natural gas would enable producers to look for additional gas supplies in regions of the Unites States that have remained virtually untapped. The two principal areas in this regard are offshore natural gas and gas in deep deposits. The former requires technology virtually the same as for offshore petroleum recovery. The latter requires technical and economic advances in deep well drilling, including low-cost materials of construction for the drills themselves.

Industry and the government are examining the problems associated with the production of substitute natural gas (SNG) from coal or oil at a relatively slow pace compared with the need for supply. Four coal gasification pilot plants are in their initial stage of development in the United States: (1) the BIGAS process, under development by Bituminous Coal Research and sponsored by the Office of Coal Research; (2) the HYGAS process, developed by the Institute of Gas Technology under OCR sponsorship; (3) the Synthane process, developed by the Bureau of Mines; and (4) the CSG process, developed by Consolidation Coal Company under OCR sponsorship. These important research efforts are an attempt to develop coal gasification processes that are more economic than the currently available Lurgi process. In addition, the U.S. process development activities are aimed at increasing the efficiency of resource utilization over the Lurgi scheme.

Most problems associated with coal gasification processes are related more to process development rather than to specific technicalities. There is considerable difficulty, however, in obtaining a coal handling system that will enable solids to be fed continuously into a coal gasification reactor operating at 1,000 pounds per square inch pressure. The HYGAS process uses a slurry feed system and the problem of handling coal-oil slurry at the pressure is formidable. The Appendix describes engineering problems associated with development of a coal gasification industry.

Most of the problems associated with an oil gasification industry are political. Since incremental oil supplies of the future must come from the Eastern Hemisphere, using oil to help solve the natural gas shortage merely shifts one problem area to another. The technological problems associated with this industry are more developmental than strictly technical as with coal gasification. Most of the concepts for gasifying oil fractions are commercial or nearly commercial today.

One area that merits further examination is that in which explosive devices are used to stimulate gas recovery from tight gas sands deposits. One technique that uses nuclear devices has met with marginal success. However, the rapidly expanding need for gas does prompt a definitive estimate or development in this area, however.

The same holds true for in-situ gasification of coal. A recent Bureau of Mines report shows this to be a development area that is riddled with technical as well as economic questions; this report shows areas that merit further examination.

4. Electric Power Generation

Electric power generation currently accounts for about 25 percent of U.S. energy use. It is predicted that this percentage will increase to 37 percent in 1985. Today's fossil-fueled power plants operate at a maximum electrical generation efficiency of about 36 percent. Advanced power cycles have been proposed that could increase electrical generation efficiency to well over 50 percent.

Advanced power cycles systems depend on high temperature gas turbines combined with lower temperature steam turbines. The principal technological limitation on developing such systems is the temperature limitation on the turbine blade material. Currently, turbine blades may be designed to withstand a temperature of about 1,800°F. Advanced power cycles with an efficiency of about 33 percent could be operated within this temperature limitation. An efficiency of about 58 percent could be achieved with an advanced power cycle if the inlet temperature could be increased to 3,000°F. Continued large-scale research is needed in high temperature turbine blade materials and blade design including internal or transpiration cooling.

Other methods of improving electric generation efficiency include fuel cells and magnetohydrodynamics (MHD). Neither method is as far along in development as are advanced power cycles. A high level of support cannot be justified for research on fuel cells or MHD for large-scale power generation because no appreciable efficiency benefit is expected over advanced power cycles.

Small-scale fuel cells to supply electricity to individual home or apartment houses, however, are under current development. The increased overall efficiency of power utilization (no transmission line losses) make small-scale fuel cells a worthwhile subject of further research and development such as that sponsored by DoD in the past.

5. Energy Transportation

Much of the energy supply problem can be attributed to the fact that fossil fuel supplies are located far from the energy markets. Large oil and gas discoveries are being made in remote Arctic regions. Gas associated with oil in remote areas often must be flared because it is not economical to transport it to market. The largest part of undeveloped U.S. coal reserves, especially low-sulfur coal, lies in the mountains far from the eastern and Pacific Coast markets. In the case of electricity, most new power plants are being located away from metropolitan areas for environmental and esthetic reasons.

The well-publicized problems of obtaining approval for the Alaskan oil pipeline in Alaska points out the problem of Arctic oil and gas transportation. Publicly funded research is needed on the Arctic environment in addition to the large sums spent by private industry. With discovery of gas and oil on the Canadian Arctic Islands, yet more difficult transportation problems loom. Proposals made so far include undersea (and under ice) pipelines, LNG submarines, dirigible LNG tankers, and icebreaker tankers. A vast amount of work is needed in cooperation with Canada on the entire Arctic environment, including Arctic Ocean ice packs, perma-frost, Arctic meteorology, glaciology, and biology. Special emphasis needs to be placed on research on effects and prevention of oil spills on Arctic land and seas.

The conventional mode of coal transportation is by rail or, where applicable, by barge. A promising new method of coal transportation is that of slurry pipelining. Coal slurry pipelining is now commercial with a 273 mile, 15,000 ton per day pipeline in operation in Arizona. Nevertheless, support for fundamental research is needed on the flow characteristics of slurry particles of various types of coal. Additional development work is also needed on auxiliary systems for coal grinding, slurry dewatering, and coal drying.

Long distance electrical transmission at the present time results in large power losses. Developmental programs are under way on reducing transmission losses by use by cryogenic temperatures for transmission cables to reduce electrical resistance. The use of liquid nitrogen (-320°F) or liquid hydrogen (-423°F) would reduce transmission losses considerably. In the case of liquid hydrogen temperatures, there are good prospects of developing superconducting materials whose use would result in nil transmission losses. A higher level of research in the field of cryogenic conductors and superconductors should be funded. New low resistance materials may also be used for generator windings, greatly reducing the size and cost of large generators.

6. Energy Utilization

The other side of the energy supply coin is energy utilization or to paraphrase the saying, "a Btu saved is a Btu supplied." The possibilities for saving energy are numerous. Many savings, particularly in industrial uses, will be made as a result of simple economics. Others will be possible only by educating the general public as to ways of saving fuel and power--and, consequently money. Still other savings require technological advances, including those previously discussed for electrical generation and transmission. Finally, future energy savings require social acceptance of limits to population growth and the growth of per capita energy usage.

The category of savings of energy of primary interest in this study is the one that depends on technological advances. Two important end uses of energy are home heating (and cooling) and automobile propulsion. Both end uses have inelastic supply curves, i.e., increasing the price does not affect the demand. However, the design of the dwelling or automobile does have a substantial effect on the energy usage.

Improved insulation, storm doors and windows, and awnings can greatly reduce home heating and cooling requirements. New research funds could be profitably used to study methods for partial solar heating of houses by storing heat in hot water during sunny periods. A more controversial proposal would be to study cheap tamper-proof systems for remotely controlling individual thermostats during periods of energy shortages or environmental crises.

Fuel conservation in the automobile is a more complex problem involving both quantity and quality of the fuel consumed. The most obvious method of fuel conservation is to have fewer automobile miles driven. Additional mass transit systems should be developed, particularly for commuting to and from work in densely populated urban areas. The preference shown by the commuter for the convenience of the automobile should not be ignored. For example, studies should be made of "minirapid transit," a scheme whereby publicly-owned and maintained vehicles (car or small buses) are driven to and from work by car-pooling commuters.

Fuel economy per mile driven can be improved by reducing engine size or increasing the compression ratio, requiring higher octane gasoline. New engine development may be needed to economically meet impending federal environmental standards. The Wankel engine is already commercial but in need of improvement. Types of engines for which exploratory development money should be available include electric, hybrid electric, and steam-powered (external combustion). These new engines might be more practical for powering "minirapid transit" vehicles than for private automobiles.

In summary, a number of energy topics exist that require research and development to meet the future resource recovery and utilization needs of the nation. Later sections of this report provide additional information on these and other matters important for development of an energy program by the Department of Defense.

Appendix

ENGINEERING PROBLEMS IN COAL GASIFICATION

The developing coal gasification industry presents a number of technical problems. These may be classified as both technical problems and problems associated with process development.

Figure 1 is a general process scheme of a pipeline gas (methane) from coal plant. The drawing shows the major operations and chemical reactions entailed in forming CH_4 from coal or lignite.

One of the most important reactions in the coal gasifier is the "devolatilization reaction."

$$\text{Coal volatile matter} \xrightarrow{1100\text{-}1500^{\circ}F} CH_4 + C. \qquad (1)$$

This reaction is exothermic, and it is important to take full advantage of exothermic reactions to reduce the required heat input to the gasification system. High pressure favors reaction (1) since it prevents decomposition of CH_4 to C and H_2.

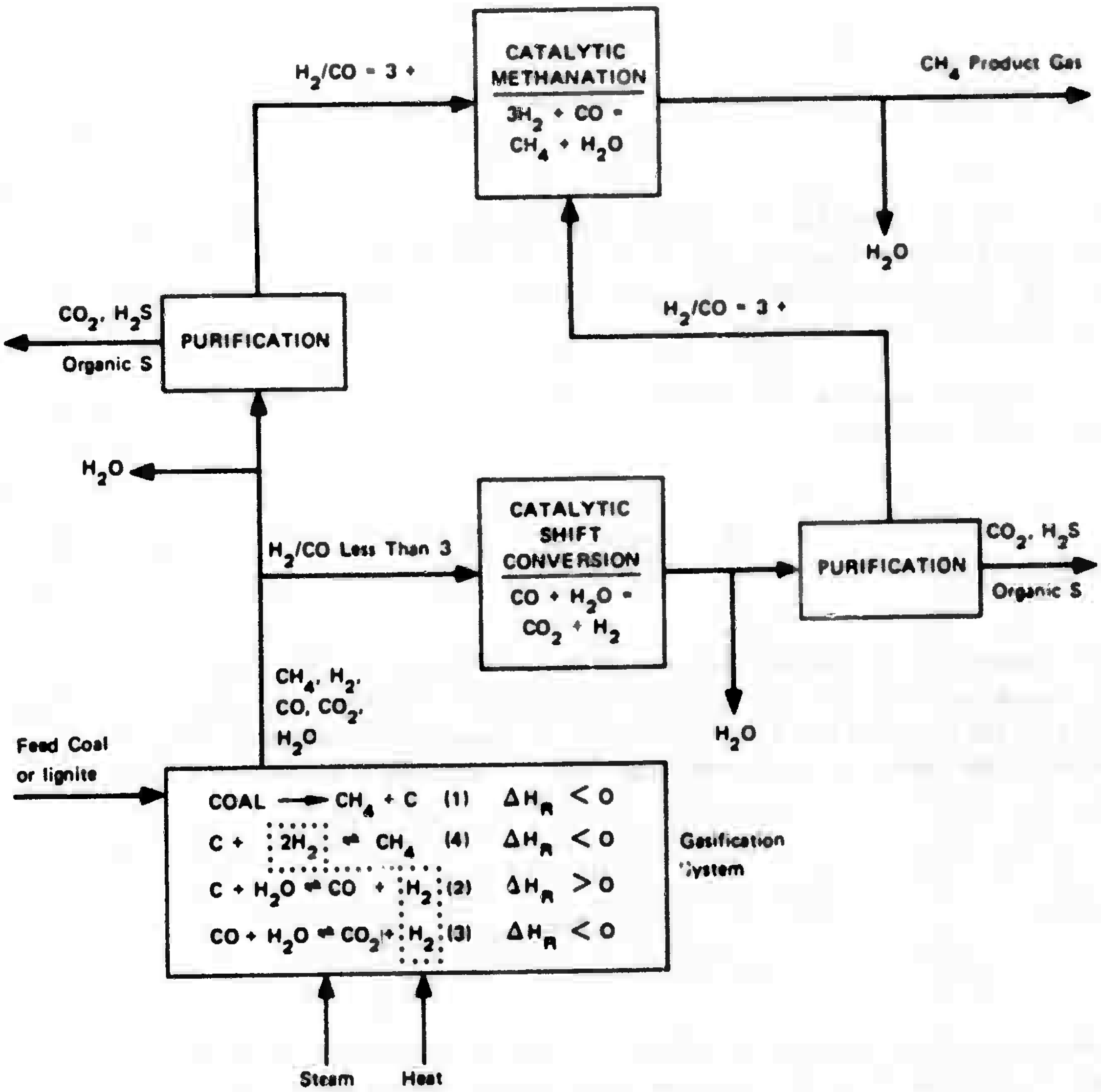


FIGURE 1 METHANE FROM COAL GASIFICATION GENERAL PROCESS SCHEME

After devolatilization, large quantities of carbon remain as char. To produce methane from the char, a supplemental source of hydrogen is required. This hydrogen is generally produced in situ by the strongly endothermic steam-carbon reaction:

$$C + H_2O \xrightleftharpoons{>1700^\circ F} CO + H_2 \qquad (2)$$

This reaction results in a large and expensive indirect* heat input to any gasification system. In terms of reaction rate, reaction (2) is the slowest of the gasifier reactions. Generally, high pressure increases the rate of this reaction.

Another important reaction in any gasification scheme is the water-gas shift reaction:

$$CO + H_2O \rightleftharpoons H_2 + CO_2 \qquad (3)$$

This reaction is only mildly exothermic, thus it is not significant as a source of heat for the steam-carbon reaction zone. The major importance of the shift reaction is its ability to generate additional hydrogen within the gasifier for promoting the "hydrogasification" reaction:

$$C + 2H_2 \xrightleftharpoons{1700^\circ F} CH_4 \qquad (4)$$

Reaction (4) is highly exothermic, and good yields of methane can be obtained at $1700^\circ F$, a temperature high enough for adequate maintenance of the steam-carbon reaction rate. Thus, if methane can be formed via hydrogasification in a steam-carbon reaction zone, the exothermic reaction heat from such methane formation can supply heat to the steam-carbon reaction. High pressure favors the formation of CH_4 by reaction (4).

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* In this discussion, "indirect" means heat supply by means other than in-situ combustion of carbon with air.

The shift reaction can be used externally from the gasification system to adjust the H_2 to CO ratio to 3, which is the required ratio for catalytically producing methane from H_2 and CO:

$$3H_2 + CO \xrightarrow[\text{700°F}]{\text{Catalyst}} CH_4 + H_2O \qquad (5)$$

Reaction (5) is strongly exothermic, but since it is carried out at low temperature in a separate reactor, it cannot be used to supply steam-carbon reaction heat. High pressure increases the rate and methane yield from reaction (5).

Before catalytic methanation of the gas, H_2S, organic sulfur and surplus CO_2 must be removed. High pressure generally results in lowest cost acid gas purification processes.

Thus, from the above discussion, operation of the gasifier at high pressure has several advantages:

(1) It favors the yield of methane in the gasifier either from the devolatilization or hydrogasification reactions--a high yield of methane has large economic significance, since it results in a lower required input of expensive indirect heat.

(2) It lowers the costs of acid gas purification and catalytic methanation.

Operation at high pressure is one of the two major differences between the U.S. processes and the Lurgi process. Most U.S. processes are programmed to operate at pressures of 1000 psi or higher, whereas the Lurgi gasifier operates at about 350 psi. The Lurgi gasifier was built to produce low Btu town gas or chemical synthesis gas. In these applications, methane formation is desirably suppressed. This is a major reason that the U.S. processes are expected to yield methane at lower costs.

The other major advantage of the U.S. processes is in the gasification reactor throughput. The Lurgi gasifier is a relatively low-rate fixed bed system, whereas the U.S. processes, for the most part, are based on relatively high throughput fluidized bed or entrained systems.

For example, to produce 250 million scf/sd of gas, about 30 Lurgi gasifiers are required as opposed to only three in the Bigas entrained process as it is now conceived.

However, the potential for economic gain in the U.S. processes presents several problems and areas for creative innovation. The first problem faced in operating a gasifier at high pressure is that of coal feeding and withdrawal of solids residues. The most common method for feeding or withdrawing solids at high pressure is the lock hopper. A lock hopper system that might be considered for delivering coal against a back pressure of 1000 psi is shown in Figure 2. In this system, coal at ambient pressure is delivered from feed hopper M-303 to lock hopper V-301 during its fill cycle. V-301 is then pressured by compressed gas from holder V-304 during its pressure cycle. When at pressure, the contents of V-301 are dumped into continuous feed hopper V-302, which must have enough holdup capacity to allow V-301 to complete its cycles. After dumping coal, V-301 is depressured by releasing gas to V-304.

Although lock hoppers have operated successfully on Lurgi gasifiers at 300 to 400 psi pressure, the question remains about how long a vessel such as V-301 can stand up under the stress of repeated cycling from 1000 psi to ambient pressure. For example, using a total fill-to-fill cycle time of 30 minutes, V-301 would be subject to a 1000 psi pressure change about 17,000 times a year. This problem might be overcome by staging V-301 to take, say, 500 psi increments, but now three lock hoppers are needed instead of two. Even with only two, the volume of lock hoppers is usually a major fraction of the volume of gasifiers, and in one process (the Bigas process), they actually would be larger than the gasifiers. Another defect of lock hoppers is the large quantity of energy needed to pressure them to 1000 psi.

Another obvious way to get coal into a 1000 psi gasifier is to slurry it in. Since water (or steam) is a reactant in the gasifier, this seems like an appropriate thing to do. Unfortunately, however, the economics of a coal gasification system suffer greatly with water used as a slurry medium. This is principally because to vaporize water within a gasifier requires very great quantities of costly indirect heat (~ \$1.50/MM Btu). This cost is compounded, because the heat used to vaporize water within the gasifier generally cannot be entirely used outside the gasifier, since gasifier waste heat from dry coal fed gasifiers is now used for at least a portion of gasifier steam generation.

The adverse economics of a water slurry system can be offset by using a low latent heat organic liquid. The Institute of Gas technology is in fact now trying organic liquids--specifically benzene and toluene. A

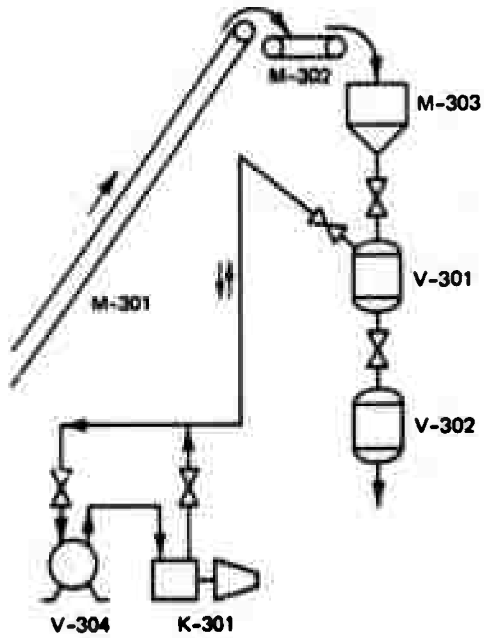

FIGURE 2 LOCK HOPPER FEED SYSTEM

diagram of its proposed slurry system is shown in Figure 3. The most significant operation in this system is the vaporization of the slurry oil in a fluidized bed at 625°F by hot gas rising from the bottom of the gasifier. The use of an aromatic oil in this service is relatively satisfactory from the standpoint of slurry oil makeup costs, since aromatics are quite refractory at the conditions of the bed. However, even if oil losses are held to 1% of the circulation rate, the cost of slurry oil makeup can amount to about 3 cents per MSCF of product gas.

Another difficulty with aromatic oils in this service is their tendency to dissolve organic matter from coals even in small quantities. If this happens, the dissolved materials, after being released from solution in the slurry drying bed, could have characteristics quite different from other solid components in the bed, resulting in loss of fluidization control, fines carry-over, or even bed agglomeration. The tendency of aromatic oils to dissolve coal components might also vary somewhat from coal to coal, or even on an hourly basis when coal from a single source is processed. The problems that might arise from coal solubility are speculative at this time--IGT will have more definitive answers as its pilot plant work proceeds.

Even if a slurry feed system were efficiently operable, such a system would be somewhat cumbersome and would require several additional control points in a process.

In an attempt to simplify and lower the cost of high pressure coal feeding, Bituminous Coal Research Inc. (BCR) conceived the idea of a "piston coal feeder." In this concept, which is shown in Figure 4, ground coal is first delivered to auxiliary feed vessel B. The coal is then transferred with low pressure inert gas into high pressure cylinder A. Cylinder A is then pressured with product gas, and, finally, the coal and gas are pushed into the gasifier by a hydraulically driven piston. BCR has had success with a feeder based on this concept in its OCR small scale test program, and it will incorporate a feeder of this type in its 5-ton per hour pilot plant.

At this time, the relative merits of the BCR feeder and other feeding systems cannot be determined because of a lack of design information. The BCR development is mentioned to illustrate BCR's recognition of the potential for improvement in the critical area of high pressure coal feeding.

Figure 5 is a drawing of the gasification section of the BCR BIGAS process. In this system, coal ground to about 200 mesh size is entrained by steam into the top stage (R-1) of a two-stage gasifier. The coal is

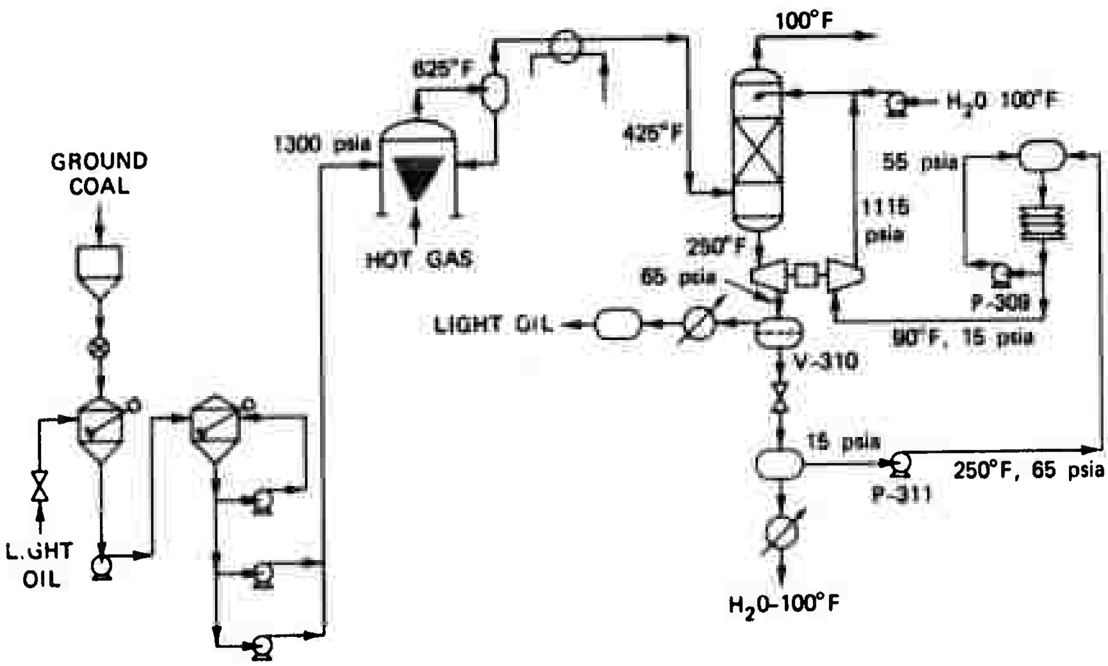

FIGURE 3 SLURRY FEED SYSTEM

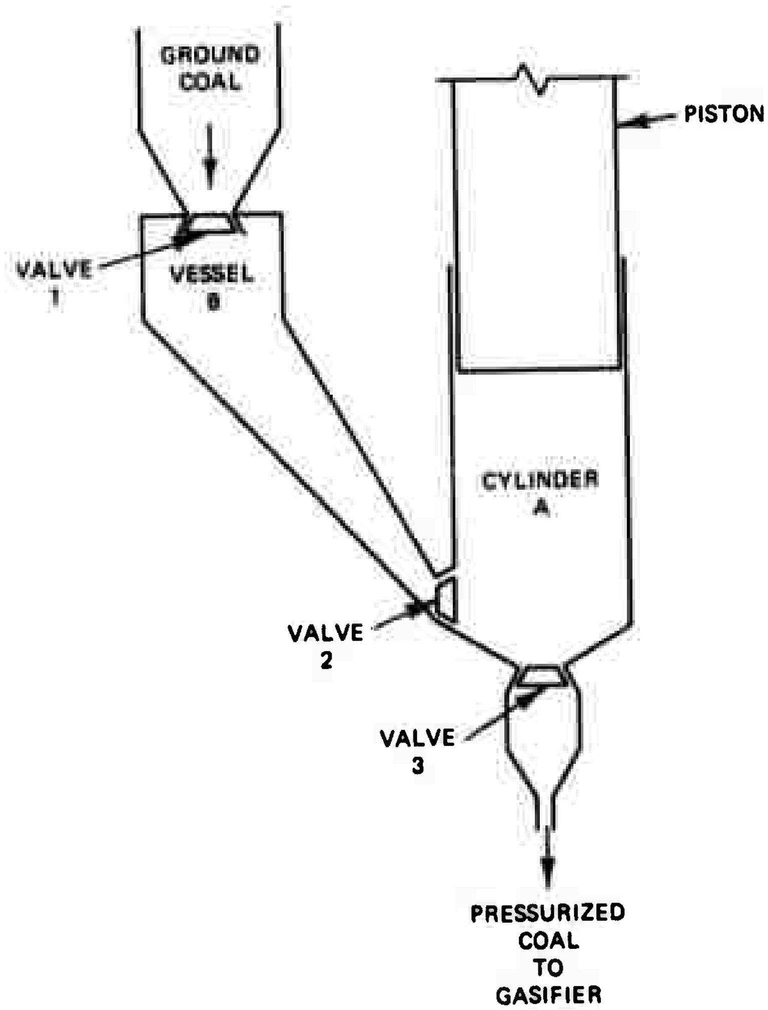

FIGURE 4 CONCEPTUAL PISTON COAL FEEDER

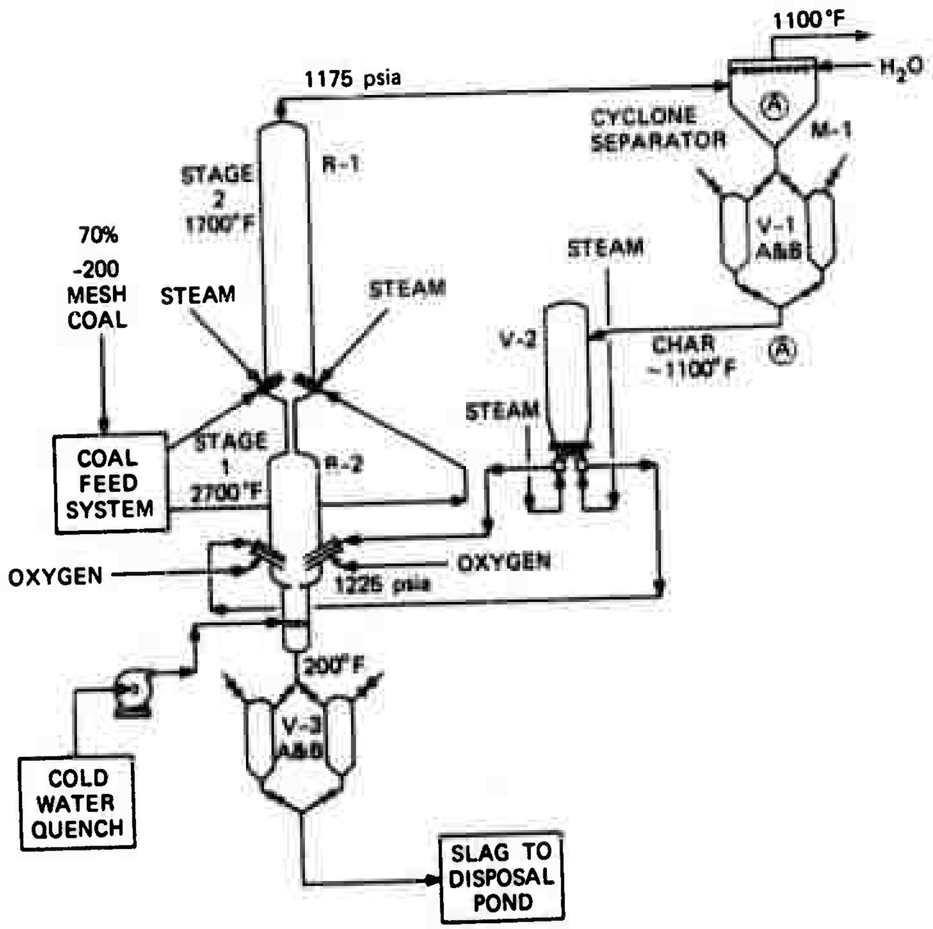

FIGURE 5 BIGAS GASIFICATION SYSTEM

then swept upward by hot (2700°F) gas (CO_2, H_2, and CO) rising from the bottom stage (R-2). During a 6-second residence time in the top stage, the coal is devolatilized to CH_4, a small amount of devolatilized char is hydrogasified to CH_4, and additional char reacts with steam to form additional CO and H_2. Char that does not react is separated from the gasifier offgas in separator M-1 and returned to R-2 through lock hoppers V-1 and feed hopper V-2. This recycled char is fed with steam into R-2, where it is contacted with oxygen at a controlled temperature of 2700°F. The char is reacted to CO_2, H_2, and CO, and these gases flow to R-1, completing the gasification circuit. Residence time in R-2 is about two seconds. The ash in the coal is slagged, quenched with water, and the ash-water slurry is let down in pressure through cyclically operated lock hoppers V-3.

If the costs of the facilities shown in Figure 5 are separated into a cost for coal feeding, char recycling, and slag discharge and a cost for the gasifiers, the cost for solids handling would be about five times the cost of the gasifiers. This multiple would not apply for other processes because the Bigas process has a relatively high gasifier throughput; but the multiple is presented to show that, in financial terms, there is substantial room for improvement in solids handling methods.

Referring again to Figure 5, the circled points A represent locations at which recycled char is essentially sulfur free. A system for delivering a portion of this char directly to the burner of a fired heater would be of significant economic benefit for two reasons:

- Combustion of this char would replace combustion of as received coal, and thus SO_2 scrubbing of combustion offgas would not be required.

- More as received coal would pass through the gasifier, resulting in relatively more CH_4 being made from coal volatile matter at a unit cost substantially less than the cost of an equivalent quantity of CH_4 made from char.

These economic benefits of char withdrawal also apply to the Bureau of Mines Synthane process.

Various flow schemes for processing gas leaving a gasification system to product CH_4 are presented in Figure 6.

Scheme A is a typical scheme now proposed for coal gasification. Shift conversion is proposed over standard iron-chromia shift catalysts. There now are serious questions about the life and mechanical strength

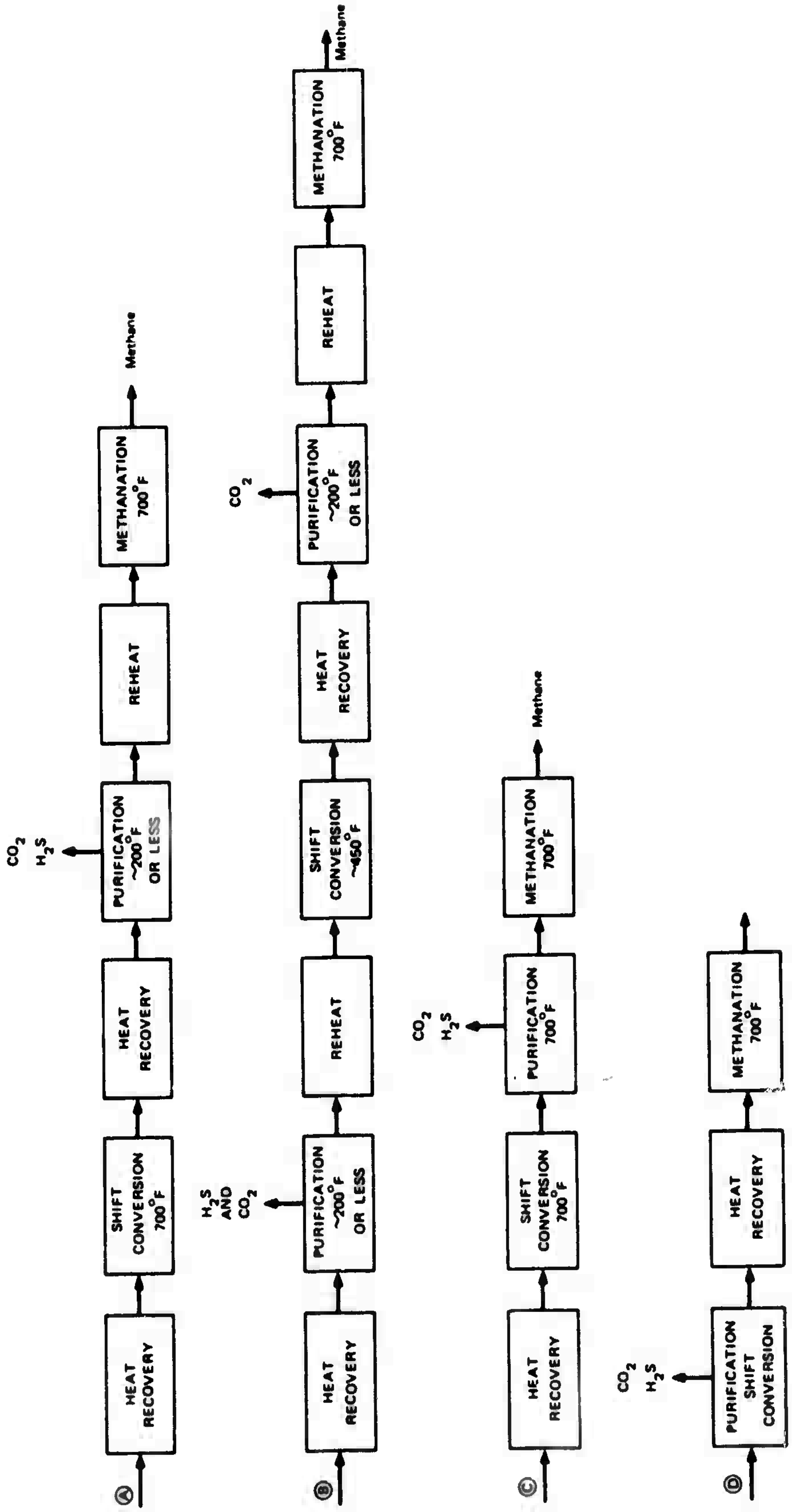

FIGURE 6 DOWNSTREAM PROCESSING IN COAL GASIFICATION

of these catalysts in this service.[1] The H_2S content of the shift feed gas will be several orders of magnitude higher than that encountered in current commercial usage of iron-chromia catalysts. Also, CO partial pressure will be higher than normal. The high H_2S content will affect the life of these catalysts adversely, and it is suspected that the high CO partial pressure will lead to serious carbon deposition. BASF of Germany has tested a sulfided Co/Mo catalyst under conditions almost as severe as those encountered in coal gasification.[2] Although this catalyst appears to have merit in this application, it is only one catalyst, and there may be prospects for additional catalyst developments in this service.

Scheme B in Figure 6 represents a process sequence felt to be adequate from a demonstrated commercial standpoint. In this scheme, low temperature copper-zinc based shift conversion catalysts can be used. But these catalysts are poisoned by H_2S, and as a result, an additional purification step and an additional reheat step are required when compared with scheme A. This illustrates the reason for the incentive to develop scheme A.

If a scheme such as C could be developed, then no heat removal or reheat would be required in the shift, purification, or methanation train. However, this scheme would be restrictive, since purification would be required at only one temperature.

The most valuable improvement of this train is represented by scheme D, where purification and shift conversion are assumed to occur simultaneously at close to gasifier temperature. One way to accomplish this is to use technology similar to the "CO_2 acceptor" process being developed by Consolidation Coal Co.[3] In this process, CO_2 and H_2S react readily and almost completely with dolomite (or lime) at temperatures as high as 1600°F.

$$MgO \cdot CaO + CO_2 \rightarrow MgO \cdot CaCO_3$$

$$MgO \cdot CaO + H_2S \rightarrow MgO \cdot CaS + H_2O$$

The dolomite can be regenerated by heating in the presence of air:

$$MgO \cdot CaCO_3 \xrightarrow{\Delta} MgO \cdot CaO + CO_2$$

$$MgO \cdot CaS + 1\text{-}1/2\ O_2 \xrightarrow{\Delta} MgO \cdot CaO + SO_2$$

By adding a small amount of shift conversion catalyst to the circulating dolomite, the shift reaction could be driven strongly toward H_2 and CO_2 production, since CO_2 would be absorbed as it was formed. Thus a combined "hot" purification and shift conversion could be performed in one step.

Perhaps other systems such as the CO_2 acceptor process can be developed. Such developments would be of great value to coal gasification processes.

Even if "hot" purification systems could not be developed, it seems that opportunities still could exist in the development of new low temperature processes. Simply from the sheer number of acid gas purification processes now available, chances seem good that new processes could be developed--particularly for the specific conditions and requirements in coal gasification plants. Some of these conditions and requirements now are:

- High CO_2 partial pressures in feed gas (~ 300 psi).
- H_2S concentrations of over 1% in the feed gas.
- H_2S removal to less than 0.5 ppm (required to prevent poisoning of methanation catalysts).
- Selective removal of H_2S so that facilities for recovery of sulfur as elemental sulfur can be minimized in cost.
- Almost complete removal of organic sulfur (i.e., COS and CS_2) for protection of methanation catalyst.

The requirements for almost complete removal of sulfur compounds could change if a sulfur resistant methanation catalyst could be developed--another opportunity for development.

The last step in making CH_4 from coal is the catalytic methanation step:

$$3H_2 + CO \xrightarrow[700^\circ F]{\text{Catalyst}} CH_4 + H_2O + 94{,}000 \text{ Btu}$$

This step has not been performed commercially under conditions in a coal gasification plant--the most important variance from current commercial practice being the high mole percent CO in the methanator feed gas.

Current commercial practice is limited to hydrogen producing plants where toxic CO is methanated, but the methanation feed gas usually contains less than 1% CO. In this case, the heat of reaction is easily taken up by the product gas with only a slight rise in temperature, and equilibrium conversion is still attained. However, in a coal gasification plant, CO content typically might be 15 to 20 mole percent. In this case, reaction heat must be removed from the reactor to hold temperature down for good equilibrium conversion. Also, temperature within the reactor must be controlled closely to prevent hot spots and attendant carbon deposition.

The Institute of Gas Technology, the U.S. Bureau of Mines, and other groups have conducted research into proposed methanation systems for this application for several years. However, at this time, optimized systems--from both cost and operability standpoints--have not been arrived at. Thus, this area is ripe for engineering opportunities.

Several schemes for controlling reaction heat during methanation are now being investigated. Some of these are shown in Figure 7.

Scheme A is a "cold gas quench" system. In this system, a multistage fixed catalyst bed reactor system is used with cold feed gas taking up the heat of reaction between stages.

Scheme B is a "heat extraction" system in which the heat of reaction is taken up by a circulating fluid. The catalyst in this scheme can be in packed beds or flame sprayed on the exterior of the tubes through which the heat removal fluid is circulating.

Scheme C is a "hot gas recycle" system in which large quantities of product gas are recycled to the reactor to dilute the CO content of feed gas so the heat of reaction can be taken up in one pass through the reactor. Reaction heat is removed from the product gas before recycle.

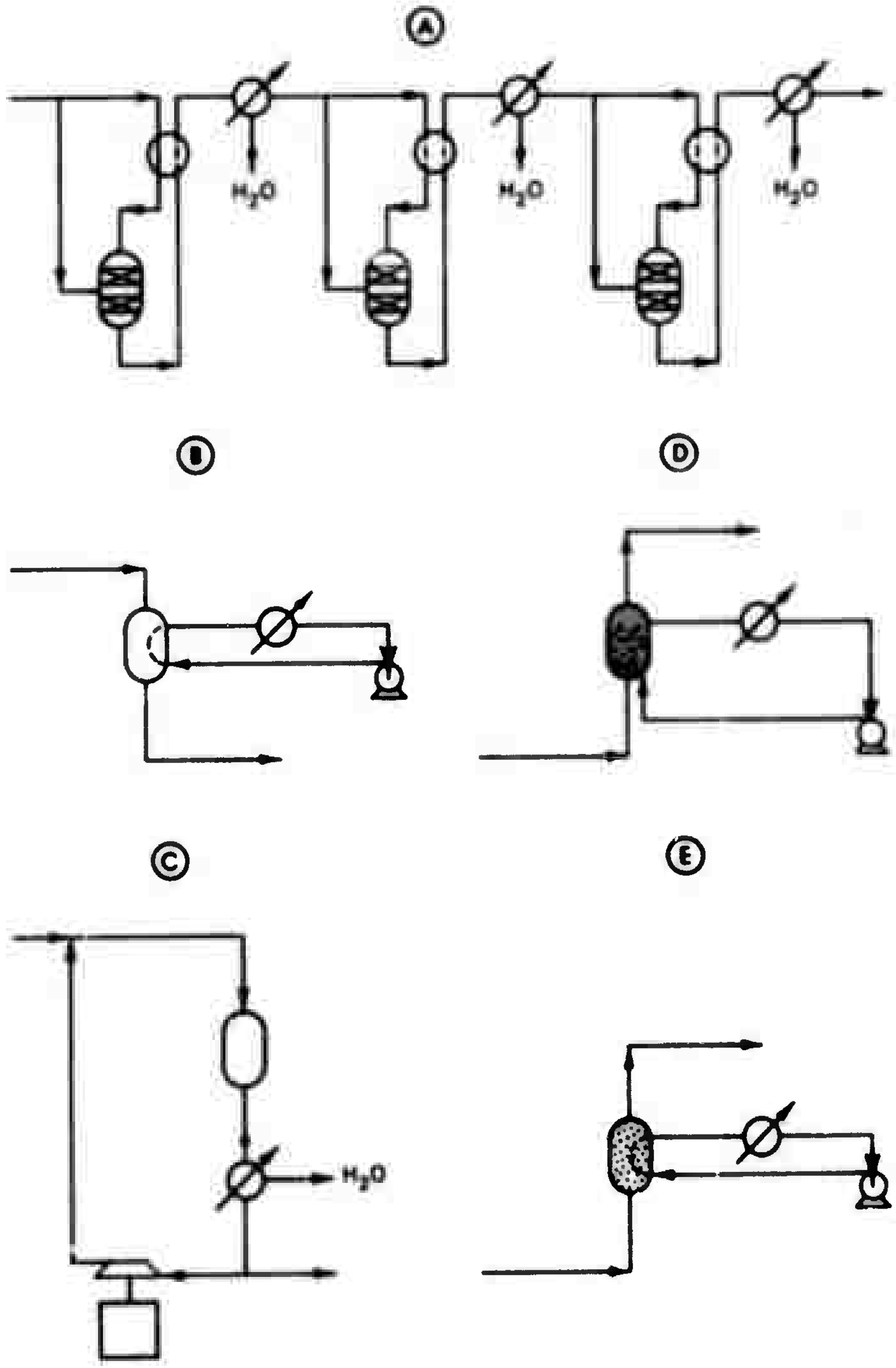

FIGURE 7 CATALYTIC METHANATION SCHEMES

REFERENCES

1. "Engineering Study and Technical Evaluation of the Bituminous Coal Research Inc., Two-Stage Super Pressure Gasification Process," Research and Development Report No. 60, prepared for Office of Coal Research by Air Products and Chemicals, Inc., page 27.

2. Auer, W., et al., "A New Catalyst for the CO-Shift Conversion of Sulfur Containing Gases," presented at the 68th national meeting of the American Institute of Chemical Engineers, Houston, Texas, February 28 to March 4, 1971.

3. Curran, G. P., et al., "Phase II: Bench Scale Research on CSG Process. Operation of the Bench Scale Continuous Gasification Unit," prepared for Office of Coal Research, 1968.

IV POTENTIALS FOR GEOTHERMAL RESOURCE DEVELOPMENT IN THE GULF COAST AREA

The attached paper is drawn from a technical proposal for assessment of potentials for geothermal resource development that SRI has submitted to an agency of the federal government. It is included in this report to provide information about an approach to the study of this resource that could prove to be locally important for the DoD. If development of geothermal resources could be realized (in the Gulf Coast area and elsewhere), it might be possible to realize savings in fossil fuel supplies that currently are used to meet fuel requirements at fixed sites. Use of geothermal resources to provide electric power or space heating could free fossil fuels to mobile uses, effectively increasing their supply for those purposes. This prospective study is seen as providing the essential information necessary to determine the focus of future effort in application of geothermal resources to capitalize upon their apparent potential.

The prospective study outlined in this paper is consistent with a recent report prepared by the Naval Weapons Center.*

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* Austin, C. F., W. H. Austin, Jr., and G. W. Leonard, "Geothermal Science and Technology: A National Program. Naval Weapons Center, China Lake, California, Technical Series 45-029-72, September 1971.

Introduction

In the last several years, SRI has conducted a series of studies on the technology and economics relative to development of several promising energy sources. This work has included evaluation of processes for conversion of solid fossil fuels (coal, oil shale, and tar sands) to liquid and gaseous products, assessment of the feasibility for gasification of certain classes of petroleum, and analysis of opportunities in development of nuclear energy. The importance of this work is underscored by the President's recent message to the Congress on energy resources* and the appraisal of energy outlook prepared by the National Petroleum Council.†

In view of increasing energy needs forecast for the near future, it is apparent that even these somewhat unconventional sources of energy may prove to be insufficient, and new energy sources will have to be sought no matter how small their contribution or how localized their impact. Among such new energy sources are the widespread but imperfectly known geothermal resources of the Gulf Coast region of the United States. The recently passed law‡ permitting leasing of federal lands for geothermal resource development is expected to stimulate exploration and development of such poorly known but apparently significant resources. Before benefits from this development can be realized, however, a number of complex technical, engineering, and economic problems will have to be analyzed and resolved. Furthermore, the role of geothermal resources needs to be established in perspective to the larger energy scene. Accordingly, Stanford Research Institute proposes to carry out a comprehensive assessment of the state of the art as a basis for appraisal of the potentials for geothermal development in the Gulf Coast area of the United States.

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* "Energy Resources, The President's Message to the Congress," June 4, 1971.

† "U.S. Energy Outlook: An Initial Appraisal 1971-1985," National Petroleum Council, November 1971.

‡ The Geothermal Steam Act of 1970, Public Law 91-581, dated December 24, 1970.

Objectives

The proposed study will assess the status of current engineering and economics for methods of development of geothermal resources in the Gulf Coast area and will project these economics out to 1990-2000. Specifically the objectives are:

(1) To identify and evaluate the technology and engineering economics of exploration, development, operation, and environmental controls for geothermal resources in deep sedimentary basins.

(2) To examine the current and likely future cost structure for operations and for resulting energy produced from these developments, at the plant site and delivered to market, in the quantities that might be generated in large scale conversion plants during the period 1990-2000.

(3) To assess the institutional factors pertaining to geothermal resource development so as to identify blockages that would constrain or limit the application of otherwise promising technology.

(4) To provide for a systematic, preliminary test of the hypothesis that geothermal resources represent an important long term potential energy resource for the nation. In particular, the study will seek to provide an initial assessment of the degree to which geothermal resources can supplement (or substitute for) conventional or synthetic fossil fuels, so as to help relieve the nation's forecast future dependence on imports of energy fuels.

Scope

The study will be concerned with the technology, engineering economics, and institutional factors relevant to the development of geothermal resources in the Gulf Coast region of the United States. Two basic types of geothermal resources will be considered: (1) localized hydrothermal systems of high-enthalpy* waters and (2) interstitial low-enthalpy thermal waters in sedimentary basins. High-enthalpy geothermal waters are locally used

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* Enthalpy is defined as heat contained per unit mass.

for generation of electricity at several sites, for example, at the Geysers in California, Larderello in Italy, and Wairakei in New Zealand and will be included for reference purposes. Low-enthalpy geothermal waters occur in greater quantity in large sedimentary basins, and while not satisfactory for electric power production by current technology, this heat is probably two orders of magnitude greater than that of localized hydrothermal systems and could be utilized depending on development of heat exchange technology.

Techniques for exploration and location of promising geothermal areas will be reviewed and evaluated, based on historical information so as to provide for projection of future methods. The analysis of geothermal exploration technology will be designed to test the hypothesis that surface heat displays are somewhat analogous to the oil seeps that occur in some petroleum bearing regions, but that, like petroleum, not all geothermal reservoirs will be associated with surface manifestations. Implications of this hypothesis for the methods (and locations) of geothermal exploration efforts will be assessed, with the particular case of Gulf Coast occurrences as the focus of the effort.

Methods of development of both high-enthalpy and low-enthalpy geothermal reservoirs will be identified and analyzed in search for understanding of the mechanisms of resource genesis. Existing facilities and processes will serve as the basis for study of high-enthalpy waters, and the processes (or their modifications) having the greatest overall technical and economic feasibility will be reviewed as a basis for assessment of their applicability to the low-enthalpy case. The possible extension of current petroleum development and refinery technology to recovery of low-enthalpy waters will be examined, and processes having the greatest feasibility for further study will be identified.

Information derived for individual processes will be assessed to determine the prospects for integrated development of geothermal resources to produce multiple benefits such as electric power, fresh water by desalting of thermal brines, and mineral by-products from the desalinization process. In each case, the probable environmental impact of geothermal development will be included in the technical analysis and accounted for in the economic estimates. Finally, the contribution that geothermal resource development could represent to the energy budget in local and regional areas will be assessed based on existing analysis of recent trends and projections of future demand.

Method of Approach

Stanford Research Institute will assemble a study team of scientists, research engineers, and economists who are familiar with resource development and with the petroleum and energy industry and with its technology, products, and markets. Members of the team are also knowledgeable about the economics of these industries and are familiar with the companies and agencies that are active in energy-related research. The team can draw on the varied backgrounds of other Institute staff members in related disciplines to the extent required. The study leader will be an economic geologist who is experienced in energy-related technoeconomic studies. The study will require nine months to complete and will be conducted in two phases, with more than half the total effort being expended in Phase I.

Phase I

During this phase, the team will conduct an extensive field survey, concurrent with a thorough literature survey, to determine the present scientific, engineering, economic, and institutional status of the identification and development of geothermal resources with particular emphasis on the Gulf Coast region. Contact will be established with public and private organizations known to be engaged in significant work related areas in North America, Europe, and the Pacific. The Institute's field offices in these areas will be employed to assist the team's survey. The field and literature surveys will provide an information base for an independent assessment of the state of the art and technoeconomics. Topics to be included in these surveys are:

- A compilation of pertinent geological, geophysical, and geochemical data so as to quantify and describe the characteristics of geothermal resources and provide for better understanding of the mechanisms by which geothermal reservoirs are formed and sustained.
- Evaluation of currently producing geothermal sites to recognize development principles and derive criteria for technical and economic evaluation of prospective new sites in the Gulf Coast area.
- Assessment of ongoing public and private research and engineering efforts related to exploration and development of geothermal resources.

- Analysis of legal and institutional factors that control or influence the potential for geothermal resource development in promising areas.

The team will evaluate the feasibility of employing INFACT, SRI's internally-developed data system, to aid in compilation and organization of bibliographic reference data acquired during this work.

Employing the data obtained and the criteria derived from them, the team will then define criteria for representative areas that appear to be most promising technically and economically for development of geothermal resources by 1990-2000. This selection will be based on present knowledge plus engineering and economic projections of development technology. Parameters for a comparative analysis of prospective development processes for each area will be defined for a common production level. Preliminary investment and operating costs will be estimated for the processes considered, and flow sheets and material balances will be prepared including necessary ancillary facilities required to support geothermal resource development.

The team will present an interim oral report on these topics at the end of Phase I. Copies of illustrative material that constitute the presentation will be distributed following the meeting.

Phase II

The most promising processes identified in Phase I will be studied in greater detail. Phase II will establish the principles for assessment of the likely future cost structure for products and by-products of geothermal resource development. This phase will also consider the timing of such developments, their possible role in supplementing or substituting for more conventional sources of energy, and the possible significance relative to forecast future levels of imports of petroleum and related resources. Particular attention will be given to an assessment of the possible use of Gulf Coast geothermal resources to relieve pressures on other energy resources in this area through assuming some present uses and freeing fossil fuels for more critical uses that require their inherent properties. The environmental impacts of geothermal development in this region will be evaluated, together with an appraisal of possible benefits to be derived from substitution for more conventional fuels.

The final report will be presented orally and in writing at the completion of Phase II. This report will provide an independent assessment of the technology and economics of the potentials for geothermal resource development, and will attempt to project these technoeconomics out to 1990-2000. The implications of alternative policies regarding the prospective role that geothermal resources may represent in the U.S. energy scene will be discussed to the extent practicable. (A tentative listing of study topics to be addressed in the final report is attached.

POTENTIALS FOR GEOTHERMAL DEVELOPMENT IN THE GULF COAST AREA

Tentative Listing of Study Topics

Resource Definition

- Regional geology; structural geology
- Thermal springs
- Deep wells
- Ground water hydrology
- Heat flow

Exploration

- Geophysical techniques (resistivity, magnetics, microearthquakes)
- Geochemical techniques (dissolved solids, isotope ratios)
- Drilling

Development

- Conventional methods (drilling, extraction, reservoir management, recirculation)
- Unconventional methods (nuclear fracturing, induced flow, etc.)

Production Purposes

- Power generation
- Water desalinization
- Mineral by-product recovery
- Space heating
- Integrated development

Perspective regarding energy supply and demand

- Local and regional supply and demand
- Timing and contribution of geothermal resource development
- Costs and returns from geothermal development

Problem areas requiring further research

Guidelines for assessment of geothermal resource development potentials

V ADVANCED RESEARCH IN RAPID EXCAVATION FOR OIL SHALE RECOVERY

A. Statement of the Problem

The application of rapid excavation technology in routine operations remains to be demonstrated. The Committee on Rapid Excavation of the U.S. National Research Council estimated that the minimum market in the 1970-90 period will be $69 billion--about evenly divided between public works and mining. These estimates were made before the current national concern with protection and clean-up of the environment developed. That concern, with the heavy emphasis it portends on urban mass transportation and independent sewage and storm water disposal, will increase the public sector demand for tunneling under cities. At least equally important will be the application of rapid excavation techniques to encourage economic development of mineral and energy resources such as oil shale. Finally, rapid excavation technology could be used in construction of hardened military sites, storage facilities, and transportation or communication arteries at strategic sites.

The potential for rapid excavation technology for oil shale development is expecially promising. Oil shale is essentially a marlstone that contains organic matter (Kerogen) that can be recovered by heating and converted into a crude oil. However, because the Kerogen is only a small fraction of the total rock, large volumes of oil shale must be mined to supply conversion plants (a commonly used figure is 34 gallons of recovered shale oil per ton of rock). Thus, a relatively small plant supplying only 50,000 barrels per day of shale oil would require from 62,500 to 72,500 tons of raw shale per day; larger plants would require proportionally more shale. These large quantities of oil shale will probably have to be mined by underground methods because overburden is too thick for surface mining, even if environmental effects were accounted for.

Conventional underground mining methods for oil shale recovery require cyclical operations--preparation, drilling, blasting, removal of broken rock, and roof bolting. This would have to be done on a massive scale--rooms and pillars 60 feet square are envisioned in most treatments of oil shale mining. There is no doubt that cyclical mining methods can provide oil shale for conversion, since this has been demonstrated in pilot operations by the Bureau of Mines and private companies. It has not been shown that conventional mining is capable of providing a continuous, high volume supply of oil shale necessary for operation of a conversion plant. In this respect, the application of rapid excavation technology to oil shale development appears to show exceptional promise.

B. Objectives

The general objective of the program is to produce information, technical data, and demonstrated methodology that will enable assessment of the cost and opportunities for rapid excavation applications to oil shale recovery. Specific objectives are to focus on obtaining data on the properties of oil shale critical for design of excavation equipment and practices, on applying research results, and on anticipating and solving new problems and bottlenecks in the several related technologies that support rapid excavation operations.

C. Present Activities and Organizations

Present activities regarding rapid excavation technology are being carried out by the following government agencies (a partial list only, based on personal knowledge of the writer):

- Department of Transportation: Several contracts let or being let for investigation of various elements of the rapid excavation process.
- Department of Interior, Bureau of Mines: Several contracts let or being let for studies related to rapid excavation technology.

University groups are also active in rapid excavation-related topics. Among these are Sacramento State University, University of Minnesota, and Pennsylvania State University.

The possibility of rapid excavation oil shale mining has been examined experimentally by Union Oil Company and Lawrence Machine and Manufacturing Company.* It was found that oil shale specimens could be cut by techniques used in rapid excavation, and a preliminary design of a mining machine was prepared. The machine has not been built and tested, so further data on this concept are unavailable. Other private sector work is done mainly by equipment suppliers who seek to sell their concepts and equipment to contractors that perform excavation projects. (An example of a present project that is using rapid excavation technology, at least in part, is the Washington, D.C., Metro project.)

D. Implications for DoD

In fulfilling its responsibility for management of naval oil shale reserves, it is essential for the DoD to be a leader in the development and assessment of technology relative to the recovery and utilization of this potentially important resource. By advancing the state of the art

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* Carver, H. E., "Oil Shale Mining: A New Possibility for Mechanization," Quarterly of the Colorado School of Mines, Second Symposium on Oil Shale, V. 60, No. 3, pp. 31-50, 1965.

Hamilton, W. H., "Preliminary Design and Evaluation of an Alkirk Oil Shale Mine," ibid, pp. 51-82, 1965.

in oil shale mining through work to develop practical means of rapid excavation, the possible use of these resources to alleviate domestic shortages of energy would be enhanced for normal conditions and especially for times of crisis. Beyond the specific increase in oil supplies available to the U.S. Government, the technology would make larger, economic reserves available to the general U.S. economy.

E. Recommended Future Research Topics

A number of research topics could be attacked in appraisal of the potentials for application of rapid excavation technology to oil shale recovery. For preliminary discussion purposes, it is suggested that topics might be chosen from the following list.

- Oil shale weakening or cutting methods.
- Handling of mined shale.
- Advanced geological exploration.
- Improved grouting procedures for water control.
- Improved methods of analyzing the interrelationships of excavation operations.
- Mechanical boring of noncircular underground openings for haulage and disposal.
- Treatment of processed oil shale and reclamation of mined lands.

1. Oil Shale Weakening or Cutting Methods

Improvements in the rapid excavation of oil shale will require improvements in materials used for bits and cutters to provide better wear-resistance and greater life expectancies and to develop new techniques to weaken the shale so that existing cutting materials can be used. Oil shale is a tough, resilient rock that will present excavation problems (especially in bit wear) unless it can be weakened to allow greater ease in excavation. Since the economy and efficiency of tungsten carbide alloys in cutting equipment are not likely to be rivaled by other materials at an early date, greatest promise for improvement in oil shale excavation appears to be in reducing the rock's resistance to breaking, either by physical alteration of rock or new methods of fragmentation.

Oil shale may be weakened by thermal and chemical treatments, and such treatments can reduce the work necessary to fracture laboratory-scale samples by 50 percent. It would be helpful if a means could be developed to combine rock treatment with partial fragmentation through controlled shock or by new techniques using explosives.

One approach would be to modify a rotary tunnel boring machine to treat and excavate the oil shale essentially in the same operation. A heated spray of an appropriate solution directed at the face would precede the excavating machine. A series of advance cutting tools would cut kerfs in the face and create additional surface area to facilitate action of the heated chemical spray on the oil shale. The main action of the boring machine would be a series of conventional cylindrical or cone-shaped cutter bits that would act on the weakened rocks between the kerfs. One problem with this approach would be the disposal of water used to spray the face; however, it is conceivable that recovery of this water could be used to facilitate the removal of mined shale as a slurry.

2. <u>Handling of Mined Shale</u>

Progress in rapid excavation for oil shale recovery will require improvements in material handling technology to remove mined shale at rates comparable with advance of the excavator. Cyclical loading and haulage systems for shale removal appear to be inadequate to achieve the required capacity for conversion operations, and continuous systems appear to have great advantages.

Conveyors for transportation of rock fragments are well known, and the feasibility of using pipelines to carry finely divided rock as slurries has been demonstrated in dredging, coal pipelines, and laboratory work. If a means could be found to implement a crusher and hydraulic system required for an efficient oil shale pipeline, it may be possible to achieve oil shale removal rates of from 25 to 50 cubic yards per minute. This should meet peak capacity requirements of 20 feet per hour of borings up to 30 feet in diameter (although this is only half the height of target shale areas, a two-level mining bench approach could be used).

One approach to the problem would be to develop a self-contained pipeline intake unit that would follow the excavation equipment in the mine. The pipeline intake unit would comprise a crusher, a hydraulic unit to mix the crushed oil shale with water introduced from the surface to the unit under pressure, and a high capacity pump to drive the resulting slurry through a pipe to a stockpile area for plant feed. Flexible pipe could be used for the interval immediately following the unit to facilitate advances. After a sufficient advance, the flexible pipe could be connected to more permanent pipes for intake and outflow.

The pipeline unit might be a companion piece to a mechanical boring machine, following it directly and receiving the discharge of oil shale fragments from the borer's conveyor. The pipeline unit could also be used in excavations resulting from more conventional means, if fed by a ramp-type loading machine and shuttle car similar to those used in underground coal mining.

3. Advanced Geological Exploration

Geological conditions are the main factor in determining the difficulty of rapid excavation. Advance determination of rock characteristics is important both in establishing excavation parameters before excavation and in defining geologic factors ahead of excavations in progress. This is especially critical for oil shale because of its horizontal and vertical variability.

Present geological and geophysical techniques for defining geological conditions were developed for exploration purposes, and they lack the precision required for engineering measurements associated with surveying for excavation dimensions or characteristics. If a means can be found to adapt existing geological techniques to the small targets presented by individual excavations, it should be possible to predict the geological conditions to be encountered in such operations.

An approach to the problem of exploring prospective excavations would be to combine programs of rapid core or full-hole drilling with systematic measurements by modified in-hole logging equipment. In addition to more conventional methods, investigation of acoustical characteristics of rocks at several frequencies may be capable of identifying geological structures to determine their amenability for rapid excavation technology. It probably will be necessary to correlate such data with those from other sources, since the complexity of acoustical returns will make interpretation difficult. Such possibilities of determining rock characteristics by measuring reflections from a radioactive source within a bore hole should be examined.

The problem of exploring geological conditions ahead of rapid excavations in progress could be approached by modifying existing boring equipment to permit small core drilling along the center line of, or in a directionally drilled hole roughly parallel to, the direction of advance of the main excavation. In addition to obtaining rock samples from the advance area for study, the pilot or side drill hole could serve as a means to carry out logging measurements to define geophysical factors along the route such as the presence of ground water or faulted or bad ground. Measurements could be performed by an instrument package incorporated into the boring machines to facilitate routine operations without requiring curtailment of operations.

Similar instrumentation could be mounted on a jumbo for use with normal operations in conventional excavations.

4. Improved Grouting Procedures for Water Control

Stability of underground openings is vital to the success of programs in rapid excavation, especially for large openings such as in oil shale mining. Accordingly, the rate of installation of ground support measures must keep pace with the advance of the excavation, and the measures must be compatible with the underground environment. Grouting to reduce water inflows and contribute to added strength or prevent subsidence is an important part of the overall problem of excavation stability, especially if grout can be applied quickly. Limited data for the Piceance Creek oil shale area of Colorado suggest that water could present formidable problems in large scale mining operation.

Development of chemical grouting materials has shown that certain silicates, resins, and polymers can effectively reduce the porosity and permeability of several soils and rocks. If a means can be found to apply grout materials to moist rock, and if greater efficiency of application can be devised to permit lower grout costs, the stability of excavations could be improved.

One approach would be to continue research on new chemical grouts, the influence of moisture and soil character on grout setting processes, and the means of grout application. The ideal grout would be low in initial cost and applied in one operation. Polymeric materials whose viscosity can be varied through adjusting mixtures may be applicable to a number of situations, simplifying the equipment and processes required.

A complementary approach would be to develop mixing and application equipment that will apply the grout to the excavation in a single operation. The equipment should be sufficiently versatile to accomodate suspended-solid grouts, such as cement, in addition to the chemicals.

5. Improved Methods of Analyzing the Interrelationships of Excavation Operations

The rapid excavation process comprises a combination of several distinct operations. Each excavation project attempts to apply an optimum combination of separate components to achieve its objective. The result is a number of special cases and a lack of standardization which impairs the incentive to invest in development of compatible units of equipment that can be used widely. Thus, specialization in excavation helps to create a limited applicability situation, which perpetuates itself.

Analysis of the capacity and output of separate operations (and the equipment used) in relation to the efficiency of the subsequent operations to determine the highest efficiency of the overall process can yield the information required to identify improvements in existing equipment and practices.

6. Mechanical Boring of Noncircular Tunnels for Haulage and Disposal

Oil shale operations will require underground haulage of mined shale to the conversion plant, as well as disposal of processed shale from which Kerogen has been recovered. This could require special excavations and present special problems.

Tunnels for transportation should in most cases be 0 or horseshoe shaped. Mechanical boring methods for hard rock produce a circular shape. This requires cutting about 20 percent more rock than is necessary for the needed cross section.

An approach to this would be to have reaming cutters mounted tangentially at the rear of a boring machine. These cutters would remove a crescent-shaped cross section to provide a horseshoe shape.

7. Treatment of Processed Oil Shale and Reclamation of Mined Lands

Oil shale mining and processing removes only a small portion of the total rock (less than 1 percent by weight). It is not a simple task to dispose of the remainder. The acts of mining, crushing, and processing reduce the size of oil shale fragments and increase its volume by about one-third; even if the mine openings could be completely refilled, considerable amounts of processed oil shale would have to be disposed of at the surface--closer to two-thirds of the total material handled. Processed shale will be finely divided (especially when mined by rapid excavation techniques) and will contain water soluble salts that could contaminate streams or ground water unless steps are taken to protect the disposal area. Control of erosion of disposal areas through revegetation also remains to be demonstrated, and species of plants and fertilizer/nutrient requirements to support vegetative growth on processed shale need to be determined.

One means of finding the solution to treatment of processed oil shale and reclamation of mined lands or disposal sites is to examine factors such as those briefly described above in connection with operations conducted or in progress at the vicinity of the Naval oil shale reserves in Colorado. Previous work in that area produced quantities of oil shale for testing; the demonstration projects should provide a basis for conducting carefully structured experiments to examine the potential environmental effects of oil shale development through rapid excavation so as to determine prospective solutions to be incorporated into the design of excavation operations.

VI ENERGY RELATIONSHIPS TO MATERIALS REQUIREMENTS

A. Summary

Future energy requirements and the corresponding energy availabilities are urgent issues in the United States, particularly to the Department of Defense. Although it is recognized that DoD activities use somewhat less than 5 percent of the total energy consumption, defense related industries may consume comparable or even greater amounts of energy. Combined energy requirements of these two could represent a significant portion of total U.S. energy use. Changes made in DoD material and equipment specifications to effect an internal energy use reduction could be used as guidelines to effect much larger energy use reduction in defense related industries, and possibly in other energy consuming activities as well.

The actual magnitude of energy conservation that could be accomplished within the DoD through material substitutions can be determined only through detailed investigation. However, a very rough approximation of the magnitude can be estimated through use of general statistical information* as follows:

- Industrial energy consumption approximates 40 percent of total energy consumption in the United States.

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* Sources: The Budget of the United States Government, Management and Budget Office; Survey of Current Business, June 1972; Annual Statistical Report of the American Iron and Steel Institute; Commodity Data Summaries, Dept. of Commerce.

- DoD budget in 1971 with respect to GNP approximated:

$$\frac{\$\ 72.6 \text{ billion - DoD}}{\$1046.8 \text{ billion - GNP}} = 6.9 \text{ percent}$$

- Energy consumed within DoD with respect to total energy approximated:

$$6.9\% \times 40\% = 2.8 \text{ percent of total energy}$$

- DoD military procurement with respect to total industrial sales approximated:

$$\frac{\$\ 15.7 \text{ billion - DoD military procurement}}{\$649.9 \text{ billion - total industrial sales*}}$$

$$= 2.3\% \text{ of total sales}$$

- DoD set-asides with respect to total U.S. consumption approximated:

	Total Consumption (000 tons)	Set-Aside (000 tons)	Percent
Steel	87,038	5,280	6.1%
Aluminum	4,600	315	6.9
Copper	2,040	1,897	93.0

From the above, the energy use in the DoD activities approximates 3 to 6 percent of total energy used. If there were a saving of even as much as 10 percent of the energy used in DoD materials, the overall saving would be only 0.3 to 0.6 percent, or roughly 0.5 percent of the total energy used.

Preliminary investigation in four general fields has revealed a few comprehensive pilot methods for reduction of energy consumption in relationship to DoD materials requirements. Detailed investigation should reveal many more.

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* Manufacturer sales (unadjusted) total.

The energy required (on a unit basis) to produce the materials used in DoD activities was developed for 18 materials. These ranged from a high of 207,000 kWh per ton to produce titanium from Ti soils, to a low of 21 kWh per ton to produce sand and gravel. The data are shown in both tabular and graph form to indicate relative material energy levels for ease in comparisons of energy consumption with material substitutions

The data indicate in general that low energy materials such as glass and plastics should replace the greater energy level materials such as steel, aluminum, or copper whenever this is possible. Exceptions exist where a switch to a low energy material in one part of a system results in a larger energy consumption in another part of that same system. Changes should only be made to result in net energy decrease.

Actual data are available on a very few DoD materials. Of these materials, the ten of most probable interest to the DoD and the best estimate of energy consumed in processing them are as follows:

	Processing Energy	
	kWh/Ton	Million Btu/Ton*
Titanium	150,000	512.0
Aluminum	22,000	75.1
Zinc	14,000	47.8
Copper	11,700	40.1
Lead	9,200	31.4
Iron and steel	7,600	25.9
Glass	5,000	17.1
Cement	2,900	9.9
Plastics	2,900	9.9
Nickel	2,000	6.8

* Conversion facto : 3413 Btu/kWh.

A comprehensive analysis will require considerable effort both to determine the full complement of major DoD material requirements and to analyze each material processing to determine unit energy needs.

The extent to which materials are substitutable can be treated only in a general way until the full complement of DoD requirements is known. In this context some potential substitution possibilities are given. These are substitution of glass or plastics for steel or iron where stiffness, resistance to oxidation, or light weight is required, or where the major function is of an aesthetic nature. In addition, areas of investigation for potential substitution are suggested such as use of foamed plastic, fiber glass wrapped vessels, and cement in lieu of steels.

Revisions of DoD specifications to include energy conservation could have a major impact on the costs and availability of required equipment or supplies.

But before a revision can be made in materials use to accomplish a decrease in energy consumption, it will be necessary to formulate a comprehensive summary of energy requirement for all major material requirements of DoD. Then it will be necessary for all contractors with DoD to design equipment to both meet the design specification and minimize overall energy consumption. In many instances, changes could significantly raise manufacturing costs and in addition change the current material balance among industries.

Recycled materials in most instances represent a benefit in energy conservation. Reprocessing of pure scrap metal nearly always is less energy consuming than manufacturing metal from raw ore. Exceptions to this exist where the scrap is an alloy of peculiar characteristics that change during processing or where the scrap includes many impurities that must be removed before and during reprocessing.

Use of aluminum scrap is an example of the latter. Pure aluminum scrap at the point of manufacture is readily and inexpensively recycled. At the other extreme, the recycling of aluminum beer cans could prove to require more energy than the manufacture of a like amount of aluminum from the raw ore.

To obtain an adequate evaluation of energy relationships to material requirements, it will be necessary to determine the principal materials and equipment required in each major category (aircraft, electronics, missile systems, administration, logistics), determine potential substitutions by material involved, and determine the related energy requirements for each substitution. This could be a huge undertaking.

B. Energy Required

Large quantities of energy are required to produce the materials and the equipment used in DoD activities. Although the materials and equipment used directly by DoD represent only a small portion of the U.S. economy, defense related industries can constitute a significant part of the total U.S. energy consumption in material production.

Significantly, information that could permit an evaluation of DoD's energy requirements is relatively unavailable. For materials that the DoD considers to be critical, "set-aside" estimates are issued. Set-aside data for steel, copper, and aluminum for 1969 through 1972 are detailed by quarter in Table VI-1 and shown graphically in Figure VI-1. Each of these have shown decreasing trends with the 1972 set-asides being roughly half of the 1969 set-asides.

Comparable estimates of the myriad other materials produced for and used by DoD are not readily available. To approximate the major portion of the energy requirements for DoD, it would be necessary to determine:

Table VI-1

DOD SET-ASIDE REQUIREMENTS

		Calendar Years				
		1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Total
Steel (tons) Carbon	1969	1,222,410	1,222,410	1,222,410	977,211	4,644,441
	1970	976,920	976,920	829,020	829,050	3,611,910
	1971	632,445	632,445	632,445	534,150	2,431,485
	1972	534,150	534,150	534,150	480,735*	2,083,185
Alloy	1969	141,540	141,540	140,883	97,050	521,013
	1970	97,320	97,320	73,695	73,695	342,030
	1971	66,840	66,840	66,840	51,195	251,715
	1972	51,195	51,195	51,195	46,075*	199,660
Stainless	1969	31,425	31,425	31,425	20,860	115,135
	1970	20,865	20,865	17,070	17,070	75,870
	1971	17,070	17,070	17,070	8,925	60,135
	1972	8,925	8,925	8,925	8,032*	34,807
Copper† (millions of pounds)	1969	300	300	300	300	1,200
	1970	250	250	220	190	910
	1971	190	190	125	125	630
	1972	125	125	125	125‡	500
Aluminum (millions of pounds)	1969	197.3	196.8	161.1	126.5	681.7
	1970	114.6	116.2	109.7	101.9	442.4
	1971	101.1	100.0	89.5	88.9	379.5
	1972	91.2	87.4	79.7	77.1‡	335.4

* 4th quarter 1972 estimated at 90% of 3rd quarter 1972. Commerce Department estimated a reduction of 10-15 percent for that quarter.

† Does not include finished copper.

‡ 4th quarter 1972 estimate by Commerce Department.

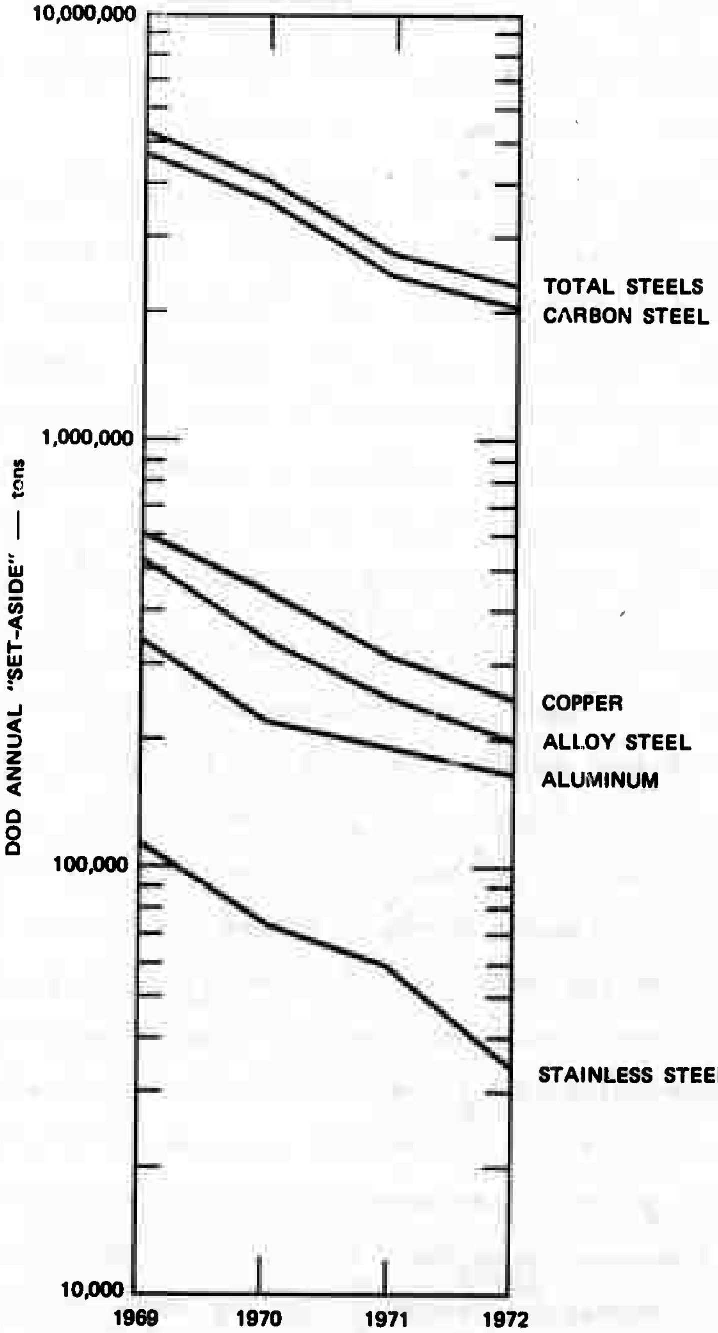

FIGURE VI-1 DOD SET-ASIDE REQUIREMENTS

(1) Quantities of major materials produced and materials used in DoD activities.

(2) Energies consumed in the manufacture and processing of each of these materials.

Because of the wide diversity of DoD material requirements, these two efforts in combination represent a massive effort.

By extension of the quantities and unit energies for each material, the total energy consumption may be estimated. Several materials have been evaluated in this way for the overall United States by Makhijani and Lichtenberg.* The basic materials and commodities believed to be of primary concern to DoD are illustrated in Figure VI-2. Significantly, data from this source indicate one level of processing energy for each basic material (indicated at the left of the figure) and extension by the quantity of use indicates that estimated total energy use.

However, processing energy can vary considerably with the method of processing. For example, processing energy could be very high when using a low grade ore, mid-level when using a high grade ore, and very low when using reclaimed scrap. The approximate ranges of a few of the above materials have been estimated and illustrated in Figure VI-3. Both the range of processing energy in kWh/ton and the estimated overall average kWh/ton are indicated. For a few of the materials, the processing energy range is moderate, covering a span of possibly ± 20 percent. By contrast, processing energy for copper can vary by a factor of 100 (60,000 kWh/ton high to 600 kWh/ton low) and aluminum process energy can vary by a factor of 30 (75,000 kWh/ton high to 2,500 kWh/ton low). To obtain even an approximation of total processing energy, it will be necessary to determine individual processing methods and energies entailed for DoD.

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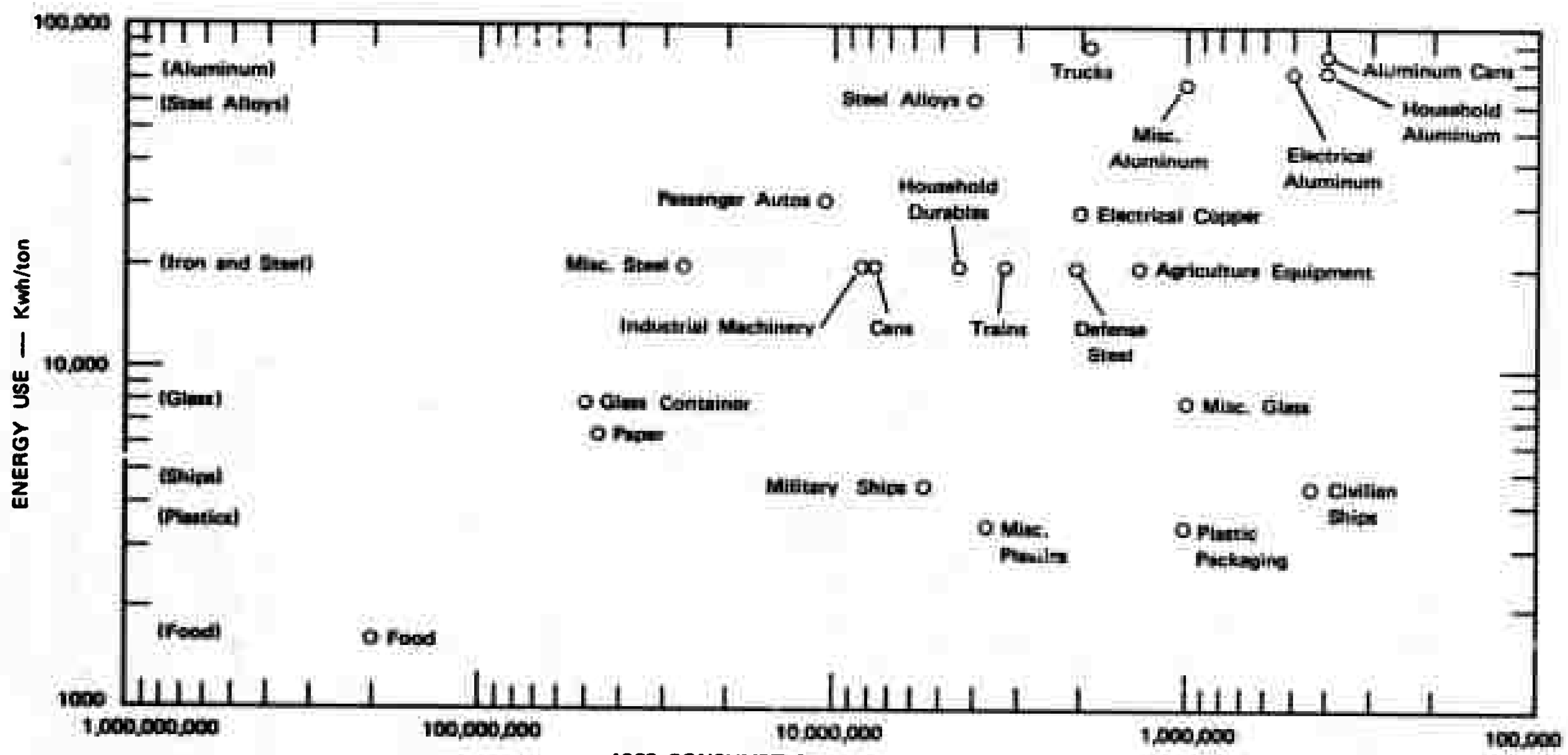
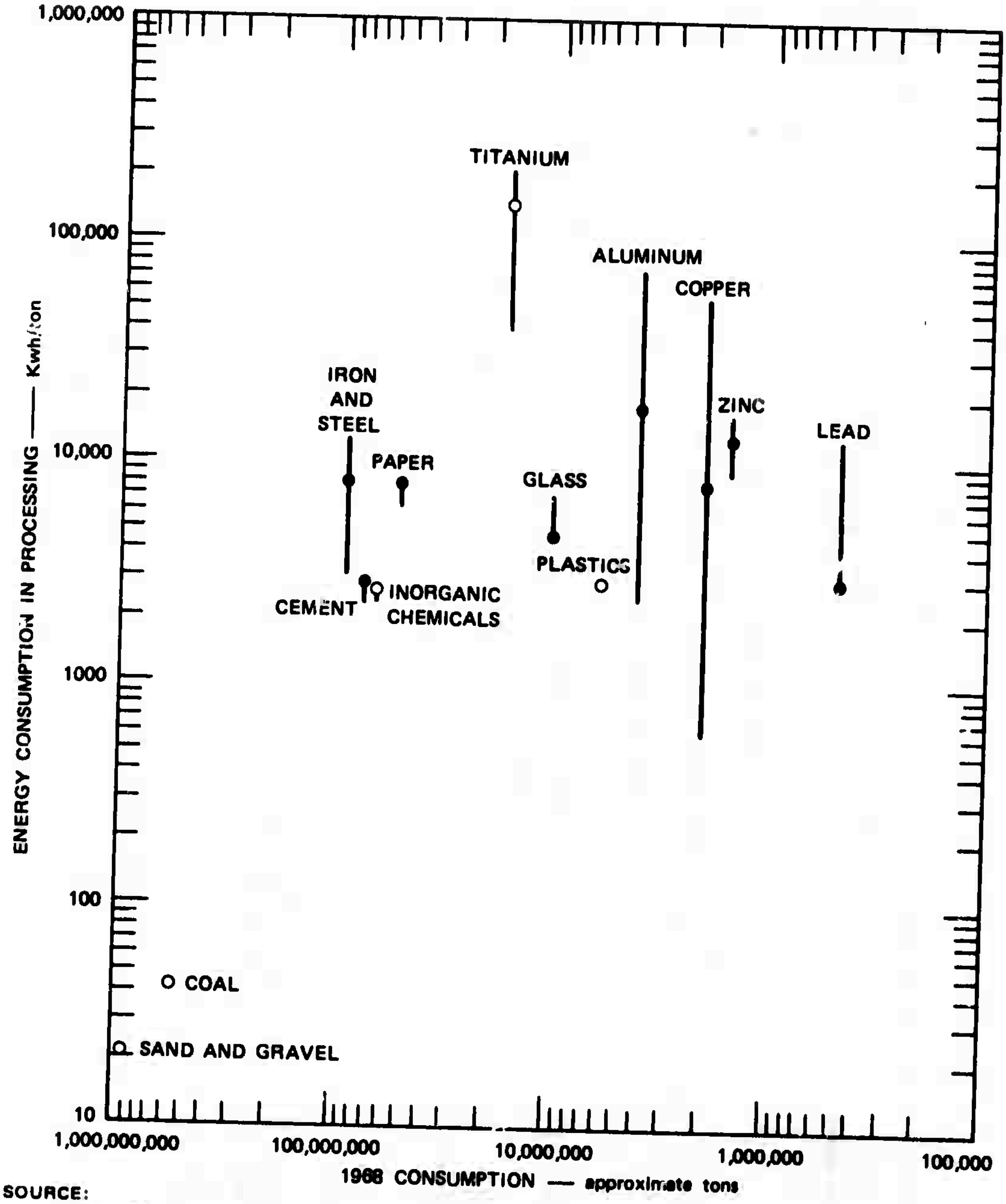
* Energy and Well Being, Makhijani, A.B. and A. J. Lichtenberg, Environment, Vol. 14, No. 5, June 1972.



SOURCE: Makhijani and Lichtenberg

FIGURE VI-2 ENERGY USE IN COMMODITIES (U.S.)



SOURCE:
O Makhijani and Lichtenberg.
● Stanford Research Institute.

FIGURE VI-3 ENERGY CONSUMPTION IN BASIC MATERIALS PROCESSING (U.S.)

Instead, DoD energy requirements may be indicated by detailing the individual material energy requirements on a unit basis. A partial list of these has been prepared. A complete list of all major materials and equipment required by DoD will necessitate considerable effort in cooperation with the DoD. Additionally, it may be necessary to segregate materials reflecting DoD activities and those of defense related activities. Table VI-2 summarizes the energy consumption in processing for 18 groups of materials that are believed to be the predominant materials used in DoD activities. These data indicate the range of kWh per ton of material for the various methods of production, including, where available, data on the production from various raw materials and production from scrap metal. These same data are illustrated in Figure VI-4.

In general, energy can be reduced by substituting low energy materials (toward right of Figure VI-4). For activities requiring many materials, shifts for a few materials can be made to high energy material as long as the net change of all material entailed is to lower energy. Such could be the case of using high energy aluminum instead of iron or steel in manufacture of equipment to accomplish decreased energy consumption in operation, maintenance, or disposal.

C. Substitution

The extent to which materials are substitutable so as to achieve the lowest practicable use of energy in their production, operation, or maintenance can be discussed only in a general way. Currently, the relative characteristics of competing materials are of primary consideration rather than the relative energy requirements. For example, some uses require strengths that are satisfied by a limited number of grades of steel alloys, where other lower energy content materials such as soft iron would be unsatisfactory. There are many other governing characteristics such as resistance to degradation at extreme temperatures; resistance to chemicals,

Table VI-2

U.S. ENERGY CONSUMPTION IN MATERIALS PROCESSING
(kWh Per Ton of Product)

Material	Makhijani and Lichtenberg: Production	Machinery Depreciation	Transportation	Total	Million Tons 1968	National Commission On Materials Policy (A. Shilepsky)	Stanford Research Institute: Gas	Oil	Coal	Other	Electricity	Total
Titanium												
From												
High grade Ti soils												
Ilmenite bearing minerals						207,000						
High grade rutile						150,000--157,000						
Ti scrap recycle						126,000						
Rolled Ti	140,000	1,000	200	141,200	16	39 000						
Magnesium from												
Sea water												
Ores						91,900						
Aluminum												27,000
From												
Anorthosite												
Clays						[illegible]2,400	2,400					
Bauxite (50 - 30% Al_2O_3)						66,000						
Aluminum scrap/recycle						51,500--59,500				5,900	13,700	22,000
Rolled Aluminum	66,000	1,000	200	67,200	4.[illegible]	2,500						2,500
Copper												
From												
0.3% sulfide ore												
1.0% sulfide ore						24,300						
Impure Cu scrap recycle						13,500	10,700				1,000	11,700
98% Cu scrap recycle						1,560						
Rolled or hard drawn	20,000	800	200	21,000	2	590						
Iron and Steel												
From												
Iron laterites												
Magnetic taconites	11,700	700	200	12,600	90	5,180						
High grade hematite						3,560			6,860		760	7,620
High grade steel alloys and silicone metal	58,000	1,000	200	59,200	2	3,180						

Table VI-2 (Concluded)

Material	Makhijani and Lichtenberg: Production	Machinery Depreciation	Transportation	Total	Million Tons 1968	National Commission On Materials Policy (A. Shilepsky)	Stanford Research Institute: Gas	Oil	Coal	Other	Electricity	Total
Lead	12,000	700	200	12,900	.47		2,340		6,530		300	9,170
Zinc												
Distillation process												
Roasting and electrothermic process							290		6,040		3,190	4,520
Roasting and vertical retort	13,800	700	200	14,700	1.5		290		13,480			13,770
Electrolytic process							5,270				9,890	15,160
Manganese												13,000
Paper	5,900	300	200	6,400	50.7		2,170	1,550	2,090	540	490	6,840
Tin												6,000
Glass--finished plate	6,700	300	200	7,200	10							5,000
Nickel												2,000
Plastics	2,400	300	200	2,900	6							
Inorganic chemicals	2,400	100	200	2,700	67							
Cement	2,200	50	50	2,300	74			2,310		590		2,900
Lime												2,000
Sand and gravel	18	1	2	21	918							
Coal	40	2	--	42	556.7							
Related materials and equipment												
Military ships, manufacture gross ton units				4,500	5.52×10^6 tons							
Military aircraft, manufacture, individual units				18×10^6	1500 units							
Defense related steel				20,000	2.06×10^6 tons							
Petroleum processing, barrel units				44.5	3.216×10^9 bbls							

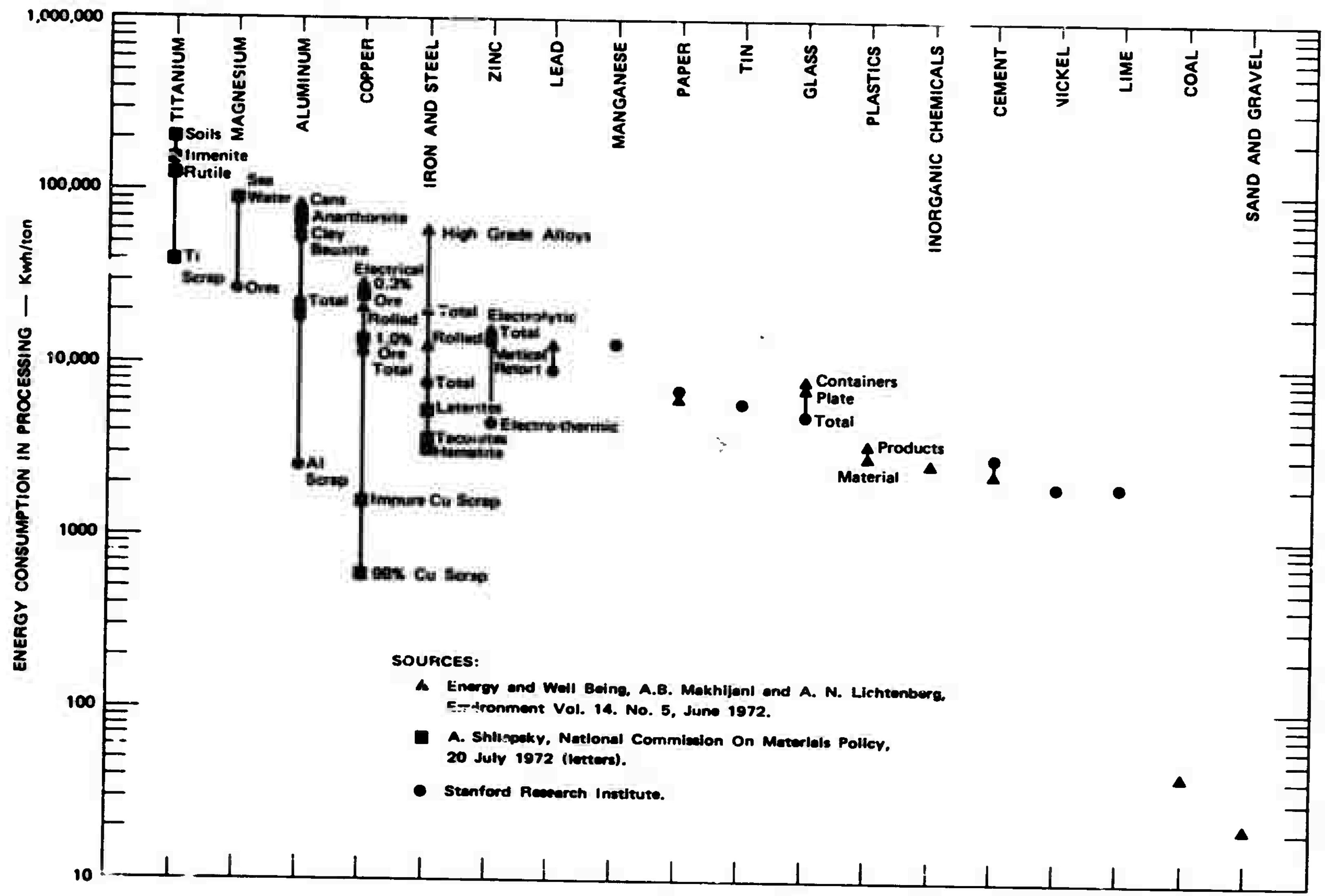


FIGURE VI-4 ENERGY CONSUMPTION IN PROCESSING OF SELECTED MATERIALS radioactivity; aging; electrical or heat conductivity; ductility; peculiar characteristics at extreme high or extreme low temperatures; and many other selective characteristics.

Detailed information on substitutability can be determined only by extensive research and testing, involving significant amounts of detailed research effort and extended time of testing. As satisfactory substitutions are developed they are incorporated into products, with the degree of incorporation generally based on economics of production.

In general, materials requiring the least energy in processing (such as glass or plastics) are to be favored over the high process energy materials (such as magnesium, iron, and steel, or aluminum) as long as the resultant product is satisfactory. Examples where these conditions could apply are:

- Stiffness in materials in which a mild degree of stiffness is required.
- Reinforcement in materials where resistance to oxidation is necessary.
- Materials in which light product weight is favorable.
- Materials required only for aesthetic reasons (e.g., shape, color, texture).

As the technology of individual materials improves, the resultant substitution and replacement greatly influence the material processing economics. One metal frequently displaces another, and the replacement of metals by plastics and glasses has become routine where strength is not a major factor. Such substitution is logical and desirable in most instances; a low processing energy material can replace a high energy processing material, and a scarce metal may be replaced by one that is readily available or by a glass or a plastic where the problem of conservation is of less importance. The replacement of copper by aluminum in high-tension electric lines resulted from the weight advantage of aluminum over copper, not because it was an equally good conductor. Copper is the better conductor, but the saving in weight permitted a wider spacing of supporting towers on high-tension lines, and this economy in the use of steel tipped the balance in favor of aluminum.

Quality considerations entered into the replacement of lead pigments by titanium pigments in white paints. Zinc and aluminum compete in the die-casting industry; some components are more suited to the one metal than the other. The trend toward increased use of glass and plastic containers results in a saving of iron and tin; the use of germanium transistors replaces metals that formerly were used in vacuum tubes. Examples are almost infinite in number among industrial applications.

While this current study is not exhaustive in detailed analysis of possible relative substitutability of materials, several potential areas of substitution can be suggested for future in-depth analysis. These incorporate areas where large amounts of lower energy materials would result in the overall lower energy use with equipment required by DoD, even though there may be isolated instances that would entail a switch to higher energy materials.

- The use of foamed plastic materials injected between metal layers to form sandwich structures rather than the use of structured materials with adhesives between the metal sandwich layers. While the most widely recognized application is in aircraft components, application is also possible to marine uses, automotive and truck body components, fabrics and clothing, furniture, and construction materials. Application would be expected where thermal insulation is desired, where integral structural strength is required, and where maintaining a specific variable geometry of the sandwich surfaces is considered to be significant.
- The use of lower energy glass in place of higher energy steel products in the manufacture of pressure containers. This could have the added advantages of decreased weight and less corrosion from the material contained. Containers could be made with an inner layer of material (e.g., plastic)

that would be impervious to the material to be stored; wrapped by glass fibers to meet the required strength; and coated with another plastic for rigidity.

Applications of this nature have already been realized in the areas of space and missile operations. Although a few industrial applications exist, potentially there are many more. Additional applications should be possible for various commercial pressure vessels (e.g., industrial chemicals storage, pressure containers for various gases) fuel containers (automotive, truck, marine), corrosive material containers (acids, caustics), food and beverage storage (wine, milk, mixed food ingredients), agricultural products (fertilizers, chemicals, insecticides) and many other services.

- The use of low energy cement materials in place of high energy iron, steel, aluminum, and lead in products that require primarily complex configuration and rigidity characteristics. Applications have been rare in this area; a notable exception has been the introduction of the reinforced concrete hull for small sailing vessels. Additional applications may exist in other marine services for underwater (e.g., habitat for petroleum activities, salvage operations) or surface activities (hulls for small high speed vessels) or even storage components to obtain maximum storage volume in an oddly configured space (e.g., fuel tank, ballast). Development of symmetric configuration storage tanks has proved useful in agriculture (silos, storage bins) and in industries (storage tanks for water, chemicals), but additional developments may prove applicable to storage of reactive or radioactive materials.

Each area of potential material substitution should receive detailed examination to determine overall energy requirements.

However, it must be borne in mind that substitution of materials cannot be done without some cost. In many instances, the current availability of a material is such that adequate substitution could not occur for several years. In other instances, substitution could be accomplished only at a significant increase in the cost of materials (increased cost of marginal production or increased processing cost). In these cases, the overall energy saving must be demonstrably clear before there could be general acceptance and realization of a change.

D. Recycled Materials

Some materials are irretrievably lost in use, but in many instances materials can be recovered as scrap, and in a few instances such scrap is essential to the processing of initial material. An example of the latter is the steel industry in which the process operations are predicated on the availability of scrap.

Most metals recovered from scrap are identical to metals from processed ore. Relatively few exceptions to this are special alloys in which the reclaiming process alters the alloy composition.* For most metals, recovery from scrap significantly reduces the energy requirement in processing, and thereby reduces processing costs.

The fact that various metal industries recognize this as a cost saving is reflected in the quantities of scrap already processed, as indicated in Table VI-3 showing scrap use in 1970 by a few of the principal metal industries.

In effect, the percentage recovery of scrap is the greatest for metals of highest manufacturing cost, scrap recovery is the least for metals of lower manufacturing cost or that have peculiar scrap recovery problems. Scrap recovery varies from a high in the 90+ percent range for rare metals (platinum group and like metals) to a midrange of 40 to 50 percent for iron, nickel, and others, and to a low range of 5 to 10 percent for metals with scrap recovery difficulties (zinc, magnesium).

This use of scrap reflects the degree to which each industry has found it economical in terms of manufacturing cost. Increased use of scrap with the intent to decrease the overall energy consumption with

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* Mineral Resources, National Academy of Sciences, National Research Council, Publication 1000-C, 1962.

Table VI-3

SCRAP USE AS A PERCENTAGE OF TOTAL PRODUCTION, 1970
(Thousands of Short Tons)

Metal	Mine	Primary	Secondary (as scrap)	Total	Scrap or Secondary As Percent of Total
Aluminum		3,976	781	4,757	16.4%
Antimony	1.1	13.4	21.4	35.9	59.6
Copper	1,720	1,765	512	3,997	12.8
Iron and steel		81,047	69,323	150,370	46.1
Lead	572	678	597	1,847	32.3
Magnesium		112.0	12.6	124.6	10.1
Mercury*	27,303		8,051	35,354	22.8
Nickel	15.9	15.3†	23.2	54.4	42.6
Platinum group‡	17.4	21.4	349.1	387.9	90.0
Silver	45,000	81,400	56,000	182,400	30.7
Zinc	534	878	77	1,489	5.2

* Quantities in 76 pound flasks.

† Plant and by-product copper refining.

‡ Quantities in thousand troy ounces.

Source: Commodity Data Summaries, Bureau of Mines, January 1972; and Annual Statistical Report, American Iron and Steel Institute, 1971.

respect to that metal or with respect to a DoD material requirement may result in a different operation and an undue financial burden on the manufacturer.

Of particular interest is the manufacture of aluminum. Reuse of scrap produced in the primary manufacturing operation is relatively simple and economical and is performed extensively. Recovery of aluminum scrap from machining operations such as in equipment manufacturing plants presents a few difficulties. Although the scrap is readily identifiable and separable it must be segregated by grade, alloy, or type to process it properly when it is returned to the manufacturing operation. Additionally, by now the aluminum has small amounts of cutting fluids, coatings, and lubricants mixed with the scrap. Purification before reprocessing in the manufacturing process will require added costs for both treatment operations and treatment materials and will require energy reflected by those treatment materials.

Reclamation of scrap aluminum from finished products that have been used and discarded presents formidable problems to the aluminum industry. Basically, the problems are similar to segregation by alloy or type and purification before reprocessing but are compounded many times by the wide variety of aluminum types and the entrained contaminants that are collected with aluminum scrap.

For example, aluminum cans are possibly recyclable. However, in the recycle process there are factors that in combination could potentially use more energy than that of simply producing aluminum from the raw ore. A few of the potential difficulties are:

- <u>Container variety</u>--Although the container that is most familiar to the public today is the soft drink can, similar containers are used for aerosols (e.g., paint, insecticides, hair sprays) small packaged goods (oil additives, solvents) and foods.

When these are consigned to scrap (trash) they include varied amounts of the originally contained materials, as well as the paint or decorative label and product advertising on the outside. To reprocess the aluminum, the manufacturer must be able to remove the many contaminating materials.

In addition, the type of aluminum (alloy) may vary according to the specifications of the canning company and the product contained. The aluminum manufacturer must be able to either segregate aluminum scrap by type or use the conglomerate material in reprocessing.

- Other products--In addition to the aluminum in the shell of the can, the container may have any of several closures, valves, or methods of opening A common method of opening is the convenient pull-tab or ring. However, this is of a different material or alloy than the shell and should be separated before reprocessing. Depending on what the can was used for, it could have plastic or rubber valves, steel or iron nozzles, pellets (spray paint cans), or plastic linings.

- Trash--Soft drink can collection is expected to be accomplished by ecology-minded persons, those who consign their refuse to designated collection containers. The empty cans of the nonecology minded usually do not contain extra trash, but they are seldom collected; they are discarded near the point of use. By nature, the ecology oriented also put other waste materials such as paper, cigarette butts, waste food, and the can pull-tabs into the nearest handy containers--the empty soft drink can.

  Reclamation of aluminum from these cans with their contained additional trash can present significant waste disposal problems to the aluminum manufacturer.

It is possible that energy consumption to solve the above difficulties could more than offset the energy saved by use of the recoverable scrap. To determine the overall energy requirements of recycled aluminum, a detailed investigation effort should be undertaken with the major producers in the aluminum industry.

Similar problems, but possibly of different natures, can easily be visualized in each area of major materials required by DoD. In many instances, the advantage or disadvantage of recycling scrap materials can be revealed only by detailed analysis.

E. Specifications to Conserve Energy

Currently, DoD specifications for materials and equipment are formulated for end results or performance, such as speed, carrying capacity, or capabilities. To meet these specifications, manufacturers then submit various individual equipment designs and configurations. In these designs, the material energy is considered only to the extent that it influences the overall specified cost limitations of manufacture, operation, maintenance, or logistics.

Revision of DoD material and equipment specifications to include factors that would conserve energy could have a tremendous impact on the design, the cost, and possibly the resulting availability of necessary equipment and supplies.

The inclusion of energy specifications would be expected to apply to all facets of material and equipment handling, including manufacture, operation, maintenance, logistics, and even disposal. In addition, energy specifications would be expected to apply to all the materials and equipment that DoD requires. Thus, a first step in this direction should be the development of a comprehensive summary of energies required for all major component materials used in manufacture, operation, maintenance, and disposal of DoD required materials and equipment. This alone could reflect a major effort.

Then from the combination of equipment capability required, the designated component material energies, and the maximum energy level specification, manufacturers would submit their individual equipment designs. Ultimate designs and resulting cost and availability under these specification conditions could be significantly different from those existing today.

Some of the potential differences from today's equipment designs would not become apparent until a complete itemization of materials' energies became available. For example, in some required items the materials of manufacture might be changed to those of higher energy content if it could result in a decrease of energy required in operation and maintenance. Such possibilities would be in the increased use of titanium for supersonic speed equipment and in the increased use of aluminum or magnesium to decrease weight and decrease use of fuels in operation and decrease energy use in maintenance.

In this context, changes in equipment comparable to the development of the British "all-aluminum" armored car could be anticipated. In that use, the Daimler Company of the British Leyland Motor Corporation (in collaboration with the Fighting Vehicles Research and Development Establishments of the British Ministry of Defense) in 1969* developed the aluminum Fox Combat Vehicle Reconnaissance Wheeled, CVR (W). Here, the turret, the hull, and many operational features are made of aluminum.

As in the case of the second generation U.S. aluminum armored vehicles (M-551 Sheridan tank and others), the armor for the Fox CVR (W) is of the 7039 type, primarily in the form of plates. In addition, some portions of the turret are extruded sections, and some critical components are forged.

The adoption of aluminum as armor shell resulted in a thicker walled and consequently considerably stiffer shell, making it possible to dispense with a number of stiffeners that would otherwise be required.

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* Automotive Industries, December 1, 1969.

This in turn saved weight and cost and also improved maintainability by giving better access to the engine and component parts. Also, adoption of aluminum throughout the vehicle wherever possible (engine, suspension system, wheels, brake calipers and many other parts) reduces the vehicle weight and results in significant reduction of fuel consumption (high energy material) in operation.

Some such changes (aluminum wheels, aluminum truck body parts) are already seen in commercial vehicles.

Conversely, changes could be made in the direction of low energy materials of manufacture without sacrificing overall energy use. Examples could be substitution of plastics or glass for some present materials of manufacture to facilitate easier or more rapid maintenance. Other substitutions could be made where structural strength is not required, and the only requirement is of an aesthetic nature.

The inclusion by DoD of total energy specifications could significantly alter equipment designs and costs and also could make contract formulation more complex. In the total-package-procurement contract a single contractor is made totally responsible under a single fixed price contract for all aspects of engineering development, production, maintenance, operation, and logistic support for a major weapon system.* The contractor then guarantees the timely delivery of the required product, which performs to specifications and whose maintenance, operation and logistic support and training cost do not exceed specified amounts. Inclusion of materials energy limitations adds another degree of complexity that the manufacturer and DoD must resolve.

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* Major DoD Procurements at War with Reality, Hudson B. Drake, Harvard Business Review, January-February 1970.

The magnitude of the potential effects can be large--DoD 1970 military procurement budget outlays approximated one-tenth of the Federal Budget ($21,584 million procurement, Table VI-4, Budget Outlays For National Defense Functions 1962-1970; $196,588 million total outlay, Table VI-5, Federal Budget Outlays By Function, 1960-1971). For just one facet of equipment--motor vehicles--DoD requires about 4,000 to 6,000 passenger vehicles and 16,000 to 18,000 buses, ambulances, and trucks each year (see Table VI-6).

The overall scope of the effects of inclusion of energy specifications is reflected in the many categories of DoD outlays during fiscal 1970-71 (see Table VI-7).

From Table VI-7 it can be seen that about one-third of DoD procurement outlay is for aircraft; another one-third for combined missiles, ordnance, vehicles, and related equipment; and the balance distributed among ships, weapons and combat vehicles, electronics and communications, and other procurement. In the bulk of these are potential material substitutions in all phases of manufacture, operation, and maintenance.

Table VI-4

BUDGET OUTLAYS FOR NATIONAL DEFENSE FUNCTIONS: 1962 TO 1970*

[In millions of dollars. For years ending June 30]

COST CATEGORY, PROGRAM, OR AGENCY	1962	1963	1964	1965	1966	1967	1968	1969	1970
Total	51,097	52,257	53,591	49,578	56,785	70,081	80,516	81,232	80,295
Dept. of Defense, military	46,916	48,163	49,577	45,973	54,178	67,457	77,373	77,872	77,150
Military personnel	12,137	11,985	12,986	13,387	15,162	17,967	19,581	21,374	23,031
Active forces	11,530	11,386	12,312	12,662	14,407	17,054	[illegible]	[illegible]	21,977
Reserve forces	607	[illegible]	674	725	755	912	871	892	1,054
Retired military personnel	894	1,015	1,209	1,381	1,591	1,830	2,095	2,444	2,849
Operation [1]	11,594	11,874	11,932	12,349	14,710	19,000	20,578	22,227	21,609
Procurement	14,532	16,632	15,351	11,839	14,339	19,012	23,283	23,988	21,584
Army	1,764	2,371	2,318	1,764	2,671	4,340	5,841	6,117	5,300
Navy [2]	5,215	6,591	6,042	4,603	5,237	6,485	7,902	6,823	7,945
Air Force	7,533	7,673	6,951	5,101	6,414	8,096	9,408	9,294	8,303
Defense agencies	(X)	7	35	42	17	41	42	54	7[illegible]
Research and development	6,319	6,376	7,021	6,236	6,259	7,160	7,747	7,457	7,166
Military construction	1,347	1,144	1,026	1,007	1,334	1,536	1,281	1,389	1,138
Family housing	[illegible]	368	[illegible]	563	677	485	495	572	61[illegible]
Civil defense	90	[illegible]	107	93	56	100	108	87	80
Other [3]	−260	−1,650	−635	−885	132	371	1,327	−1,662	−952
Military assistance	1,337	1,406	1,209	1,135	1,003	[illegible]	651	789	731
Atomic energy program	2,806	2,758	2,761	2,625	2,403	2,264	2,466	2,450	2,453
Defense-related activities	92	24	172	136	−62	−17	139	200	80
Deductions for offsetting receipts	−53	−74	−130	−291	−738	−491	−116	−138	−115

* Published in; Statistical Abstract of The United Syates, 1971, p. 242. For 1971 details see Table VI-6.

X Not applicable. [1] Includes maintenance. [2] Includes Marine Corps.
[3] Revolving, management, military trust, special foreign currency, and offsetting receipts transactions.

Source: Executive Office of the President, Office of Management and Budget; *The Budget of the United States Government.*

Table VI-5

FEDERAL BUDGET--OUTLAYS, BY FUNCTION: 1960 TO 1971

[In millions of dollars. For years ending June 30]

SOURCE OR FUNCTION	1960	1965	1967	1968	1969	1970	1971 est.
Total outlays, by function	92,223	118,430	158,254	178,833	184,548	196,588	212,755
Federal funds	74,863	94,807	126,779	[illegible]	148,919	156,301	164,0[illegible]
Trust funds	19,743	[illegible]	34,[illegible]	41,4[illegible]	43,[illegible]	49,0[illegible]	59,[illegible]
Intragovernmental transactions	−2,383	−3,331	−5,[illegible]	−5,771	−7,347	−8,77[illegible]	−11,109
National defense	45,[illegible]	49,578	70,081	80,517	81,232	80,295	76,443
International affairs and finance	3,034	4,340	4,547	4,619	3,785	3,570	3,5[illegible]
Space research and technology	401	5,093	5,423	4,721	4,247	3,749	3,3[illegible]
Agriculture and agricultural resources	3,322	4,807	4,376	5,943	6,221	6,201	5,2[illegible]
Natural resources	1,019	2,063	1,860	1,702	2,081	2,480	2,336
Commerce and transportation	4,774	7,364	7,554	8,047	7,921	9,310	11,442
Community development and housing	971	[illegible]	2,614	4,076	1,961	2,[illegible]	3,[illegible]
Education and manpower	1,[illegible]	2,533	6,135	7,012	6,[illegible]	7,[illegible]	8,3[illegible]
Health	756	1,730	6,721	9,672	11,696	12,995	14,9[illegible]
Income security	17,977	25,493	30,841	33,445	37,400	43,790	55,[illegible]
Veterans benefits and services	5,4[illegible]	5,722	6,[illegible]	6,[illegible]	7,640	8,677	9,[illegible]
Interest	8,2[illegible]	10,357	12,5[illegible]	13,744	15,791	18,312	19,433
General government	1,3[illegible]	2,210	2,510	2,561	2,[illegible]	3,3[illegible]	4,3[illegible]
Pay increase and contingencies	(X)	(X)	(X)	(X)	(X)	(X)	[illegible]
Undistributed intragovt. transactions	−2,2[illegible]	−3,109	−3,[illegible]	−4,4[illegible]	−5,117	−6,3[illegible]	−7,197

X Not applicable.

Source: Statistical Abstract of The United States, 1971, p. 374.

Table VI-6

Motor Vehicles Owned by Federal Agencies, 1969

	Sedans	Station Wagons	Ambulances	Buses	Trucks by G.V.W. Under 12,500 lbs. 4x2	4x4	12,500-16,999 lbs.	17,000 and Over	Total
Department of Defense									
Air Force	5,740	3,049	1,247	2,788	28,996	5,997	4,793	7,007	60,617
Army	17,837	1,491	1,626	5,593	22,047	*	1,821	17,067	78,477
Navy	5,304	2,130	669	1,801	22,732	*	4,562	6,225	44,427
Civil Works, Corps of Engineers	722	64	4	3	3,047	629	384	263	5,217
Defense Agencies	563	88	28	66	1,074	*	207	171	2,197
Military Assistance	259	102	—	26	599	*	13	92	1,202
Other	42	3	2	2	199	1	1	3	254
TOTAL MILITARY	30,072	6,927	3,576	11,289	90,689	6,627	11,981	30,839	192,801
Civilian Departments									
Aeronautics and Space Administration	46	105	12	19	844	76	127	102	1,343
Agency for International Development	968	451	—	77	1,025	1,656	157	73	4,407
Agriculture	2,615	422	—	45	22,712	2,317	1,327	665	30,114
Atomic Energy Commission	1,864	208	56	325	6,007	625	472	741	10,268
General Services Administration	22,922	4,155	195	643	17,952	3,175	1,586	697	51,225
Information Agency	151	70	—	10	291	592	5	14	1,234
Interior	1,367	575	17	172	5,510	1,992	1,717	1,440	12,791
Justice	5,038	148	1	69	601	279	246	70	6,552
Post Office	—	—	9	14	75,689	258	2,146	2,269	80,385
State	712	210	—	12	686	—	105	92	1,819
Tennessee Valley Authority	872	—	8	7	1,095	306	271	209	2,768
Transportation	59	34	8	10	455	289	128	268	1,361
Treasury	2,168	48	—	—	186	—	5	6	2,413
Other Civilian Agencies	202	67	22	68	907	687	191	171	2,397
TOTAL CIVILIAN	38,986	6,003	330	1,482	134,141	12,464	8,483	6,818	209,177
TOTAL OF ALL AGENCIES	69,589	13,430	3,906	12,771	224,830	19,091	20,434	37,657	401,678

*4x2's and 4x4's not reported separately.

Motor Vehicles Acquired by Federal Agencies

	1968 Passenger Carrying Vehicles	1968 Buses, Ambulances, and Trucks	1969 Passenger Carrying Vehicles	1969 Buses, Ambulances, and Trucks
Civilian Agencies	11,462	30,072	12,858	28,993
Military Agencies	4,544	16,396	6,117	17,926
Total	16,007	46,468	18,978	46,919

NOTE: Excludes military vehicles. Includes vehicles acquired by purchase or forfeit.

SOURCE: General Services Administration, Transportation and Communication Service, *Annual Motor Vehicle Report.*

Published in <u>1970 Motor Truck Facts</u>, Automobile Manufacturers Association.

Table VI-7

DOD TOTAL OUTLAYS, 1970-1971

([illegible] of Dollars)

[illegible]	Jul 1970	Aug 1970	Sep 1970	Oct 1970	Nov 1970	Dec 1970	Jan 1971	Feb 1971	Mar 1971	Apr 1971	May 1971	June 1971	Jul thru 30 Jun 1971	Unpaid Obligations At Start of Year	Unpaid Obligations As of 30 Jun 1971
[illegible]															
[illegible]	1,477,710	1,833,004	1,707,448	1,765,096	1,480,704	1,733,[illegible]	1,798,269	1,761,447	1,825,788	1,819,909	1,720,[illegible]	2,036,532	21,428,226	392,292	410,225
[illegible]	133,014	151,998	98,606	84,660	83,900	90,085	78,981	77,480	85,616	93,192	82,734	148,965	1,204,353	226,256	227,161
[illegible]	6,[illegible]	-46,861	18,903	23,260	64,576	-1,[illegible]	-41,300	-11,709	15,781	16,448	-13,[illegible]	17,227	*	*	*
[illegible]	1,81[illegible]	1,[illegible]	1,904,975	1,872,970	1,889,180	1,[illegible]	1,835,949	1,827,424	1,927,185	1,925,[illegible]	1,781,[illegible]	2,20[illegible]	22,632,575	618,532	637,386
[illegible]	254,037	273,042	276,055	276,821	279,693	282,872	283,441	285,482	287,582	289,872	291,474	306,066	3,385,632	9,799	13,612
[illegible]	1,770,[illegible]	1,688,107	1,706,068	1,717,918	1,906,177	1,666,292	1,570,021	1,576,870	1,739,104	1,816,176	1,670,940	2,305,600	20,941,353	3,871,232	3,418,151
[illegible]															
[illegible]	671,[illegible]	578,720	606,[illegible]	587,930	546,691	648,613	417,992	483,757	525,946	448,796	477,809	556,199	6,549,126	5,777,212	5,985,988
[illegible]	328,749	296,758	282,720	273,986	248,219	276,210	225,976	277,[illegible]	204,379	256,541	221,654	294,765	3,030,847	2,699,308	2,792,989
[illegible]	212,623	160,909	169,088	201,[illegible]	157,290	188,207	167,481	162,150	201,620	165,579	157,008	169,961	2,113,573	2,956,167	3,762,638
[illegible]	73,[illegible]	29,224	30,098	38,289	25,087	23,367	36,106	13,779	26,207	31,801	35,887	35,135	353,153	492,038	498,773
[illegible]	263,242	189,836	326,440	291,133	321,020	335,327	359,718	245,511	340,695	277,097	247,193	482,343	3,669,535	3,865,387	2,886,724
[illegible]	94,415	84,109	72,974	79,998	88,393	109,846	81,970	120,445	120,045	37,806	95,881	177,179	1,192,704	1,162,158	1,125,515
[illegible]	11[illegible],304	158,805	150,463	151,886	157,842	116,596	131,712	199,458	148,946	131,652	120,217	405,872	1,988,821	2,138,364	1,865,531
[illegible]	182,806	91,630	65,908	-33,649	-35,692	96,092	99,260	-79,[illegible]	-9,046	-4,[illegible]	-16,[illegible]	-2[illegible]1,1[illegible]			
[illegible]	1,[illegible]	1,544,[illegible]	1,693,614	1,590,443	1,908,980	1,734,250	1,4[illegible]9,718	1,423,1[illegible]	1,5[illegible]	1,3[illegible]3,3[illegible]	1,3[illegible]5,976	1,877,905	18,857,758	19,390,614	18,522,155
[illegible]															
[illegible]	65,977	76,092	87,852	69,098	72,723	83,739	81,091	83,093	93,970	69,242	99,279	97,676	979,807	667,229	982,909
[illegible]	107,014	96,948	127,442	135,855	145,872	207,[illegible]	125,[illegible]	104,789	142,618	216,642	149,780	139,706	1,629,[illegible]	828,000	908,124
[illegible]	145,981	170,629	166,648	193,627	152,313	169,604	141,947	147,278	176,692	156,588	157,536	175,615	1,994,[illegible]	993,825	1,006,072
[illegible]	57,334	52,254	44,175	56,130	42,491	48,910	38,[illegible]	31,605	51,743	33,056	34,166	25,749	512,[illegible]	409,965	345,986
[illegible]	28,342	41,[illegible]	44,[illegible]	27,[illegible]	44,177	33,[illegible]	21,[illegible]	20,761	11,[illegible]	41,[illegible]	20,779	35,752	392,402	223,508	152,906
[illegible]	19,364	19,942	46,[illegible]	21,379	24,043	88,104	20,136	22,954	23,357	28,936	27,021	26,518	284,056	167,249	397,135
[illegible]	63,408	61,670	81,399	72,129	73,005	73,847	65,521	79,338	80,263	89,299	72,524	137,651	954,244	491,498	482,624
[illegible]	64,671	57,801	37,[illegible]	22,[illegible]	22,[illegible]	98,193	44,095	35,[illegible]	25,309	51,143	44,716	45,449	5[illegible]	203,209	194,118
[illegible]	56,472	17,[illegible]	-37,[illegible]	22,[illegible]	[illegible]	[illegible]	20,[illegible]	-11,[illegible]	13,[illegible]	[illegible]	-5,[illegible]	-33,[illegible]			
[illegible]	5[illegible]	594,203	591,905	641,472	5[illegible]6,709	670,177	557,192	523,881	661,270	657,935	609,[illegible]	650,973	7,303,018	3,964,882	3,911,654
[illegible]	98,499	85,143	93,017	81,646	76,553	101,[illegible]35	87,902	92,173	97,528	71,8[illegible]	95,665	121,399	1,095,155	1,656,056	1,737,737
[illegible]	35,658	43,853	53,096	49,651	49,698	53,880	48,348	46,023	54,895	44,824	54,993	63,051	997,860	201,617	262,278
[illegible]	881	5,404	10,274	5,053	6,931	6,684	8,194	6,64[illegible]	6,690	9,734	2,396	6,410	74,564	43,969	43,548
[illegible]	15	7	144	94	56	858	123	96	256	-44	197	482	1,800	1,239	2,658
[illegible]	212,289	-47,429	-166,841	-80,353	36,991	-1,786	-34,838	-65,307	4,438	-104,[illegible]3	-49,531	77,995	-218,775	5,446,932	4,651,486
[illegible]	-19,191	-80,409	-1,[illegible]	-14,351	-5,006	-6,108	-17,730	9,684	-12,039	-15,369	6,094	-18,182	-119,957	-	-1,[illegible]
[illegible]	6,571,295	6,042,991	6,160,908	6,141,370	5,835,[illegible]	6,3[illegible]0,083	5,776,308	5,721,055	6,309,718	6,040,0[illegible]	5,809,994	7,592,024	74,550,988	35,17[illegible],076	33,196,571
[illegible]	-1,439	-1,496	-863	-1,722	15,680	-9,289	2,794	-952	-899	738	665	-2,160	1,166	4,449	6,560
[illegible]	*	-2,053	-6	-2	*	-1	-1,819	-5	-1	-	-2,095	-23	-6,005	-	-
[illegible]	6,569,823	6,039,443	6,160,039	6,139,645	5,850,941	6,380,853	5,777,296	5,720,097	6,308,8[illegible]	6,040,799	5,808,564	7,589,840	74,546,148	35,178,526	33,203,130
[illegible]															
[illegible]	29,638	40,785	28,930	32,984	48,989	67,158	52,813	50,780	207,371	124,669	63,255	287,673	9[illegible],385	1,180,872	1,3[illegible]
[illegible]	30,098	-[illegible]7,848	-11,394	-11,792	-128,535	-37,297	1[illegible],672	41,819	-8,404	-34,375	-38,156	52,218	1,[illegible]	197,309	330,2[illegible]
[illegible]	59,736	22,987	17,536	21,139	-73,546	29,861	[illegible]7,485	92,599	198,967	90,294	25,099	[illegible],891	998,081	1,378,18[illegible]	1,5[illegible]
[illegible]	6,629,559	6,[illegible]82,370	6,177,575	6,160,776	5,780,395	6,350,715	5,9[illegible],771	5,812,696	6,507,826	6,131,0[illegible]	5,8[illegible]3	7,8[illegible]	[illegible]	36,5[illegible]	[illegible]

[illegible]

Source: Monthly Report on Status of Funds by Functional Title, Dept. of Defense, F[illegible] 670, 30 June 1971.

ENERGY TRANSFORMATION, STORAGE, AND DISTRIBUTION

VII MATERIALS REQUIREMENTS IN ADVANCED ENERGY CONVERSION SYSTEMS

A. Statement of the Problem

As the demand for energy grows and conventional resources dwindle, the need for new energy generation and conversion systems becomes more pressing. Immediate objectives must include the development of new techniques for the more efficient recovery of known fossil fuel resources, together with evolutionary developments of current conversion systems, to allow known lower-quality resources such as shale oil and high sulfur coal to be used. At the same time, the developmental activities related to nuclear power should be supplemented by development of entirely new or underutilized energy systems--thermonuclear, MHD, fuel cells, solar and geothermal power--to ensure the continuing adequate supply of clean energy.

Both objectives will rely for their success on the availability of materials able to withstand ever more rigorous operating conditions. In many cases suitable materials are not available today to meet the demands of the future, and in many areas our basic understanding of the behavior of materials is too fragmentary to allow the materials scientist to develop improved materials on other than an empirical basis. Failures occurring during early service experience with new materials, which are a probable consequence of this method of materials development, are not likely to be greeted with enthusiasm either by the power generating authority or by an increasingly vocal, environmentally conscious society. Thus, it is important to attempt to assess the materials requirements that must be satisfied if advanced energy generation and conversion techniques are to succeed and, by matching these requirements with the properties of existing materials, to determine the areas where additional research and development are most urgently needed. This has been the objective of the present study, although time has not allowed the kind of in-depth study that is a prerequisite to making detailed recommendations as to specific new materials research and development programs that DoD should fund. Indeed, our strongest recommendation is that such an in-depth study should be initiated as soon as possible.

B. State of the Art

Recent technoeconomic studies of the future market for advanced materials in the electric power, process, and aerospace industries conducted by SRI indicate present or potential materials problems in all the energy generation and conversion systems considered. There is a striking consistency in the nature of the materials problems identified irrespective of the system considered; thus, it is possible to classify the future materials requirements into four major areas that apply to a greater or lesser extent to all the advanced systems so far proposed.

1. Materials for High Temperature Service

Many of the advanced systems feature very high operating temperature mechanical properties. Conventional nickel-based superalloys have reached a stage of development where it is difficult to foresee further substantial improvement in properties. Development of high temperature alloys based on the refractory metals necessitates the simultaneous development of long life, protective coating materials to provide adequate oxidation and nitridation resistance. The development of some form of self-repairing coating appears necessary before refractory metal alloys can be used in long term high temperature application with any confidence.

The use of ceramic materials appears more immediately promising, although a more detailed understanding of the interrelation between mechanical properties and microstructure of these materials is needed, for example, to allow optimization of high temperature creep behavior while retaining acceptable thermal shock and impact resistance. Additional practical experience of the problems encountered when ceramics are used in applications for which prior experience relates only to metals also appears to be essential. The insight gained from the ARPA-funded ceramic gas turbine will be valuable in this regard, but other programs of this type covering other application areas will probably be needed. Finally, some development of electrical materials for extended high temperature service may be needed, including both improved high temperature conductors and insulators.

2. Materials for Long Term Service in Aggressive Environments

This area dominates all others in advanced energy conversion systems and at the same time is the area where our present knowledge and understanding of the important factors are most rudimentary and incomplete. Even the seemingly innocuous step of diluting natural gas with a few percent of air can under certain circumstances lead to unforeseen catastrophic corrosion problems in both copper and steel piping. The potential problems in advanced energy systems are usually much more obvious than this, but a major difficulty remains that of considering in advance every circumstance that might lead to an environment-related failure during a 30-year or longer service life.

Another difficulty is to maintain adequate environmental resistance while satisfying other materials requirements. An illustration in a different field of application is provided by the development of a titanium alloy suitable for the hull of a deep-diving undersea vehicle. The requirements for this application include moderate strength, high toughness, good weldability and formability, as well as resistance to corrosion and stress corrosion cracking in sea water. The weldability requirement necessitates the use of an all alpha or near-alpha composition, and the first alloy developed for the application was the near-alpha Ti-8Al-2Cb-1Ta. However, since this alloy was subsequently found to exhibit an ordering reaction that severely impaired its toughness, the aluminum content was reduced to 7 percent. The resultant Ti-7Al-2Cb-1Ta alloy was delivered in considerable quantity before its susceptibility to accelerated crack growth in seawater was discovered. This necessitated a further reduction in aluminum content to 6 percent, which resulted in the alloy being too weak for the intended application. A 1 percent Mo addition was found to increase the strength sufficiently without leading to seawater stress corrosion susceptibility, and the resultant alloy Ti-6Al-2Cb-1Ta-1Mo is currently a top contender for a role as a marine structural metal. Its development illustrates the typical problems encountered when a range of properties must be optimized simultaneously.

The range of possibly damaging environments encountered in advanced energy generation and conversion systems is very wide and therefore will be summarized briefly with a few illustrative examples. Aqueous environments are commonly encountered in cooling and heat transfer systems and can lead to stress corrosion and corrosion fatigue as well as general corrosion problems. A wide range of prior experience exists from conventional systems. In most cases, suitable materials already exist, provided close control of solution chemistry is feasible and the service stresses to which the component is subjected are well understood. However, they have not always been used in the past because their use commonly requires a cost premium.

Experience has tended to show that the use of the best material available is often cost-effective in the long term even allowing for higher initial costs. For example, the British electric power industry is now seriously investigating the use of titanium tubing in steam condensers, taking the view that the initial materials investment (which is increased by more than an order of magnitude) will be more than offset by the decreased downtime and repair costs over a 30-year lifetime. In hot water reactors, additional problems can result from superimposed effects of radiation; for example, radiolytic decomposition of water can lead to a potential hydrogen embrittlement situation.

A major barrier to fundamental investigations of corrosion behavior in hot aqueous solutions has been the absence of adequate basic research techniques. For example, it is necessary to develop reliable reference electrodes to make electrochemical corrosion measurements in high temperature, high pressure environments. This is an area where extensive additional work is clearly indicated.

Liquid metals are widely proposed for use as coolants in advanced systems, and metal vapor/liquid loops appear to offer potential efficiency improvements. In this area, little or no backlog of service experience exists, and basic knowledge of the potential containment problems is in its infancy. Liquid metal embrittlement is a well known metallurgical phenomenon and, in long term service, mass transport of alloy constituents by hot liquid metals may lead to major problems. We need to know much more about the behavior of both metals and ceramics in the presence of liquid metal vapors before these environments can be used with confidence. Localized corrosion, stress corrosion, and corrosion fatigue behavior must be investigated in detail. Once again, the basic techniques required for generating the needed data are only in the early development stages. We also lack the instrumentation for continuous monitoring of the chemistry of the liquid metal coolants that is required, for example, to determine mass transport rates of carbon in service.

Environment-related problems are also encountered in most types of fuel cells and to a lesser extend in more conventional energy sources as well. Gas and fuel oil transmission pipelines and distribution systems are particularly subject to problems and may become increasingly so as lower quality resources are developed and put on-line. Most problems arise because of specific combinations of small quantities of impurities (e.g., sulfur compounds plus amines plus oxygen in natural gas) which are more likely to be found in fuels derived from lower quality resources.

3. Improved Materials for Structural and Mechanical Applications

The needs of advanced energy systems in this area are not very different from those of other advanced systems. Materials are required with greater stiffness, strength, and toughness than those available today. Composite materials offer the potential of greater stiffness and strength and may find wide application. Uranium enrichment by the centrifuge technique may become more attractive if advanced composite materials can reliably attain their projected properties, and novel propulsion systems based on composite material flywheels can become significant as fossil fuel resources decline. Emphasis on failure safe design will encourage the development and use of materials with greater fracture resistance than those available today, under both static (fracture toughness) and dynamic (fatigue) loading. Improvements in nondestructive testing and inspection techniques will also be required, aimed at decreasing the minimum detectable flaw size and hence improving our ability to identify potential sources of catastrophic failure in critical structural members.

4. Improved Fabrication Techniques

As new materials become available, fabrication techniques must be improved to enable us to fabricate useful products from them. Changes in design practice will also be needed--for example, design principles developed for relatively isotropic homogeneous metals cannot be applied when highly anisotropic materials such as composites are used. Design experience in the use of relatively brittle materials such as ceramics is also needed for cases in which other considerations dictate their choice.

Although of secondary importance, the use of energy-conserving fabrication techniques such as powder metallurgy and superplastic forming should be encouraged. Moreover, resource conservation as well as energy conservation appears increasingly critical. Fabrication techniques that lead to much higher levels of materials utilization than those common today are needed, and new processes must be developed to effectively and economically recycle mineral values that are currently wasted.

C. Assessment of Current Work

The four areas listed constitute a substantial part of the complete materials research and development program in the United States. Therefore, relevant work is currently being conducted in virtually every significant research and development activity in the nation, and funding is being provided by essentially all DoD agencies with a materials research and development mission. Consequently, a rigorous comparison of current work and future needs for advanced energy systems would require a much more detailed analysis than has been possible in the present study.

Superficially, it appears that Area 3 (mechanical applications and most of Area 1 (high temperature materials) are adequately covered by current DoD-funded work. Additional work on coatings for high temperature and refractory alloys and on the basic behavior of ceramic materials may be warranted. Areas 2 (environment resistant materials) and 4 (fabrication techniques) may require significantly increased DoD attention. In particular, work on environment-related phenomena in liquid metals probably requires an increased level of effort at this time. DoD should also increase its participation in materials utilization and recycling studies.

D. Recommendations and Conclusions

A major study should be initiated to assess in detail on a system-by-system basis the materials needs of advanced energy generation and conversion systems. A priority listing should be established and compared with current DoD funding to identify areas in need of accelerated study. On the basis of the current superficial study, it is believed that these areas may include development of protective coating systems and high temperature strengthening techniques for refractory metals, understanding and improving the high temperature mechanical properties of ceramic materials, the mechanical and electrochemical behavior of metals and ceramics in liquid metal and metal vapor environments, and the development of advanced fabrication and recycling technologies.

VIII PRODUCTION AND UTILIZATION OF NONHYDROCARBON CHEMICAL FUELS

A. Statement of the Problem

The Department of Defense directly accounts for only a small fraction (less than 5 percent) of the nation's total energy consumption. However, this figure does not include the energy consumption of Defense-oriented industries. Moreover, DoD has an unavoidable interest in and responsibility for maintaining an appropriate energy base for the entire economy, since that base represents a critical component of our national security.

Thus, although there are many direct military reasons for considering the role of nonhydrocarbon chemical fuels, it is necessary also to consider the much broader fuel needs of the country as a whole.

It is widely recognized that "premium" fossil fuels (natural gas and low sulfur oil) are already in short supply and that all fossil fuels (including coal, lignite, tar sands, and shale) will be in short supply within a few generations at projected growth rates for total energy consumption. The priority that one places on the need for alternative, nonfossil-based chemical fuels depends on the time scale of the scenario under consideration. For the shorter term of one or two decades, the major priority is likely to be placed on the need for transformation of the relatively more abundant fossil fuels (coal and lignite) into the less abundant premium forms. Nevertheless, it is appropriate to consider what research should be devoted to the long term total energy problem whose solution will require chemical fuels made from nonfossil fuel sources.

The current and projected increased emphasis on pollution abatement makes it desirable to develop and stimulate the use of new, inherently less polluting fuel types. Here it is important to assess not only the principal products of combustion for each fuel but also the products resulting from incomplete combustion, from combustion of fuel impurities, and from side reactions such as nitrogen oxide formation.

Any consideration of new fuel types must take into account questions of safety, reliability, and economy. In regard to the latter, it is necessary to develop fuel types that are not only cheap to produce but are also cheap to transport and store and can be efficiently utilized.

Most of the above needs are not specific to defense fuel requirements, but apply quite generally to the total national energy plan. Many other needs are more easily identified with military goals; e.g., the need for fuel types offering advantages in portability, in specific energy storage capacity, in high power density or specific impulse, in light weight or added buoyancy, or in the capability of the fuel to perform other useful functions such as structure cooling.

This study is concerned with a relatively limited category of fuels, namely those that are not primarily hydrocarbons (a criterion that excludes essentially all fossil fuels) and that are vigorous reducing agents rather than vigorous oxidizing agents (which excludes such oxidizers as fluorine, NO_2, HNO_3, and ozone). Some potential candidate fuels, like sulfur or H_2O_2, can act either as oxidizing or reducing agents but are excluded from this study because their main fuel potential is as oxidizing agents.

Thus, this study is limited to the following fuel types:

- Hydrogen
- Inorganic hydrogen carriers (ammonia, hydrazines, silanes, boranes)

- Partially oxygenated carbon compounds (CO and CH_3OH)
- Active metals (e.g., Li, Na, Al, Mg, Zn).

It may be noted that solid hydrogen carriers such as metal hydrides are considered to be a variation of hydrogen itself, rather than to be in the second category.

B. State of the Art

The following discussion will attempt to cover for each fuel type, the current status of methods of production, utilization, storage and transmission and to identify the principal future opportunities and any critical technical barriers that must be overcome.

1. Hydrogen

Hydrogen is now produced commercially primarily by catalytic steam reforming of natural gas. This will doubtless remain the most economic production method as long as natural gas (or synthetic natural gas made from other fossil fuels) remains available at low cost. Other available methods for hydrogen production include the catalytic partial oxidation of hydrocarbons, the steam-iron method, and the electrolysis of water. Water electrolysis is a likely first step in the preparation of deuterium, which is a fuel for thermonuclear reactors. Therefore, hydrogen will be a readily available by-product of thermonuclear power generation.

Hydrogen finds practically no present use as a conventional fuel except in mixture with CO and other gases. Liquid hydrogen is highly successful as a rocket fuel and as a fuel cell material for power generation in spacecraft. Its disadvantages include its relatively high cost and its relatively hazardous character, the latter because of its wide explosive limits and its tendency to diffuse through metals. Because of the above factors, hydrogen is used industrially mainly as a captive intermediate to make other chemicals such as ammonia and methanol.

Hydrogen fuel cell technology is well advanced technically but still economically uncompetitive. Hydrogen has been evaluated as a non-polluting fuel for internal combustion engines and has been found to be eminently suitable, if appropriate engine modifications are made to counteract its tendency for preignition.

In regard to storage and transmission, hydrogen is handled almost exclusively in one of two forms: as a cryogenic liquid or as a highly compressed gas. Both methods are relatively costly and hazardous. Pipeline transport of hydrogen has been used between nearby petrochemical plants but has not yet been demonstrated on the scale of natural gas pipelining.

In contrast to the relatively modest current utilization of hydrogen, it is widely regarded that tremendous opportunities exist for growth in its utilization. As Gregory[1] and Weinberg and Hammond[2] have pointed out, unlimited hydrogen from the sea could serve as the key to synthesis of many kinds of potentially scarce resources, including metals and portable fuels.

Although electrical energy is undeniably convenient and clean, it suffers from a number of technical disadvantages, foremost among which are its lack of storability (without prior conversion to another form) and its high transmission cost over long distances. The reversible hydrogen fuel cell offers a simple, efficient way to store off-peak electrical energy, thereby reducing the capital requirements for future nuclear electric power plants. (The same advantages would also apply to fusion powered or solar powered electric plants, when and if these become realities.)

In regard to transmission costs, underground electric power lines are reported to cost 10 to 40 times as much as common overhead lines of similar capacity. Since we are accustomed to moving large quantities of natural gas across the country in pipelines, the same approach can be applied to hydrogen. Even today, it should be possible to make and deliver energy in the form of hydrogen more cheaply nationwide than the average selling price of electricity.

Even before the projected depletion of fossil fuel resources makes the cost of natural gas exceed that of nuclear-electric-based hydrogen, the "hydrogen economy" will probably be justified on the basis of resource conservation and pollution abatement. Schoeppel[3] has pointed out that hydrogen is substitutable for any other mineral fuel currently available. Its use has already been demonstrated in reciprocating internal combustion engines and turbines, and its adaptation to external combustion engines would be even simpler. Its light weight and high energy density as a liquid give it desirable storage features of particular value in aircraft and space vehicles. Its ability to chemisorb reversibly with certain metals to form hydrides enables it to be conveniently stored at ambient pressures and temperatures, thereby potentially making it even less hazardous than gasoline.

According to Witcofski,[4] a distinguishing feature of the projected hypersonic transport (HST) airplane will be its use of liquid hydrogen fuel, which has 2-3/4 times the energy per pound of conventional JP fuel. This large energy density more than compensates for the reduction in aerodynamic efficiency ascribable to housing the low density fuel. In addition, the large heat sink capacity of liquid hydrogen (10 percent of the combustion energy) allows active cooling of the airframe, which can thus be made of conventional aluminum structures. It is significant to the future prospects for a hypersonic transport (speed above about Mach 3) that it may avoid or overcome some of the environmental problems so critical to the decision to halt development of the U.S. supersonic transport (SST).

The problems that must be solved before hydrogen fueled vehicles can be universally accepted are: (1) the design and construction of adequate hydrogen production, handling, and distribution systems, (2) the development of hardware necessary to store and utilize hydrogen efficiently, and (3) the oversoming of the generally held but undeserved public attitude that hydrogen is too hazardous.

2. Inorganic Hydrogen Carriers (ammonia, hydrazine, silanes, boranes)

Ammonia production technology, now very advanced and economic, is based on the high pressure catalytic reaction of hydrogen and nitrogen. Hydrazine, in turn, is produced mainly from ammonia by reaction with sodium hypochlorite, followed by dehyrdation and distillation. Silanes are made by acidic solvolysis of electro-positive metal silicides such as Mg_2Si. Boranes other than diborane are produced by pyrolysis of diborane, whereas the latter is synthesized by reaction of a metal hydride with a boron halide.

Most of today's ammonia production goes either directly into agriculture or into nitric acid manufacture. Ammonia has been evaluated as a fuel for internal combustion engines but has not found favor because of its very low combustion rate and its potential for formation of nitrogen oxides. Ammonia fueled engines are also subject to emissions of considerable unburned ammonia, a pollutant in its own right. The technology of ammonia fuel cells is highly advanced.

Hydrazine and its methyl-substituted derivatives have high heats of combustion and high specific impulse, which make them excellent rocket fuels. They also have good potential as fuels for fuel cells, except for their high cost. They are all extremely toxic and are subject to a detonation hazard because of their instability.

Silanes and boranes are very hazardous, being toxic, hygroscopic, and pyrophoric. All have high heats of combustion, making them attractive as rocket propellants. However, interest in them has waned because of the difficulty of exhausting the condensed phase combustion products, the inadequacy of engines for utilizing their available energy, and their high cost.

Ammonia, hydrazines, silanes, and boranes are all easily and economically stored and handled as liquids, at temperatures much more readily attained than those for liquid hydrogen. Pipelining of liquid ammonia is soon to be put into commercial practice on a large scale.

3. Partially Oxygenated Carbon Compounds (carbon monoxide and methanol)

Carbon monoxide is produced (generally in admixture with hydrogen and other gases) by various modifications of partial combustion or controlled oxidation of fossil fuels, either with air or steam. Its high toxicity, low heating value, and low boiling point all tend to favor its role as an intermediate to other fuels, rather than as a fuel for general use (except in low Btu gas mixtures, which appear to have a future for power generation and other industrial applications).

Methanol is produced by the high pressure catalytic reaction of carbon monoxide and hydrogen in equipment similar to that used for ammonia synthesis. It is a clean-burning fuel that has been used successfully in internal combustion engines and in fuel cells. It is being seriously considered as a substitute for liquefied natural gas, because of its easier storage and transportability. Its vapors are toxic, and it has only about half the heating value of methane on a weight basis.

The real opportunity for large scale use of methanol may come when liquid fossil fuels ultimately become depleted. Then it may be necessary to develop a methanol synthesis route for which the carbon monoxide is derived by hydrogen reduction of atmospheric carbon dioxide, as suggested by Williams et al.[5]

4. Active Metals (e.g., Li, Na, Al, Mg, Zn)

With the exception of zinc, which can be liberated from its ores by roasting and carbon reduction, all the active metals are made by electrolysis of their salts.

The principal fuel use of these and other metals is as the anode material in high energy density batteries. Lead/acid, nickel/cadmium, and nickel/iron secondary batteries will probably continue to provide rechargeable energy sources for applications where their low energy density and high cost per unit of power are unimportant. However, the limitations of the present storage batteries have stimulated research in high energy density systems such as (1) secondary zinc/air cells, (2) organic electrolyte cells, (3) molten salt cells, and (4) refuelable batteries.

The military has used mechanically refuelable batteries for communications equipment,[6] based on zinc/air, aluminum/air, magnesium/air, iron/air, and cadmium/air cells. None of the existing cells meets the requirements projected for the ultimate nonfossil fuel society. The improvements that must be made to achieve energy densities of 100 watt-hours per pound and power densities of 75 to 100 watts per pound at acceptable costs include:

- Develop lower cost cathode catalyst
- Reduce irreversibility of the cathode
- Reduce heat generation at rated current

- Develop improved removal of discharged anodes
- Avoid adsorption of CO_2 by alkaline electrolyte

C. Present Activities and Organizations

Bobo[7] gives an extensive list of federal, state, and independent agencies and their fuel information categories. Only a few agencies, such as EPA, AEC, and NASA, regularly publish lists of active research contracts. One of the most convenient tabulations available is the (copyrighted) Market Intelligence Report, published by DMS Inc. That report includes sections dealing with "Combustion and Ignition," "Energy Storage," "Fuels," and "Rocket Propellants." The report lists the major Army, Navy, Air Force, and NASA sponsors for each designated research topic, and gives the current funding levels for each program. What is needed is a systematic analysis of these topics for their relevance to energy-related matters treated in this report.

D. Implications for Dod

As pointed out in Section A, the maintenance of an appropriate energy base for the entire economy is crucial to national security. Specifically, the development and increased utilization of nonhydrocarbon chemical fuels will permit the conservation of strategic fossil fuels and will ultimately provide a means for attaining freedom from dependence on fossil fuels.

Hydrogen may be considered a "universal reducing agent;" thus, the development of cheap production, storage, transportation, and utilization methods for hydrogen will guarantee the means to produce metals, portable fuels, and other strategic materials.

Reversible hydrogen fuel cells could provide efficient storage of off-peak nuclear electric power, as well as a source of emergency power.

From the narrower tactical viewpoint, fuel cells can make possible more buoyant submarines, silent frontline power, more efficient use of fuel for motive power, silent portable electric generators, and minimum-weight spacepower systems.

Cryogenic hydrogen as fuel and refrigerant is probably the key to development of a viable hypersonic aircraft. Hydrogen-fueled internal combustion engines provide the means to meet 1976 air pollution standards immediately, without resort to catalytic or thermal exhaust reactors.

High energy rocket fuels make possible large savings in fuel weight and increased payloads. High energy density batteries make possible lightweight, portable power sources for critical equipment such as communications sets.

E. Recommendations for Further Studies

The development of automatic dual-fuel internal combustion engines appears to warrant a high priority effort. It is known, for example, that the addition of about 2 percent hydrogen to ammonia or to conventional fuels can permit lean operation, with greatly reduced nitrogen oxide formation. What is really needed is a dual-fuel system that will meet all safety and logistic requirements. This will probably entail improved methods for reversible storage of hydrogen in the form of hydrides, plus methods for odorization of hydrogen, for leak detection.

The concept of storage of combustion heat by dissociation of hydrides, with recovery of heat during recharging of the hydrides, needs to be demonstrated on a practical scale.

In the area of fuel cells, an urgent need still exists to develop cheaper and more effective catalysts, and to develop ways to use existing expensive catalysts more efficiently.

Although prospects for fusion power (presumably based on deuterium) are now much more encouraging, the technical feasibility is still not assured. An optimistic timetable calls for first pilot plants in the late 1980s. At current funding, the first large scale applications may not occur until about the year 2000.

None of the existing refuelable battery systems meets projected future requirements, and improvements should be sought in reducing heat generation, reducing cathode irreversibility, and reducing catalyst costs.

As a long term goal, perhaps the most important effort should be the development of large scale reversible hydrogen fuel cells to be used as peak electrical energy storage devices in conjunction with advanced generating systems, whether they be conventional nuclear, breeder nuclear, solar, geothermal, or fusion powered.

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IX WASTE HEAT FROM ENERGY PRODUCTION PROCESSES

A. Statement of the Problem

A typical modern power plant using pulverized coal discharges in the range of 60 percent of the input energy to the atmosphere as waste heat. About 10 percent of this waste goes up the stack with combustion gases and 50 percent goes out with the condenser cooling water. Although nuclear power plants claim to be relatively clean, the waste heat burden from these plants is even higher than for fossil fuel-fired plants. Almost two-thirds of the heat released in the reactor has to be dumped into the environment. This thermal waste problem becomes of greater importance as our energy resources decline. The ecological implications of this low-level heat burden are little understood. However, the diseconomy of discarding two-thirds of our energy resources as low grade heat indicates its importance to the energy supply situation and emphasizes the need for research.

B. State of the Art

Statements have been made for a dozen years or more that the total energy concept would have to be used at all levels to conserve energy and reduce pollution levels. Action at management levels in both the power industry and government is clearly necessary.

Over the past years, a large number of intelligent suggestions have been made for the deposition of waste heat. The AEC and the Interior Department have studied for several years the feasibility of using the waste heat from nuclear plants for water desalting. However, no nuclear plant now in construction or being planned has such provision for the

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use of its waste heat. A pioneering effort in the utilization of waste heat is now under way in Oregon in preparation for the use of heated water, when the 1,000 MW Trojan nuclear plant comes on line, to provide frost protection and to extend the crop growing season. This demonstration project entails 170 acres in efforts to improve the productivity of a number of crops. The results of most other projects that supply heating water, air conditioning, and greenhouse heating have been small indeed compared with the total heat wasted.

One of the obvious approaches to end this waste is for the government to tighten up on licensing by requiring that total energy concepts be used in the development of future power plants. To prepare for such an eventuality requires that proven processes be available to the wasted energy. Unfortunately, we have only unproven concepts, some of which will be explored in this chapter.

A complex heat cycle was recently proposed by A. P. Fraas of the AEC to reduce thermal discharge by improving the thermodynamic efficiency of a power plant by raising the operating temperatures. This would be accomplished in a binary system using potassium as a working fluid in the primary boiler-turbine complex and supercritical steam in the secondary system. Such a cycle is claimed to be capable of a 54.8 percent efficiency compared with a maximum of 40 percent for present plants and would reject only half the heat of a conventional steam cycle of comparable capacity.

Yet there is a practical problem. The use of potassium, or for that matter sodium or cesium, as a working fluid in a turbine has never been attempted on the scale required to be practical. Not only are the thermodynamic and fluid properties not adequately defined, but the possibility exists that an insurmountably severe materials problem will exist not only in the boiler but also definitely in the turbine. Almost nothing is known of the interaction of such vapors with present materials or future materials of construction of turbines.

Another development aimed at improved thermal efficiency concerns the use of helium to operate a helium turbine in a closed cycle nuclear reactor loop. Such a closed cycle gas turbine is claimed to provide an efficiency as high as 48 percent with a side stream of process steam for industry. This is far above the 33 percent efficiency of water-modulated nuclear plants common in the United States. A 25-MW plant was scheduled for 1972 in Geesthacht, Germany, with a 600-MW plant in the design stop for 1976.

Another interesting experiment in power development is the Commonwealth Edison/North American effort to drive a 11-MW power turbine with tho steam output from a Saturn rocket engine fueled with LNG and liquid oxygen. Although this is envisioned as a convenient source of peaking power, the implications of such an experiment are much broader. Little work has been done on developing boilers using oxygen as the oxidant rather than air. Not only would stack heat losses from carrying along 80 percent N_2 be reduced, but higher combustion temperatures also could be attained with little or no NO_x generated, dependent of course on the N_2 content of fuel. There is also the interesting feasibility of such a primary heat reactor using coal rather than HC fuels. A further outgrowth of this experiment concerns the use of LNG as an energy source for military operations. This particular cycle could be operated as a closed loop whereby the input LNG is used to operate an air liquefaction plant to give LO_2 (the Japanese are constructing such a plant now) and the products (methane and LO_2) are used to generate power. This could give LN_2 as a by-product for refrigeration or for further use.

The foregoing suggests the practicality of a confined power plant/industrial complex to utilize waste heat from the power plant. We have already suggested coupling an LNG-using power plant with an air liquefaction plant to produce LO_2. This appears to be a combination that can be considered with both conventional and nuclear power plants of present day design. It should be possible to use an ammonia expansion process on the condenser side of the power plant, where most of the heat is rejected, as the first stage in a cascade process to liquefy air to produce LO_2 and LN_2. Using a three-fluid cascade of ammonia, ethylene, and methane (a commercial process still in use), it would be possible to save a portion of the heat rejected by the power plant. Another working cycle to be considered in this respect should be the use of expansion energy in equipment such as a turboexpander where ammonia or propane is used to condense water from the steam turbine and is thereby heated to high temperature. This fluid could also drive a turbine to generate electricity in a lower energy cycle than the original steam. Thus the binary cycle would be used at a lower energy level than the potassium/steam proposal described earlier.

Another energy combination to be considered is the power plant/oil refinery complex whereby the incoming crude is given a preliminary preheat by using it on the condenser side of the power turbine. This would not only conserve waste water discarded by the power plant but it would also reduce the use of bunker oil to preheat the crude oil before refining.

C. Present Activities and Organization

The AEC has been investigating the use of sodium as a reactor heat transfer fluid for a number of years. It is believed that the physical property investigations have not encompassed the pressure range required for turbine operations. Some of the material problems apparently have been solved, although such a reactor is not a commercial reality at this time. The influence of such a vapor on turbine blade material at high temperatures and pressures is almost wholly unknown.

Since the technology required for predicting thermochemical reactions for rocket combustion processes has been well established, advanced fuel cycles using hydrocarbons and coal with oxygen are for the most part predictable. Here again though, the time scale of development is limited by materials requirements. Most material problems in rocket technology have been solved by trial and error rocket firings, and these solutions for a few minutes of operation are undoubtedly not relevant to the year-round continuous operating required of power plants. It is highly likely that there will have to be a trade-off between the operational pressure and temperatures against the economic life of materials used for advanced boiler techniques such as those proposed here. NASA technology would appear to be the best starting point in this respect.

There has been no unified analysis of advanced power cycles as proposed here. Many of the proposals are susceptible to theoretical thermodynamic and economic analysis, which should qualify them in terms of priority for allocation of research and development funds.

U.S. Bureau of Mines has scheduled a pilot plant for a coal-gasification process utilizing a fluidized-bed gasification with oxygen and steam to yield methane, hydrogen, and carbon monoxide with a heating of 900 Btu per cubic foot. The possibility of using this gas for a power plant feed stream for reaction with oxygen is an alternative to be considered. Another is to complete the oxidation in the fluidized bed and generate steam for power turbine operation. Again, the point is to raise the efficiency of energy conversion by operating at higher temperatures and to lower the pollution potential of NO_x by not using air.

D. Implications for DoD

The time when aircraft operations will have to be curtailed because of the lack of hydrocarbon fuels is approaching rapidly. It may be possible to predict this today. The political atmosphere surrounding the Arab nations might bring this to reality even sooner if our present oil supplies are cut off. Any power or process development that conserves hydrocarbon fuels for aircraft operation should be of vital concern to DoD. Additionally, such an event signals a requirement for new propulsion fuels for aircraft. Lead times for such projects are decades, not years.

If LNG is to become a part of our energy picture within the immediate decades, it behooves DoD to be thoroughly familiar with this technology. We have few remaining oil reserves that might sustain a large war effort for a few months. It is not out of the question to consider ways of stockpiling LNG for use as an alternative fuel for power and ground transportation and reserve petroleum for aircraft operation.

E. Recommendations for Further Studies

To better understand the implications of the waste heat problem, it is recommended that further studies be made in several areas. They include:

- Economic and thermodynamic analysis of utilization of power plant waste heat for liquefaction plants and the use of binary generative cycles using high vapor pressure refrigerants.
- Feasibility studies of stock piling LNG in underground reservoirs. There has been some work done in this respect.
- Initiation of R&D in advanced power boiler cycles utilizing oxygen rather than air for the combustion of coal or synthesis gas.
- Study of the interaction of sodium or potassium vapor with advanced turbine materials.

- Feasibility study of a closed-loop energy cycle using an LNG/oxygen boiler for steam operation and an air liquefaction plant for waste heat utilization. This would be aimed primarily at supporting DoD operations at home and at remote bases.

X LIQUEFIED NATURAL GAS (LNG) USAGE

A. Statement of the Problem

Some foreign and domestic defense installations need independent utilities for reasons of security, economics, and/or environmental impact. Heat, electricity, water supply, and waste water or sewage treatment might be logically provided by an internal plant. LNG is an extremely likely source of energy for such installations because of its increasing availability and because of its minimal contribution to atmospheric pollution relative to other fossil fuels.

It currently costs about 12.2 cents per million Btu for LNG at the producing site and another 5.4 cents per million Btu to regasify this fuel before combustion at the using site.* Bringing LNG from its liquid state at -160°C to a gas at 0°C requires about 200,000 calories per kilogram. In existing facilities the regasification cost and energy are not recovered.

Possible uses of the LNG to reduce energy costs include air separation, refrigeration at -15°C, and to enable the cooling condenser in a power plant to increase generation efficiency. One estimate† of the power saved or recovered ranks these three uses about an order of magnitude apart (0.5, 0.04, and 0.003 kWh/nm^3 LNG, respectively). A joint venture of five Japanese companies selected air separation to use LNG coldness to produce liquid nitrogen and liquid oxygen.

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* Chemical Week, p. 35, July 12, 1972.

† "Manufacture of Liquid Oxygen Using LNG Coldness," Chemical Economy and Engineering Review, p. 11, December, 1970.

The liquid nitrogen/liquid oxygen ratio can be varied somewhat by shifting the plant operating conditions. The liquid nitrogen is useful as an inerting blanket for certain materials and manufacturing processes and as a refrigerant. The liquid oxygen uses include rocket propellants, aviators' breathing supply, and water treatment. This last-named use is of most interest currently, because the oxygen is useful by itself or as an intermediate for ozone manufacture.

Oxygen and ozone are technically unique in waste water and potable water treatment in some instances where ammonia and phenol content are high and there is a possibility that chlorine disinfection forms toxic materials. When produced from oxygen instead of air, ozone can compete in cost with chlorine and hypochlorite disinfection, especially when new ozone generator designs are applied.*

B. State of the Art

1. LNG Coldness Recovery

The aforementioned joint venture of five Japanese companies is constructing an air separation plant near Tokyo to use the coldness from LNG supplied at the rate of 8 tons per hour to manufacture:

Liquid oxygen	- 7,000 Nm^3/hr
Liquid nitrogen	- 3,050 Nm^3/hr
Liquid argon	- 150 Nm^3/hr

Three other air separation plants are in various stages of planning and design in Japan.

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* Chemical Week, p. 48, October 6, 1971.
Chemical Week, p. 53, November 3, 1971.
Chemical Week, p. 52, January 12, 1972.
Industrial Research, p. 29, August, 1972.

2. Ozone Generator Designs

Welsbach, W. R. Grace, and AIRCO are designing and manufacturing ozone generators in the size range considered suitable for water treatment plants in the United States. Research in a number of U.S. and foreign companies is directed toward reducing the size, cost, and power consumption of the generators. Conspicuous by its absence is work on ozone generators capable of operation near the boiling point of liquid oxygen, even though one company believes a 50 percent conversion of oxygen to ozone can be achieved in a single pass at this temperature compared with the 3 to 5 percent yield at ambient temperature. The present generators are about 10 percent efficient in their utilization of electrical energy. The current published efforts are directed toward design of "resonant" generators that can use pulses of power more efficiently and toward higher frequency power supplies. There is no evidence of more sophisticated application of useful potentials by solid state switching techniques.

3. Ozone Use in Water Treatment

More than 1,000 cities in Europe ozonate potable water (including a 238 million gallon per day plant for the city of Paris). Philadelphia, Pennsylvania; Louisville, Kentucky; Washington, D.C., and Wyoming, Michigan, are operating plants to obtain economic and technical data on a useful scale. Boeing Aircraft has been using 120 pounds per day of ozone for oxidation of cyanide and phenolic wastes.*

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* Chemical Week, p. 54, November 3, 1971.
"Ozonation, Next Step to Water Purification," Power, August 1970.

4. Military Applications of Cryogenics

Liquid nitrogen is carried on some military aircraft as a refrigerant for infrared sensors. Liquid oxygen is used for breathing oxygen supply and as a rocket propellant for certain launch vehicles. (These vehicles could obtain improved performance from liquid oxygen/liquid ozone mixtures.)

Future uses being studied include liquid methane, liquid hydrogen, and liquid oxygen for fueling hypersonic aircraft where the cryogenics can be used effectively to relieve the heat burden on the aerodynamic surfaces. Propulsion for such aircraft may have the capabilities for operation from jet fuel or hydrogen in the sensible atmosphere and hydrogen/oxygen in a rocket mode outside the atmosphere.

Some military magnetohydrodynamic applications require superconductivity obtainable with the cryogenics.

For all of these, the state of the art of cryogenic manufacturing and handling exists. The thermodynamic characterization is not complete for all such applications.

C. Present Activities and Organizations

In addition to the intense commercial and industrial activities in air separation and ozone manufacture and use, the Navy and Air Force have performed significant research on liquid oxygen/liquid ozone as a rocket propellant. This experimental characterization is well documented at the Defense Documentation Center, although some reports are still classified CONFIDENTIAL. The Air Force interest in cryogenics in general is expected to continue.

D. DoD Implications

The military, especially the Air Force, has a continuing need for cryogenics, including liquid nitrogen and liquid oxygen. The installations using cryogenics are remote and are likely to be self-contained for utilities. These installations have a need for potable and waste water treatment systems and chemicals, perhaps liquid oxygen and ozone.

The likely fuel for some such defense installations will be LNG, and its heat absorption capability of 200,000 calories per kilogram during regasification might be recovered in an air separation plant that could supply all or part of the liquid nitrogen and liquid oxygen requirements of the installation.

E. Recommendations for Further Studies

The fuel and cryogenics requirements of selected and representative defense installations should be compared to determine where LNG regasification energy might be economically recovered in an air separation plant.

Johnston Island is suggested as representative of a remote, manned installation with a need for liquid oxygen propellant supply. Fort Ord might be included as representative of a domestic training facility with need for waste water treatment. The AF Flight Test Center at Edwards, California, could be the site of a large-scale research on the use of cryogenics and need for industrial waste water treatment. An Alaskan defense installation might be included as representative of large heating requirements and waste water treatment, and in a reverse situation, a tropical installation would have large refrigeration requirements and need for potable water treatment.

Where the cryogenic requirements and the available LNG coldness are in an approximate economic balance, a preliminary design for an integrated system should be made. This would include, at a minimum, the LNG regasification, the air separation, and the ozone generation for water treatment. Depending on the installation selection, it would also include the refrigeration, heating, research, and rocket or aircraft cryogenic needs.

The economics comparison of the integrated system with a conventional combination of LNG regasification without energy recovery and with purchase of cryogenics and water treatment chemicals would then determine whether ARPA could assist DoD in energy utilization in this area.

Finally, if it appears that ozone generation from liquid oxygen is a promising approach to water treatment, ARPA can support experimental work to advance the state of the art of ozone generators.

XI ENERGY IMPORTS AND THE DEPARTMENT OF DEFENSE: EFFECTS OF SEALIFT CAPABILITY AND ESCORT VESSEL REQUIREMENTS

A. Statement of the Problem

Section 101 of the Merchant Marine Act of 1936, as amended, specifies the policy of the United States to be as follows:

> It is necessary for the national defense and development of its foreign and domestic commerce that the United States shall have a merchant marine (a) sufficient to carry its domestic water-borne commerce and a substantial portion of the water-borne export and import foreign commerce of the United States and to provide shipping service essential for maintaining the flow of such domestic and foreign-borne commerce at all times, (b) capable of serving as a naval and military auxiliary in time of war or national emergency, (c) owned and operated under the United States flag by citizens of the United States insofar as may be practicable, (d) composed of the best-equipped, safest, and most suitable types of vessels, constructed in the United States and manned with a trained and efficient citizen personnel, and (e) supplemented by efficient facilities for shipbuilding and ship repair. It is hereby declared to be the policy of the United States to foster the development and encourage the maintenance of such a merchant marine.

DoD has long recognized the U.S. Merchant Marine as its fourth arm of defense--providing sealift to DoD in time of war or national emergency. Under section 902 of the Merchant Marine Act of 1936, as amended, under conditions of national emergency, requisitioning of commercial vessels by DoD may be authorized by executive order (both U.S. flag as well as foreign flag shipping owned by U.S. citizens and considered to be under "effective U.S. control").

Imports of crude oil, petroleum products, and liquefied natural gas (LNG) are projected to increase enormously over the next 15 years. Most of the increase will be from foreign sources as indicated in Tables XI-1 and XI-2.

Table XI-1

U.S. PETROLEUM SUPPLY

	Millions of Barrels per Day					
	1960	1965	1970	1975	1980	1985
U.S. production of petroleum liquids (except North Slope)	8.0	9.0	11.3	10.5	9.8	9.1
North Slope crude and condensate	--	--	--	0.6	2.0	2.0
Syncrude from oil shale	--	--	--	--	--	0.1
Imports	1.8	2.5	3.4	7.3	10.7	14.8
Total	9.8	11.5	14.7	18.4	22.5	26.0
Imports as percent of total supply	18%	22%	23%	39%	47%	57%

Table XI-2

U.S. GAS SUPPLY

	Trillions of Cubic Feet			
	1970	1975	1980	1985
U.S. (except North Slope)	21.82	19.80	16.30	13.00
North Slope	--	--	1.17	1.50
Synthetic P/L gas	--	0.37	0.55	0.91
Imports	0.92	1.55	3.75	6.08
Total	22.74	21.72	21.77	21.49
Imports as percent of total supply	4%	7%	17%	28%

Source: U.S. Energy Outlook, an Initial Appraisal 1971-1985, Volume One, National Petroleum Council, Washington, D.C., July 1971.

The significantly larger import requirements to meet U.S. energy demands will create a corresponding significantly large increase in the number of tankers required to transport crude oil petroleum products, and LNG. As a result, two questions that are of direct concern to DoD are raised.

(1) Will sufficient numbers of tankers under effective U.S. control be available to meet DoD sealift requirements in the event of a war or national emergency and at the same time be able to meet domestic consumption requirements?

(2) What effect on escort vessel requirements will result from having to import large quantities of energy products? (During World War II, relatively little petroleum was being imported into the United States; thus, the situation for the future will be completely different in that for the first time the United States will have to protect vessels carrying import of energy products in addition to protecting vessels carrying exports of war materials).

B. State of the Art

With respect to Question (1) stated above, only one study has been identified that addresses the issue of the number of vessels under effective U.S. control. This is:

Effective United States Control of Merchant Ships, a Statistical Analysis, U.S. Department of Commerce, Maritime Administration, Washington, D.C., 1970.

However, this study is a historical analysis covering the period 31 December 1959 to 31 December 1968 and does not address the problem of how many ships would be under effective U.S. control in the future or during an international crisis.

It is logical that the Military Sealift Command (MSC) or some other agency within DoD would have studied this question, but no published reports were found.

With respect to Question (2), the Department of the Navy may have similarly studied the problem of escort vessel requirements, but it could not be determined from the literature review that the increased requirements for escort vessels convoying tankers carrying energy product imports has been addressed. The Chief of Naval Materiel discussed this problem before the 1972 annual meeting of the Edison Electric Institute.

At the initiation of further study of this problem, the literature review should be supplemented by a search of DD-1498s to determine the extent of current, and perhaps unpublished, DoD efforts toward answering both of these questions.

C. Present Activities and Organizations

Little is known as to past, ongoing, or future plans for studies concerning sealift capability and escort vessel requirements. The Maritime Administration may be studying the question of ships under effective U.S. control on an ongoing basis, and we will check this out to determine precisely what MARAD is doing. Even if an analysis exists, it would simply give a picture of the present rather than the future situation.

MSC or some other agency within the Department of the Navy may well be looking at the future picture of total sealift capability and escort requirements including petroleum imports in time of emergency. These possible sources should also be checked to determine present and possible future in-house studies.

D. Implications for DoD

The changing situation with respect to future energy product imports will have an impact on both the number of tankers that would be available for DoD sealift requirements and Navy escort vessel requirements.

E. Recommendations for Further Studies

It is recommended that a computerized method for assessing the number of tankers, by type and size, required to meet U.S. energy product import requirements out to 1985 be developed. Such a model could take the form of a transportation linear programming (LP) problem and of necessity would also have to consider all sources of supply, as well as all consuming areas worldwide, since the United States is competing with other countries for energy product supplies. In such a model, the objective function could be to minimize total tanker ton-mileage worldwide on the assumption that consuming areas would import from the closest sources to minimize transportation cost. On the other hand, it may be necessary to use a cost-based objective function directly so that differences in cost at the wellhead and the cost of transporting energy products to a marine terminal, as well as ocean transportation costs, can be explicitly considered. Port constraints limiting the size of vessel that could be used also would be explicitly considered in the model.

Once such an LP model were constructed, it would be a simple matter to assess the effect on the number of tankers required to meet U.S. energy product import requirements if a change were made in the value of a constraint equation or in the objective function. Questions that could be answered with the aid of such a model would be such as "What would the effect be of losing the Persian Gulf as a source of supply for crude oil?" or "What effect would building supertanker terminals in the United States have?" on the number of tankers required to serve the United States.

The next point that then must be addressed is "How many of the tankers operating worldwide in the future would come under effective U.S. control in the event of a national emergency?" This question can be answered only be considering the following:

- MSC requirements for tanker tonnage and the policy for chartering tankers from tanker operators versus maintaining a nucleus tanker fleet.
- The effect of the Merchant Marine Act of 1970 insofar as the building of the U.S. flag tankers for foreign trade in the United States is concerned.
- The effect of changing policies on the part of the maritime administration in administering the Merchant Marine Act of 1970 on tankers to be built in the United States for foreign trade.
- The changing requirements for transporting energy products by tanker in the domestic trade (i.e., U.S. Gulf to the North Atlantic, Alaska to West Coast United States, Puerto Rico to U.S. North Atlantic ports).
- The attitude of U.S. oil and gas companies and independent tanker operators with respect to building ships under the Merchant Marine Act of 1970 and operating them in foreign trade under the U.S. flag versus building foreign and operating under a foreign flag.
- The degree to which DoD deems foreign flag tanker tonnage to be under effective U.S. control.

The final point that must be addressed is the impact on U.S. Navy escort vessel requirements. There is no single value effect here but a range of values depending on the range of scenarios that Dod wishes to consider. In performing this analysis, the linear programming model could be used to determine the number of tankers the United States requires to meet energy import requirements from each supply source to each marine terminal area in the United States, for each scenario. Then, again, depending on the scenario, the number of U.S. Navy escort vessels required to convoy inbound tankers can be determined and compared with actual U.S. Navy capabilities, taking into consideration other demands placed on the escort vessel fleet. Additional factors that would need to be included in a complete analysis include the impacts at this exemplar situation on the other services.

XII LIQUID FUEL TRANSPORTATION

A Statement of the Problem

The import of Alaskan crude oil to CONUS refineries and the transshipment of refinery products from foreign sources to support U.S. military operations in foreign theaters add a new dimension to DoD's problems of providing security for such material. The use of pipeline and tankers to carry tne Alaskan supply is vulnerable to distruption by sabotage or direct attack. Shipment by tanker vessels between foreign ports is vulnerable to similar disruption and to delays or reroutings based on economic or political pressures applied at the source, port, or by the tanker owners (especially if these elements of the supply system have some unique advantages of geographic location or immediate availability in a crisis).

The economics picture for petroleum fuels used by DoD is changing because of the demand, supply, refinery technology, tanker availability and size growth, and route length changes between refinery and using site. The extent of the changes warrants a current appraisal of inventory practices and transportation alternatives to determine the most economical combination for using imported refinery products in foreign theaters.

The use of foreign petroleum products in foreign theaters may give DoD an improvement in response times--the Air Force "Rare Base" concept might benefit, for example. The current technology can support fuel transportation alternatives to perhaps improve Army mobility in some instances when proximate foreign refinery output is available.

Liquid fuel transportation for future DoD needs can be a problem because of changes in composition of the fuels. Cryogenic liquids such as LNG may be the only or the most economical fuel available to some using sites. Liquid hydrogen and liquid oxygen are seriously considered for future hypersonic aircraft. Such fuels can be costly and present storage problems severe enough to warrant faster, though more expensive, transportation systems.

B. State of the Art

Materials of construction, propulsion, and the critical technology for several new bulk fuel transportation systems and concepts are now available. In most instances, the critical design data are in hand. Operating and cost data on designs sized for DoD requirements have not yet been developed.

The range of fuel transport systems of possible interest for one or more DoD requirements is illustrated by four selections:

- Air cushion vehicle
- Liquid cargo aircraft
- Cargo airship
- Cargo submarine

These selections could transport from 450 to 90,000 barrels of product at speeds from 4 to 400 knots through ranges of 100 to 6,000 miles. Projected costs (some quite optimistic and preliminary) range from 10.0 to 0.5 cents per ton-mile.

Air-cushion vehicles capable of transporting 75 tons have been designed and constructed with no significant technology problems. The liquid cargo aircraft design is based on well-established technology and design data. The cargo airship designs propose use of existing, well-characterized materials and propulsion, but they are of such size that structural response to dynamic loads and some questions of aerodynamics are not yet resolved. Cargo submarine designs are based on well-characterized (and, in some instances, very low cost) materials of construction, and the hydrodynamic data are available, but the structural-to-total weight ratio depends on a number of design features and is not easily predictable.

C. Present Activities and Organizations

ARPA is supporting the study directed toward use of a surface effect ship for carrying specialized radars in areas not otherwise accessible. Since the most likely use of such vessels in fuel transport would be to supply such areas, the design and operating data now being obtained could possibly be directly applicable, or the uses of the present vessel might include the fuel transport by suitable modification. The U.S. Maritime Administration (MARAD) has supported recent studies on commercial use of surface effect ships that included conceptual designs with up to 3,000-long ton capacity, and these could contribute useful data. SRI was one of several contractors in the parallel effort.*

The Boeing Company is fostering the use of a specialized cargo aircraft that would carry 2.3 million pounds of crude or minerals from Alaskan and Canadian fields through the first 500 to 1,000 mile (and the most difficult for pipeline or other surface transport) stage to the refinery or processing plant.†

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* "Surface Effect Ship Economic Opportunity Study," Contract MA-4536, SRI Project MU-7371 (August 1969).

† Aviation Week and Space Technology, p. 25 (May 22, 1972).

Cargo airships are being proposed in current periodicals, and conceptual designs based on current aerospace materials and propulsion are being offered to the Canadian government and others interested in bulk transport from remote and inaccessible areas.

Semisubmersible ships and concrete cargo submarines are in design and model testing at the Naval Undersea Research and Development Center and the Naval Civil Engineering Laboratory.*

The National Aeronautics and Space Administration (NASA) has characterized cryogenics and the materials and equipment for its large-scale handling in the Apollo program and will continue such work for Space Shuttle and hypersonic aircraft research.

D. Implications for DoD

The changes in sources for DoD-required petroleum products present new security problems that might be best solved by introduction of fuel transportation systems other than conventional pipelines and tankers for some scenarios. The changes in source-user locations can result in a significant economic effect from the combined changes in inventory requirements and ton-mile transportation costs. The present state of flux presents the opportunity to introduce new forms of fuel transportation, and these new systems may offer advantages of security, economy, and response time.

E. Recommendations for Further Studies

The DoD needs for crude feedstock and the refinery products in several scenarios can be compared with the capacity, speed, range, and other

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* Ocean Industry, p. 21, p. 27 (November 1971).

performance of likely transports to rank the candidate systems. Since all the concepts are not of equal technological maturity, it will be necessary to estimate development risk and time for critical components or design features. From this ranking, ARPA can decide whether any of the concepts are worthy of additional support and can identify technology that warrants further investigation. About one man-year of professional effort could yield a useful assembly of data and conclusions.

XIII PREPOSITIONED FUELS STORAGE FACILITIES

A. Statement of the Problem

The relatively static U.S. refining capacity and the locations of crude oil feedstock have increased our dependence on foreign refinery products as the least costly petroleum support for our foreign military operations. DoD is depending less and less on shipments from U.S. refineries as their relative cost rises. The dependence on foreign sources for fuels is typified by the 1971 usage in the South-east Asian conflict, where all the DoD petroleum products were obtained from foreign sources. The evidence visible to new petroleum explorations and refinery investments here and abroad and ton-mile shipping cost considerations leads to the conclusion that nearly all usage in foreign theaters will be supplied by direct transfers of fuels from the nearest available ("friendly) foreign supply to the U.S. force. Therefore, it is necessary to examine selected shipping and storage alternatives to the present U.S. based refineries and U.S.-controlled tanker vessels.

The tankers that will be available for U.S. shipments are steadily and rapidly increasing in size, as illustrated in Figure XIII-1. If such conventional vessels are to be used, provisions must be made for mooring at locations available to U.S. forces and for transfer of the fuels to the using vessels or shore-based operations in an expeditious, secure, and economic manner.

Since large quantities of fuel will continue to be used, the storage alternatives in foreign theaters must be of the most economical construction. Since the frequent changes of the past can be expected to continue,

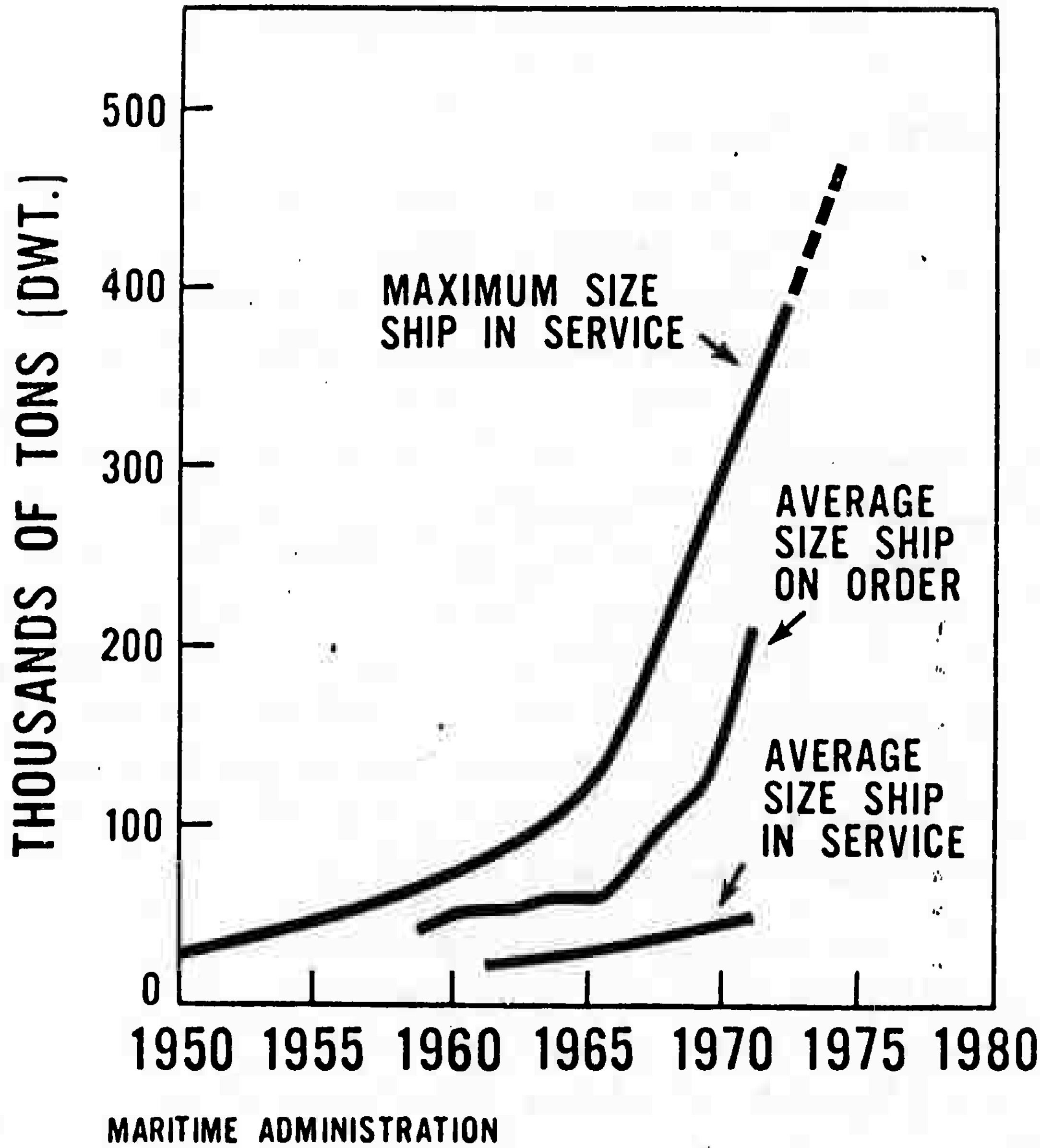

FIGURE XIII-1 GROWTH IN TANKER SIZE

mobile mooring, storage, and transfer facilities could have distinct advantage in some scenarios.

Finally, DoD usage of foreign refinery products requires secure mooring, storage, and transfer capability at or near the sources and the using operations. This requirement presents one set of problems if the facilities are shore-based, another if the facilities are offshore in "friendly" waters, and yet another if the facilities are in U.S. territories or international waters.

B. State of the Art

Commercial petroleum operations and current research make available a number of feasible design concepts and materials of construction for the components and subsystems that might be adapted to a range of DoD requirements for prepositioning of fuels. These include mooring, storage, transportation, and fuel transfer subsystems and materials.

For mooring large tankers whose dimensions exceed port/harbor limitations, a variety of single-point mooring systems (SPMs) have been developed and put in use. At the beginning of 1971, 61 such SPMs were in operation, some in seas averaging 12 feet. A second type of conceivable mooring is an adaptation of offshore oil exploration and drilling rigs. Semi-submersible rigs now dominate the design trends (patterned largely on the Mohole platform design). In 1972, 53 rigs are under construction at a cost estimated at $244 million. Some of the designs can survive 120-knot winds and 100-foot waves and can operate in 60-foot waves. A third class of potential mooring is appearing in the scale models of stable platforms being built and tested by the Navy and Scripps Institute of Oceanography.

Examples of storage systems that might be used on conjunction with a mooring range downward from the million barrel concrete crude oil storage dome under construction in the North Sea near the Ekofisk field. A 900,000-barrel floating storage barge for crude has been rented for use in the Arabian Gulf near the Cyrus field. At the other end of the spectrum are fiberglass lighter-aboard-ship ("LASH") barges of 2,500-barrel capacity and neoprene rubber bags capable of storing 200 barrels of specialty hydrocarbons that might be required in some military operations. Concrete, ferrocement, a ferrocement with lightweight aggregate, fiberglass, and reinforced elastomers such as neoprene are available as construction materials, in addition to the conventional steels and aluminum alloys (the latter are of special interest as inner tanks for LNG storage).

There is a growing fleet of high-power tugs, workboats, and crewboats to support the selected SPMs, offshore rigs or platforms, and storage systems. This support includes towing, positioning, and manning. In June 1972, it was estimated that 2,000 such vessels were available for hire or charter and another 364 planned or under construction. These range up to 12,500 horsepower in the effort to keep pace with the increasing size of drilling rigs that must be towed. Models of semisubmersible ships are demonstrating the feasibility of a vessel that is self-propulsive and could serve a dual purpose of mooring and storage.

Fuels can be transferred by adapting a variety of techniques. SMPs and similar moorings generally rely on a bottom pipeline to the shore source or using point. A reel-barge has successfully laid 2 miles of a 12-inch pipeline in 12 hours in the Gulf of Mexico. The previously-mentioned fiberglass barge is designed for use in the LASH vessels and the Seabee vessels. Thirty-five to seventy of such barges would constitute a load, and they could be used to transfer from the refinery to prepositioned storage to the using force.

The materials, components, and subsystems that could be assembled into one or more DoD-unique fuel supply systems are therefore state of the art. The technology required to adapt these elements to DoD requirements of cost, security, mobility, and response time are not yet known.

C. Present Activities and Organizations

ARPA is currently funding Scripps Institute of Oceanography through Office of Naval Research for the construction of a superstable platform of modular unique construction. The Naval Undersea Research and Development Center is supporting works on a semisubmersible ship, floating stable platforms, and concrete cargo submarines with large surface platforms.* Industry work is supported principally by the petroleum exploration and development companies and their associated maritime contractors.

D. DoD Implications

With growing dependence on foreign refinery products as its fuel source for foreign theater operations, DoD must consider alternatives to CONUS-based refining, storage, and supply. Penalties in cost, security of supply, and response time can be exacted by arbitrary or politically-motivated shutdown of supply at the foreign source, by unavailability of specialty fuels, and by unavailability of mooring, storage, and transfer facilities that will accommodate the new deep-draft tankers. These penalties can be mitigated by advance preparations for use of new fuel supply systems based on current offshore oil exploration and development technology, perhaps modified or adapted by some new technology supported by ARPA.

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* Ocean Industry, p. 37, August 1971; pp. 21, 24, 27, November, 1971.

E. Recommendations

The first two phases of effort directed to solution of the problem are separable, sequential, and independently capable of yielding useful data for ARPA decisions regarding support of energy research.

It is recommended that the kinds and quantities of refinery products first be determined for satisfactory DoD maintenance of operations in the following representative situations:

(1) Shutoff of supply from a foreign refinery as a result of arbitrary decision, internal politics, disapproval of a U.S. action, or to bring short term economic pressure.

(2) Changing of source based on economic analysis.

(3) Support of a local conflict involving U.S. ground, naval, and air forces.

(4) Support of a local conflict by supply of material only.

(5) Support of relief for a natural disaster.

Next, it would be possible to use these defined needs to review and rank available materials of construction, components, and subsystems that could be adapted to the needs. From this review and ranking, costs and performance could be estimated, and the technology barriers to adaptation could be identified for ARPA support decisions.

XIV VULNERABILITY OF ENERGY SYSTEMS TO NUCLEAR ATTACK

Since modern economies depend on energy, the effect of a nuclear attack on energy systems is an important factor in assessing the feasibility of national survival and recovery from a heavy nuclear attack.

Many studies have been made of the effects of nuclear attack and the feasibility of recovery, including consideration of energy systems. SRI has been engaged in these studies, beginning with a major study for DDR&E in 1963 and continuing with studies for the Defense Civil Preparedness Agency (DCPA, formerly the Office of Civil Defense) and the Army Research Office. DCPA in cooperation with other agencies has conducted a series of "damage limiting" studies. The Joint Chiefs of Staff have sponsored a series of Post Nuclear Attack Studies (PONAST). The Office of Emergency Preparedness (OEP) has a large scale damage assessment system, with a detailed data base including energy systems, which is used in many of these studies. The Defense Electric Power Administration has made studies of the capability to deliver electric power after a nuclear attack. The Office of Oil and Gas has studied the vulnerability of gas utilities to nuclear attack. Other organizations that have conducted postattack studies include the Engineer Strategic Studies Group, RAND, and the Institute for Defense Analyses.

These studies have generally concluded that sufficient resources and industrial capacity would survive even very heavy attacks that destroyed upward of 50 percent of the population to permit national survival and recovery. The survival of petroleum refining capacity is generally higher than that of other industrial sectors and comparable with the level of population survival.* Also sufficient transportation capacity survives for distribution of fuel. Electric power generating capacity survival is substantially higher than the level of population survival.*

However, in most of these studies, the hypothesized attacks were not designed with the explicit objective of hampering recovery. As offense technology moves into the MIRV era, with large numbers of small-yield weapons, the opportunities for targeting to destroy specific critical elements of the economy increase. One SRI study examined the vulnerability of petroleum refineries, petroleum product pipelines, and electric generating stations if specifically attacked.† The following summarizes the conclusions of that study.

A. Petroleum Refineries

The distribution of the petroleum refining industry is indicated in the tabulation below, which summarizes the locations of the refineries within the coterminous United States. About half the nation's petroleum refining capacity is located within the top 71 SMSAs and is concentrated in 48 target points. The remaining refineries constitute 143 targets. All but three of these 143 targets are essentially single-point targets.

Location	Refineries	Targets	Percent of Capacity
Within top 71 SMSAs	86	48	49.7%
Within remaining SMSAs	60	43	28.8
Outside SMSAs	112	100	21.5
Total	258	191	100.0%

* Goen, R. L. et al., "Analysis of National Entity Survival," Stanford Research Institute, November 1967.

† Goen, R. L., et al., "Potential Vulnerabilities Affecting National Survival," Stanford Research Institute, September 1970.

Assuming complete loss of the refineries in the 71 largest SMSAs, Figure XIV-1 shows the number of additional delivered weapons required to reduce the remaining refining capacity (in terms of barrels per calendar day) to any level. An additional 75 weapons on target points with at least 10,000 barrels per day capacity (about 0.1 percent of total national capacity) would leave only about 2 percent survival of refining capacity. Consideration of weapon reliability would increase the number of weapons required. Since the targets are essentially single points, small yield weapons would suffice, perhaps less than 100 kT depending on CEP.

Use of petroleum products for farming purposes now takes about 7 percent of petroleum products' consumption. At 50 percent population survival, 3.5 percent of refinery capacity would be needed just for farming. Targeting of the refineries could reduce capacity even below that needed just for farming.

B. Petroleum Product Pipelines

Pipeline transportation is the major method of distribution of refined petroleum products. Disruption of the pipelines plus loss of water ports would eliminate most of the current system of transportation of petroleum products.

The pipeline system is very vulnerable if specifically attacked. The greatest volume of products flows by pipeline from the Gulf Coast and Texas-Oklahoma refining areas to the East Coast and Midwest. Only six hits are required to stop this flow. Ten hits on three major pipelines would halt about 63 percent of total pipeline shipments, and 126 hits would essentially halt all major product pipeline operations.

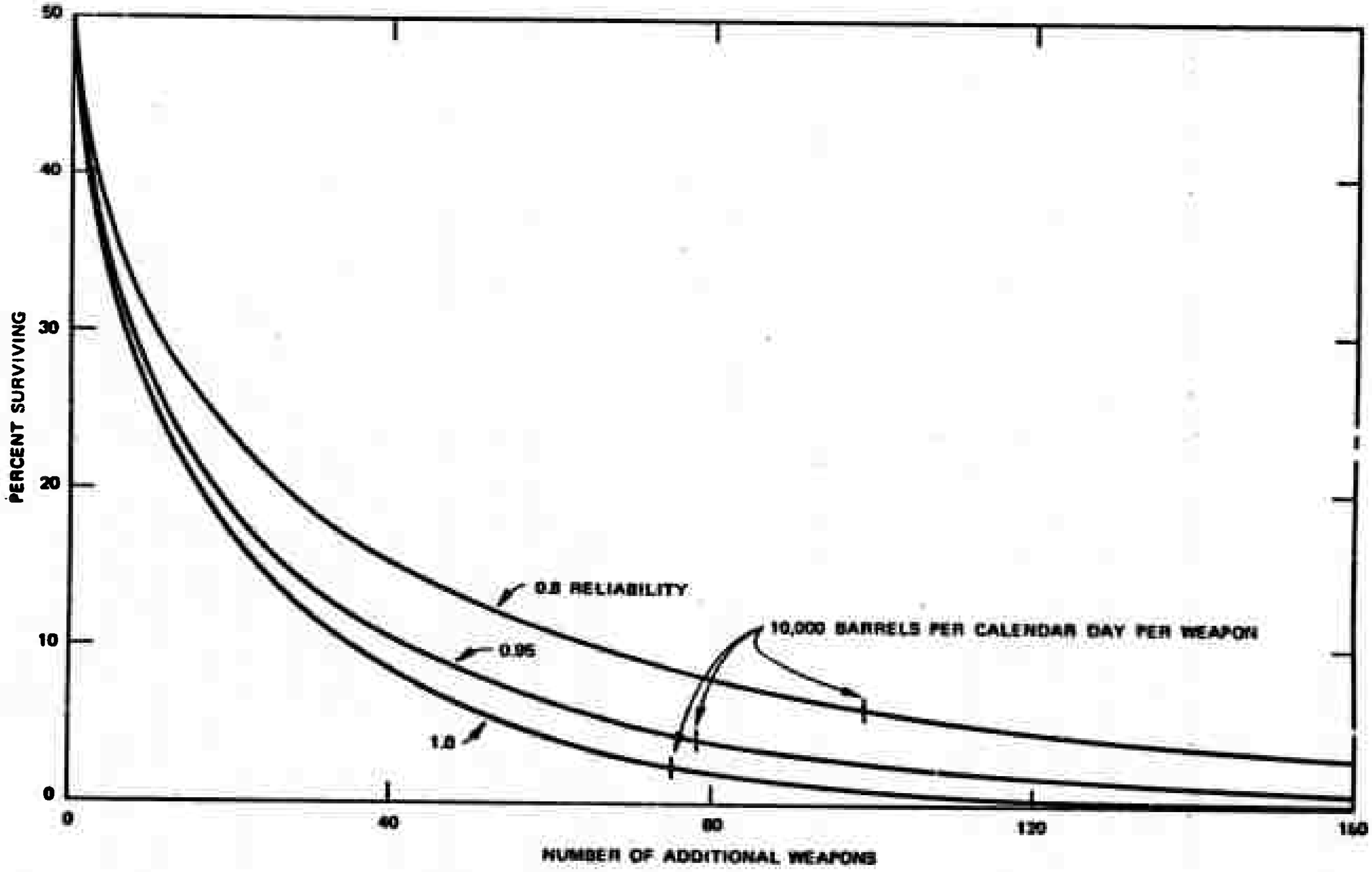

FIGURE XIV-1 VULNERABILITY OF PETROLEUM REFINERIES OUTSIDE THE 71 LARGEST SMSAs

However, a substantial capability would exist for substituting rail and truck transportation of petroleum products for the pipelines. With use of all surviving rail tank cars, the tank car delivery capability would be about one-fifth of the combined preattack pipeline and rail petroleum product deliveries. Tank trucks provide an even larger delivery potential. The pipeline deliveries could be met using 57 percent of the tank trucks with over 2,000 gallons capacity.

C. Electric Generating Stations

The electric generating stations are much less vulnerable than the petroleum refineries, because there are more of them and because a larger proportion of generating capacity is located outside the large SMSAs. There are 2,430 electric generating stations with over 5 megawatts capacity, and 1,530 of these are outside the SMSAs. Only 39 percent of capacity is concentrated in the 71 largest SMSAs, and 14 percent in the rest of the SMSAs.

Even so, an attack directed at generating stations can reduce generating capacity disproportionately. A rank-ordered generation attack was examined by Winter.* Hitting 300 target areas with 10 MT weapons resulted in 32 percent survival of generating capacity, along with 60 percent survival of population.

Critical shortages could occur in local areas where the bulk of capacity exists in a small number of facilities and if these facilities are considered as targets.

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* Winter, S. G., Jr., "Economic Viability After Thermonuclear War: The Limits of Feasible Productions," RM-3436-PR, the RAND Corporation, September 1963.

Electric power transmission systems play a role almost as critical as the central stations themselves in providing the capability for the transfer of bulk power from the central stations to the distribution system serving customers. Additionally, the transmission system usually includes high-capacity interconnections among central stations, principal load areas, and elsewhere for purposes of increased reliability, load sharing by central stations, and other economic and technical reasons. As a consequence, in contrast to the central stations, the transmission system appears as a widely distributed target array with literally thousands of relatively low-valued aimpoints. For example, more than 10,000 substations, compared with 2,430 central stations, with capacities over 10 megavolt-amperes are currently incorporated within the National Resource Analysis Center data base.

Power-supply areas correspond essentially to operating areas of the principal public utility companies. Transmission grids within each area are highly interconnected, frequently providing multiple links between central stations and load areas. On the other hand, the interconnections among the power-supply areas tend to have substantially less capacity because of economic, regulatory, technical, and other valid reasons. Also, the links between power-supply areas are relatively few in most cases. The general consequence of the relatively low-capacity links among power-supply areas is that large-scale central station losses in one area could not be heavily compensated for by surviving stations in contiguous areas. At the same time, however, under conditions of proper postattack control of power consumption and the potential reduction in demand, interarea transfers could be far from negligible.

D. Implications for DoD

Since the petroleum refineries are so important to national survival and recovery and so vulnerable to attack, it would be desirable to make plans for adjusting to an extreme shortage of refining capacity. Pressure vessels would not be very vulnerable, and it might be possible to improvise stills using salvaged pressure vessels. The feasibility of improvising simple refining equipment would be enhanced if plans for this were developed ahead of time.

Research could well be directed into providing enhanced capability for improving the transferability of energy or fuels from surviving facilities into areas that have been attacked, so as to extend the remaining supplies.

Substantial refining capacity excess to local needs exists in other parts of the western hemisphere. Venezuela, the Netherlands, East India, and Trinidad together have a refining capacity equal to about 20 percent of U.S. capacity. The availability of supplies from these sources might depend on the postwar military situation. Possibly military plans could be developed that could increase the prospects for obtaining petroleum products from those countries in postwar situations.

UTILIZATION

XV ENERGY CONSERVATION IN THE DEPARTMENT OF DEFENSE

A. Statement of the Problem

Although the DoD uses only about 5 percent of the U.S. energy budget, it represents one of the largest single energy consumers in the nation. The major use of energy for military purposes has been to provide mobility,* but energy is also required to operate and maintain fixed installations that provide for command control or support of field units.

In the event of a future energy shortage, it would appear that government agencies could be required to practice measures to conserve energy and energy-producing fuels. Should the energy shortage be of short duration, then it appears possible to meet DoD needs through temporary diversion of energy supplies from other, nonessential uses and rationing of remaining supplies until the emergency situation is relieved. However, available estimates of near term energy supplies and projections of future energy demand indicate that a serious energy shortage is in prospect for the United States and that this shortage will be experienced for a protracted period of time. While rationing may need to be imposed to some degree, if projected conditions are realized, it is entirely possible that it will become necessary for the government and the DoD to observe far-ranging energy conservation activities. In other words, the energy shortage could become so severe that agencies of the federal government including DoD could be restricted to an "energy budget" requiring strict energy accountability, conservation, and management. Should such a

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* Vansant, Carl, Strategic Energy Supply and National Security, 135 pp. (Praeger Publishers, N.Y. 1971).

situation take place, it will be vital to know the degree to which DoD can practice efficient energy conservation without impairing operational mission effectiveness.

B. State of the Art

At the present time, DoD's energy use represents about 5 percent of the nation's energy consumption, and it seems unlikely that future DoD energy needs will exceed this percentage under normal conditions. However, the future absolute amount of DoD energy consumption is likely to increase from present levels in proportion to the forecast growth of national energy consumption and security requirements. It is not known precisely how much energy is consumed by sectors of the civilian economy that provide support or services to the DoD. In part, this reflects the fact that many industries use processes or produce products that meet commercial as well as military needs, complicating the establishment of a complete or exclusive listing. The energy consumed by industry that is related in some way to DoD activities could possibly be estimated in gross terms to be several times that consumed directly by DoD itself.

In the past there was little need to conserve energy, because the nation's supplies were more than adequate to meet any potential demands. The recent growth in domestic energy demand and apparent reductions in available supply have changed this situation, and it is forecast that domestic supplies (even if supplemented by imports) will be insufficient to meet projected demands. Under the situation that existed formerly, energy consuming equipment, facilities, or processes could be designed and developed to perform a particular function with little attention given to efficiency of fuel conversion (except as related to the then-modest costs for abundant fuel supplies). As a result, a number of relatively inefficient energy-conversion devices are now in widespread use; if it is attempted to meet future demands with such devices, additional pressure will be placed on fuel supplies solely from the inefficient use of fuels. Inefficiency in fuel conversion also leads to serious environmental quality problems from incomplete consumption or wastes discharged into the adjacent environment. The degree to which existing energy-conversion devices could be modified to achieve fuel conservation through greater efficiency is not clearly known; indeed, provisions to control adverse environmental effects could have decreased overall fuel conversion efficiency in certain cases.

Improvements in energy conversion efficiency could be accomplished by alternative equipment designs, changes in materials, or improvements in fuels. At present, however, the relative priority of equipment or operations in terms of their energy requirements is not well established (neither for the DoD nor supporting industries).

The significance of present procedures and practices used by DoD in the energy sector is also unclear. It might be that significant accomplishments in energy conservation in the DoD (and supporting industry) could be made through revision of current practices (as well as modification to present technology).

Available information on DoD energy uses appears to be limited to consumption, supply, and to a certain extent, expenditures. Even this information is limited to fuels that are directly used in DoD activities and does not include the energy demands of critical industries that are required to support the DoD operations.

The present state of the art regarding energy conservation is not limited solely by technological constraints or problems. Existing practices and procedures used by other public and private agencies having interest in or responsibilities for the energy sector largely control the manner of DoD energy use. In many cases, these factors could restrict the latitude of technological developments to deal with active energy conservation by DoD will require attention to both technological and institutional aspects of the problem to arrive at workable solutions to implement advances in technology to achieve desired conservation goals while maintaining or enhancing operational capabilities that depend on secure energy supplies.

C. Present Activities and Organizations

The possibility of conserving energy in both public and private sector activities is receiving increasing attention as the prospect of energy shortages becomes more real. A number of organizations have addressed the need for energy conservation recently, among which are the Department of the Interior, the Federal Power Commission, and the National Petroleum Council. It was reported in the press recently* that the Office of Emergency Preparedness conducted an overall analysis of possible energy conservation methods and their related costs. This report has not yet been released.

D. Implications for DoD

Imposition of energy conservation practices on the DoD could lead to changes in the manner and degree to which normal operations are carried out. Conceivably, the inefficiency by which certain items of equipment use energy could be such as to restrict or limit their use, either generally or locally, depending on the application and the energy supply situation in given circumstances. Alternatively, the necessity of operating essential equipment no matter what its level of efficiency in fuel use could result in consumption that would constrain the availability of these

* "Federal Study Suggests Fuel Tax as Way to Promote Conserving of Energy Supply," by Burt Schorr, The Wall Street Journal, p. 2, Wednesday, August 23, 1972.

fuels for other DoD uses. In either case, as a part of normal DoD operations, it would appear that operational effects should be examined from the standpoint of a need to conserve energy. Nonessential operations would have to be identified to establish a priority ranking for use of energy, probably according to a range of anticipated conditions from normal peacetime operations to emergency crisis situations.

Energy conservation implications for DoD would extend beyond the obvious specific cases of energy use described above. It would be necessary to institute conservation practices at every stage along the sequence of energy use by DoD. This would include (1) energy sources (especially those for which DoD has management responsibility), (2) processes by which energy-bearing materials are treated and the energy transformed to some convenient or more usable form, (3) means by which energy fuels are stored to prevent losses in quantity or quality and procedures by which stockpiled energy supplies are recovered for use to meet operational demands, (4) systems for energy distribution from either transformation facilities or stockpiles and storage areas to the sites where it is required to fulfill mission requirements, and (5) the alternative means of energy utilization that were identified above. Although present practices in each stage of the sequence are directed to providing adequate energy supplies, the possible requirement for more stringent accountability, conservation, and management of energy sources could lead to potentially significant changes in present patterns. Many of these changes may be of a nontechnical or procedural nature; many may require modifications to existing technology, or both. In either case, the need to conserve energy could require operational changes by DoD. Such changes would not be limited to the DoD itself but would include industrial sectors that provide support or services; this is described in greater detail in the following paragraphs.

E. Recommendations for Further Studies

To design prospective programs for energy conservation by DoD, it is necessary to determine the scope and character of present energy uses by category of activity, priority, and efficiency of energy use. The possibility of energy substitutability to meet priority uses needs to be determined. Similarly, the use of energy residuals (e.g., waste heat, recyclable products, currently unused fractions of conventional fuels) needs to be assessed and their potential to aid in conservation measures identified.

Possible energy savings in the several stages of energy production and use by DoD need to be determined and catalogued and the implications of these savings from improvement in energy supplies for DoD operations delineated.

Particular constraints on energy conservation practices that are indicated by mission responsibilities of the individual services need to be identified and analyzed. The technological implications on changing fuels relative to performance of key items of equipment or facilities need to be analyzed, together with the amendability of present technology to deal with such matters. The institutional implications of energy conservation on the services need to be determined relative to counterpart supporting sectors in government and industry.

Criteria to guide the assessment of energy-efficient activities consistent with operational performance requirements need to be developed. Currently available equipment needs to be evaluated with respect to energy use, and the duty cycles of inefficient equipment examined to determine the mission value of continuing to employ such equipment. The criteria and information from evaluation of present equipment could be used to derive guidelines and specifications for development of new devices that offer greater energy conservation potential with no degradation of performance.

XVI ENERGY CONSERVATION IN THE INDUSTRIAL SECTOR RELATIVE TO THE DEPARTMENT OF DEFENSE

A. Statement of the Problem

The consumption of energy in the United States is immense and is growing exponentially. Total consumption of energy, excluding nonenergy uses of fossil fuels, has been increasing at a rate of about 5 percent per year, with consumption of electricity growing at an even faster rate of about 7 percent per year. On the one hand, this growth is coupled with an increase in industrial productivity and an improved standard of living. On the other hand, it results in an accelerating depletion of energy resources and detrimental effects on the environment. Some areas of the country already face serious problems because electric generating capacity has not kept pace with demand and because of shortages of petroleum and natural gas.* Meanwhile public interest groups are holding up the development of new refining or generating capacity and pipeline construction because of projected adverse environmental effects. In the long term, these energy problems may be alleviated by the development of new technology such as fast breeder and fusion reactors and magnetohydrodynamics. In the meantime, we must make more efficient use of the technology and resources we have. Since industry uses about 40 percent of the energy consumed in the United States, improved efficiency of energy consumption in industrial production could have a significant impact on the demand for energy. Industry might improve the efficiency of its energy

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* See, for example, "Refining Pinch: Another Energy Crisis is Looming as Gasoline, Heating-Oil Stocks Dip," by Roger W. Benedict, The Wall Street Journal, p. 1, Tuesday, August 22, 1972.

utilization through the use of industrial processes that require less energy to produce the same products, or by changing the product mix. For example, containers made of aluminum, steel, glass, plastic, and paper have quite different energy components and offer significant possibilities for product substitution to reduce energy demands. Natural fibers such as cotton have much lower processing energy components than man-made fibers such as nylon.

The first objective in seeking possibilities for improving the efficiency of use of energy by the industrial sector is to uncover the products that require excessive energy for their manufacture. They are, then, the candidate products for elimination or substitution or the candidate products for manufacturing process changes. The industrial production system consists of a large number of interdependent processes. For this reason, determination of the energy used in the manufacture of a product requires analysis of product origin and summation of the contributing energies of each process leading to the final product. The analysis is complicated by the fact that many industrial processes produce more than one product, and the energy of these processes must be apportioned among the primary product and the by-products. In many of these cases, however, energy can be apportioned according to the relative energy that would be required to produce each product by separate single-product processes.

For the purpose of energy conservation, the prime candidate processes are those requiring large energy expenditures. For example, at the two-digit SIC level, the food processing industry (SIC-20) expends about 1 kilowatthour of electricity per dollar of manufacturing value added (1 kWh/MVA), whereas the chemical industry (SIC-28) expends over 7 kilowatthours of electricity per dollar of manufacturing value added (>7kWh/MVA). As previously stated, however, a finished or final consumer product is not a product of a single manufacturing process but of a series of processes, and the problem is more that of determining the energy used to produce a product than the energy used by an industrial category. Although chemicals are a class of products that require large energy expenditures, chemicals are used in virtually all industrial processes. Furthermore, not all products can be as easily eliminated, substituted, or altered in process.

Therefore, this avenue of product selection will not necessarily include all the products that require high energy consumption for their manufacture and that are amenable to energy conservation practices. An alternative product selection criterion could be one that is based primarily on product or process substitutability and production volume. Small containers, for example, are high-production items that are also highly substitutable. Assuming interchangeability in the use of the product, then the shift in utilization toward the container type, e.g., glass, metals, plastics, or paper, that requires the least amount of energy to manufacture will conserve the most energy.

The kinds of energy used in industrial production other than manual labor are heat energy, mechanical energy, and electrolytic processes. The proportionate use of energy types depends on the production process. Some processes rely heavily on mechanical energy, and other processes require large expenditures of heat. Comparative measures of energy use per unit production or per unit value could be in Btu and kilowatthours. The ultimate comparative energy unit will probably be the thermal equivalent of all fuels consumed, including the fuel consumed in producing electricity. It should be recognized that products generally classified as fuels, such as coal, natural gas, and various petroleum products, are not always used as fuels in industrial production processes, and consequently input process fuels should be converted to energy equivalent only when they are used as fuels.

B. State of the Art

It is one thing to seek energy conservation, quite another to realize it in the industrial sector relative to DoD. Several key questions must be addressed for a sequence of raw materials, facilities, and products.

- To what extent should energy conservation practices be implemented by agencies of the government that relate to or support DoD operations?
- In the event of an energy emergency, what procedures or mechanisms exist (or should exist) to ensure that supplies exist to meet high priority uses?

In many cases relative to common products, the actual chain of energy-related operations that contribute to final production is imperfectly known. The state of the art is such that important data need to be compiled and assessed in an integrated fashion to permit informal decisions regarding energy conservation programs. Although a start is being made to determine the energy requirements relative to materials production by the National Materials Policy Commission, understanding of the energy budget of the entire production sequence of such materials is imperfectly known.

C. Implications for DoD

The present situation suggests that DoD's effectiveness in formulating positive efforts to direct operations by its components, suppliers, or contractors to achieve energy conservation will be limited by incomplete knowledge.

D. Recommendations for Further Study

To establish an effective program in energy conservation, further study of the hierarchy of processes that lead from a number of raw materials to produce a common product is needed. For example, one study might examing the energy associated with steps that lead from mining iron ore, transporting it (and coal, limestone, and flux) to a steel mill (plus the energy in the raw materials to fabricate and operate the mill), producing the final steel, and then to making some item of equipment from the raw steel. A series of such studies might be done for selected key materials important to DoD. This would provide an assessment of the possible savings to be realized from substitution of materials or to provide support to improvement in industrial operations to utilize less energy, thereby contributing to possible modernization of domestic operations. This is covered in greater detail in another section of this report, with specific emphasis on the energy requirements for production of materials used by the DoD.

XVII ENERGY DATA MANAGEMENT

A. Statement of the Problem

The process of obtaining data on energy as related to the functions of the DoD and various supporting or complementary organizations will probably need to be continued in some manner. The present energy situation is in a state of considerable flux, and it is to be expected that the next decade will see substantial developments in energy technology, economics, and institutions that will require regular monitoring to ensure that the DoD is prepared to fulfill its responsibilities. To accomplish this objective, it appears desirable to examine means to establish, or participate in, a systematic approach to energy data management.

B. State of the Art

The capacity of modern computer systems is such that enormous amounts of information may be entered into them. Developments in the programming art enable greater flexibility and versatility in data entry, manipulation, analysis, and retrieval. These existing capabilities could be applied to the problem of management of energy related data to facilitate updating this information and to permit greater depth of analysis.

The problem is not with computer technology or usage. Instead it is attributable to the complexities of energy supply and demand. We have concluded that although there is a wide variety of energy sources, processes, and applications, the data management problem does not appear to be so complex as to defy rational solution. One key to the problem may lie in the fact that energy can be described in units that are readily converted to a common basis to facilitate comparison. Energy from different fuels or sources may be expressed as British thermal units (Btu).* The Btu equivalents of common fuels are:†

Fuel	Common Measure	Btus
Crude oil	Barrel (bbl)	5,800,000
Natural gas	Cubic foot (cf)	1,032
Coal	Ton	24 million to 28 million
Electricity	Kilowatt hour (kWh)	3,412

Using these conversion factors, it is also possible to express amounts of energy from one fuel in terms of equivalent amounts of another fuel to aid in comparative analysis (e.g., total energy may be expressed as equivalent barrels of petroleum or tons of coal).

If combined with a factor representing mode of energy use (e.g., for different types of equipment of facilities) or efficiency of use, it may be possible to achieve representation of the character and scope of energy use in a wide range of otherwise unrelated activities or operations. This would provide for better focus of energy management efforts. However, the state of the art appears to be such that the factors relating energy type to mode or efficiency of use are imperfectly known or absent entirely. A further limitation is that for DoD purposes an additional factor that relates to operational effectiveness needs to be included to complete the management analysis. Clearly, it will be of little value to achieve optimum energy use if this could preclude or impair fulfillment of the defense mission.

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* A Btu is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. The Btu is a very small unit of measurement, and large numbers are commonly used to describe common energy units.

† National Petroleum Council "U.S. Energy Outlook: An Initial Appraisal, 1971-1985," November 1971.

C. Present Activities and Organizations

A number of organizations have studied the possibility of establishing natural resource information systems over the years. Among these are the U.S. Bureau of Mines, U.S. Geological Survey, Bureau of Indian Affairs, and Atomic Energy Commission. Additionally, the American Geological Institute is exploring the problems associated with such an approach. At present, however, no system is in routine operations. However, many such systems had merely a custodial function, rather than an action-orientation function.

In regard to data management for DoD use, SRI recently defined an approach to establishment of an environmental protection data system for the Navy.* It would appear that a similar approach could be taken to determine the requirements for an energy data management capability.

D. Implications for DoD

The history of past work by other agencies provides a foundation for assessment of the potential for establishment of an energy data management capability. The potential for achieving improved energy conservation and efficiency in DoD operations would be enhanced with more complete, up-to-date knowledge of the status of information regarding energy topics.

E. Recommendations for Further Studies

An assessment of the applicability of previous attempts at data system development should indicate the applicability of such approaches to DoD. A parallel study of DoD energy information needs could serve to determine

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* Berg, D. N. "Concept Definition of the Navy Environmental Protection Data Base (NEPDB) System," Contract N62399-72-C-0006, U.S. Naval Civil Engineering Laboratory, Point Hueneme, California, Final Report, 15 August 1972.

the scope of the dimensions of a possible system. Design of an energy data system could proceed from such work and could support related energy studies (such as conservation of energy in materials production) by serving as a means to organize and analyze complex interrelated data.

XVIII INSTITUTIONAL FACTORS

A. Statement of the Problem

Numerous domestic government agencies have responsibilities regarding resources, materials, and energy. At the federal level, at least 19 departments and agencies sponsor applied research on materials, 15 are engaged in long range materials policy planning, and 20 are engaged in materials information management functions.* The situation is further complicated by the often significant role of regional, state, and local agencies in the energy and resource field; for example, the activities of the Texas Railroad Commission in regulating petroleum production is of national significance. The diversity of agency jurisdictions that pertain to energy or resource development is such that knowledge of their organizational procedures and practices is essential to guide related programs in the energy and resource area. Furthermore, attention to the activities of Executive Branch agencies needs to be balanced by knowledge of the duties and jurisdictions of cognizant parts of the Legislative Branch so as to complete the description of the institutional aspects of energy resource development.

Knowledge of domestic agencies must be complemented by similar information regarding international organizations that exert influences in the energy area. Principal among these is the Organization of Petroleum Exporting Countries (OPEC). In the past two years, OPEC has established

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* See "Toward a National Materials Policy," a report prepared for the Committee on Public Works, United States Senate, April 1969. Reorganization since publication of this report has led to changes in names and locations of some agencies.

itself as a dominant force in the international petroleum market, and the balance among oil-producing (exporting) countries and consuming (importing) countries appears to have shifted in favor of the exporting countries. The institutional factors that influence policy and procedures of these nations relative to energy resource production and distribution need to be understood if planning is to be accomplished for supply of fuels from sources in OPEC members according to a range of possible contingencies.

B. State of the Art

Achievement of better understanding of institutional factors that relate to energy will require careful analysis of the authorities, regulations, procedures, and practices of the several organizations that deal with energy (as well as with environmental restrictions on energy production). The currently available documentation for cognizant agencies should be sufficient to permit analysis of interlocking and complementary jurisdictions and responsibilities by various organizations. If coupled with an assessment of the relationship of technological factors relative to energy production and consumption (especially by DoD-related activities), the definition of institutional transactions derived from analysis of present patterns should allow for formulation of action programs to better use advanced technology consistent with policy constraints.

An indication of civilian energy activities by federal government agencies can be obtained from analysis of energy appropriations (Table XVIII-1). Nearly 70 percent of funds appropriated for all energy purposes go to large capital expenditures, with one-third of these funds committed to payment of special benefits to coal miners (Title IV, Federal Coal Mine Health and Safety Act of 1969). The remaining two-thirds of capital expenditures is primarily devoted to generation and transmission of electricity. About 30 percent of total energy appropriations are for

Table XVIII-1

SUMMARY OF APPROPRIATIONS FOR CIVILIAN ENERGY ACTIVITIES, FISCAL YEAR 1972*
(Millions of Dollars)

Agency or Department	Capital Expenditures	Operations, Regulation, R&D	Total
HEW/SAA (benefits to miners)	$ 644.0	$ --	$ 644.0
USDA/REA	545.0	1.3	546.3
DoD/COE	330.0	85.3	415.3
DOI	186.0	185.0	371.0
AEC	98.0	375.0	473.0
DOC	64.0	0.4	64.4
DOS	6.3	3.3	9.6
TVA	35.7	--	35.7
DOT	--	4.6	4.6
EPA	--	59.5	59.5
FPC	--	22.0	22.0
NASA	--	15.4	15.4
NSF	--	12.0	12.0
ICC	--	30.6	30.6
FTC	--	25.2	25.2
OTP	--	12.8	12.8
Total	$1,909.0	$832.4	$2,721.4

* Source: SRI, derived from tables included in, "A Review of Energy Policy Activities of the 92nd Congress," First Session, United States Senate, Committee on Interior and Insular Affairs, Serial No. 92-17, pp. 16-17, (January 1972).

operations, regulation, and R&D. Nearly half these funds go to the Atomic Energy Commission.

In terms of energy form, about 70 percent of federal energy appropriations go for production, regulation, operation, or transmission of electricity. Yet, the generating capacity of federally-assisted utilities represents only 20 percent of the total generating capacity, and electricity represents only 25 percent of the nation's total fuel demand.

Federal expenditures for fuels are imbalanced. Coal is the largest domestic fuel resource, yet it received only 16 percent of operations, regulation, and R&D funds. Petroleum and natural gas amount to 75 percent of the energy supply but received only 2 percent of these funds. Nuclear energy represented 1 percent of total supply but received about half the operation, regulation, and R&D funds for fiscal year 1972.

C. Present Activities and Organizations

A number of organizations are carrying out work in the energy field. These can be identified, in part, by a listing of studies currently being compiled by the Congressional Reference Service of the Library of Congress and included as Exhibit A. Further indications of energy activities is provided by the publications of cognizant Congressional committees (Exhibit B). Finally, the scope of present studies related to fuels and energy by a number of public and private organizations may be illustrated by a listing of selected publications (Exhibit C)*.

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* See, especially, "An Inventory of Energy Research" U.S. House of Representatives, Committee on Science and Astronautics, Serial R. March, 1972 (in two volumes).

D. Implications for DoD

It is apparent that the activities of the Department of Defense relative to energy matters require a thorough analysis and assessment of institutional factors that influence or control energy supplies and production.

E. Recommendations for Further Studies

A comprehensive, interdisciplinary analysis of the patterns of institutional transactions among cognizant government agencies is needed to identify the factors that are particularly important as potential constraints on energy supply. Assessment of the effects of alternative means of conducting these key transactions is needed to determine the significance of possible changes to present practices, as well as to indicate the mechanisms of realizing such changes under normal or emergency circumstances. This information will be of value in developing new advanced studies to deal with the technological conditions posed under likely conditions.

Exhibit A

ENERGY STUDIES CURRENTLY UNDER WAY

June 1972

Compiled by Congressional Reference Service,
Library of Congress

Exhibit A

ENERGY STUDIES CURRENTLY UNDERWAY - JUNE 1972

Organization	Title/Purpose of Study	Target Date of Completion
Atomic Energy Commission	The Year 2000 Study	1972
	Cost-Risk Benefit Study of Alternative Means of Producing Central Station Power	Mid-1972
	Shipping Study on Civilian Nuclear Fuels and Wastes	In Progress
	Integrating Nuclear Power into Utility Power Systems (with Commonwealth Edison and TVA)	Continuing
	Cost Estimates for Steam Electric Power Plants	Continuing
	Updated Analyses of Nuclear Gas Stimulation	June 1972
Delaware River Basin Commission	Environmental Criteria for Power Plant Siting	Not Yet Funded
Department of the Interior	Southwest Power Study	1972
Bureau of Land Management	Atlantic Outer Continental Shelf Environmental Study	Mid Summer
	Gulf of Alaska Outer Continental Shelf Environmental Study	Mid Summer
	Royalty Bidding on Outer Continental Shelf	Ongoing
Bureau of Mines	An Application of Systems Dynamic Modeling to Energy Systems Planning (Econ. Anal.)	July 1972
	Coal Availability by Sulfur Levels	In Progress
Geological Survey	Analysis of Potential Fuel Resources	1973
	Techniques for Estimating Oil and Gas Resources	Ongoing
	Survey, Investigations, and Research on Fuel Minerals	Continuing

Exhibit A (Continued)

Organization	Title/Purpose of Study	Target Date of Completion
Office of Oil and Gas	Vulnerability of Natural Gas and Petroleum Systems	October 1972
	Petroleum Refinery Vulnerability	April 1972
	Inter-Agency Study of Oil and Gas Fields	End 1972
Federal Power Commission	National Gas Survey	Late 1973
Federal Trade Commission	Existing Situation and Trends in Concentration in Fuels Industry	Fall 1972
	Effect on Fuels Pricing of Mergers	1974
	Effect on Fuels Research and Development of Mergers	1974
National Petroleum Council	U.S. Energy Outlook 1971-1985	
	Part II	Summer 1972
	Part III	Late 1972
National Science Foundation Rand Corporation	Projection of Energy Demand: Methodology of Forecasting	Late 1973
Oak Ridge National Lab	Analysis of Total Societal Cost of Electricity	After 1972
	Prospects for Reducing Environmental Impacts of Electricity by Improved Technology	After 1972
	Analysis of Ways of Reducing Environmental Impact by Reduction in Growth Rates	After 1972
Argonne National Laboratory	Research and Development on Lithium/Sulfur Secondary Batteries	1972
Massachusetts Institute of Technology	Dynamics of Energy Systems	1972

Exhibit A (Continued)

Organization	Title/Purpose of Study	Target Date of Completion
National Science Foundation (cont.)		
California Institute of Tech.	Studies in Environmental Quality	June 1974
Cornell University	National Energy Needs and Environmental Quality: Biological Factors Associated with Power Plants	In Progress
University of Denver	Factors Affecting Fly-Ash Resistivity and Voltage Breakdown in Electrostatic Precipitators	1972
University of Missouri (Columbia)	Digital Computer Control of Electrical Power System Substations	1972
University of Pennsylvania	Energy Conversion and Power	Ongoing
	Conservation and Better Utilization of Energy	Ongoing
	Solar Heating and Thermal Storage	Ongoing
Purdue University	On-Line Transient Control of Power Systems	1972
Office of Emergency Preparedness		
Oil Policy Committee	Oil Import Quota Modifications	Continuing
Joint Board on Fuel Supply and Fuel Transport	Monitoring Energy Supply/Demand and Transport	Continuing
Staff Study	Security and Economic Implications of Import-Based Pipeline Gas	Summer 1972
Office of Science and Technology		
(Professor Garvey)	Social Costs of Energy	1972
(Paul Weir Co.)	Supply Curve for Coal	March 1972
(Resources for the Future)	Gas Price Regulations	Early 1972
(Stanford Research Institute)	An Analysis of Energy Demand	April 1972
(National Economic Research Assoc.)	Effect of Federal Tax Policy on Energy	---

Exhbit A (Continued)

Organization	Title/Purpose of Study	Target Date of Completion
Office of Science and Technology (cont.) (Battelle Northwest)	Input-Output Analysis of Energy Use Changes	Continuing
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American Association for the Advancement of Science and the Scientist's Institute for Public Information (University of Minnesota and elsewhere)	Social Consequences of Environmental Effects of Electric Power Generation	June 1972
Battelle Memorial Institute (Environmental Protection Agency)	Fossil Fuel Cost-Availability Models for Air Quality	Continuing
Edison Electric Institute	Fuels and Energy Study	1972
Intertechnology Corporation (all privately funded)	Cutting the Cost of the Off Peak Storage	Continuing
	Economic Utilization of Solar Energy	Continuing
	Thermal RAM	Continuing
	Environmental Consequences of Specific Prime Movers	Continuing
	Conservation of Energy in Housing	Continuing
Mitrie Corporation	Symposium on "Energy and Resources"—Japan	July 1972
National Academy of Science Environmental Studies Board	World Problems of Energy Resources and Relation of Energy to the Environment--Planning Phase	June 1972
National Research Council	Synthetic Fuel Gas, its Technological and Economic Future	
	Part I - Pipeline Quality Gas	June 1972
	Part II - Low BTU Fuel Gas	August 1972
	Part III - Coal Liquefaction	October 1972

Exhibit A (Concluded)

Organization	Title/Purpose of Study	Target Date of Completion
National Academy of Science (cont.)		
National Research Council (cont.)	SO_2^x from Industrial Sources	July 1972
	Part from Stationary Sources	July 1972
Resources for the Future	The World Petroleum Market	Summer 1972
	Residuals Management in Mining Coal and Producing Power	In Preparation
	Resources and Environmental Consequences of Population Growth in U.S., Report to Population Commission	1972
	Analysis of Energy Consumption Growth in the New York Metropolitan Area	Late 1973
	Energy, Economic Growth and the Environment	1972
Stanford Research Institute (Industrial Studies)	Recovery of Liquid Hydrocarbons and High BTU Gas from Coal Lignite, Tar Sands and Oil Shale	April 1973
	Oil Gasification for Production of Methane, Hydrocarbon and other Fuel Gases	Probably Published
	Desulfurization of Fuels	—
Energy Policy Project (Ford Foundation)	Energy Policy Project	Ongoing
State of Maryland Department of Natural Resources	Power Plant Siting Program	Ongoing

Exhibit B

CONGRESSIONAL COMMITTEE PRINTS ON ENERGY

June 1972

Compiled by Congressional Research Service,
Library of Congress

Exhibit B

CONGRESSIONAL COMMITTEE PRINTS

(Issued after July 1, 1971, Supplements Committee Print No. 92-6 of Senate Interior and Insular Affairs Committee entitled "A Bibliography of Congressional Publications on Energy from the 89th Congress to July 1, 1971.)

Joint Committees

Atomic Energy Committee
: Nuclear Power and Related Energy Problems 1968 through 1970, December 1971.

Economic Committee
: Report on Crude Oil and Gasoline Price Increases of November 1970: A Background Study, November 3, 1971.

Senate Committees

Interior and Insular Affairs
: Review of Energy Issues, 91st Congress, January 29, 1971.

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XIX ENVIRONMENTAL ASPECTS OF ENERGY DEVELOPMENT AND USE

A. Statement of the Problem

All U.S. institutions that produce, distribute, or use significant quantities of energy are coming under close public scrutiny. The effect of this public pressure is to achieve some measure of control over the heretofore rapid growth in energy use so as to begin to ameliorate associated environmental effects. Air pollution probably is the most conspicuous impact of energy in most people's environment. An additional factor relates to the land use patterns associated with energy. Objections have been raised not merely to the space occupied by generating stations, fuel refineries, and coal mines but also to the transmission lines that accompany them.

Another class of concerns relates to the public safety aspects of energy production and transport--most notably, nuclear hazards, although pipelines and fuel transportation by rail and tanker are also important in this regard. Also of concern are the effects of ecological changes from energy production and use--principally heating of local waters, air pollutant effects on local flora and fauna, and the potential of climatological change resulting from intense local use of energy. Another growing source of environmental pressure derives from the belief that economic growth is itself responsible for environmental degradation, and thus some limits to energy supply would be an effective means to halt these advance effects.

The impending fuel supply shortage will exacerbate the environmental concern. It will force utilities and large fuel consumers to use coal instead of gas and oil. Emissions of sulfur dioxide and particulates will probably increase, resulting in further deterioration of air quality in affected urban areas. There will be a drive to avoid the emissions from dirty fuel by using stack gas scrubbing equipment and by installing coal gasification plants; but it seems probable that some actual further deterioration of urban air quality will be experienced, stimulating the development of institutional reforms that will provide more effective incentives for improvement of environmental quality.

The additional coal supply can most cheaply be obtained from strip mines. These mines already are a focus of public concern because of the disruptions to the landscape and impairment of amenities through offsite effects that accompany mining. Unless progress is made in rehabilitation of surface mined lands to permit some further use, it is apparent that public pressure will severely restrict coal supply from this technique. As more nuclear plants are built, the risk associated with them will become more immediate or, at least, more readily appreciated. All these effects of the fuel shortage will be highly visible environmentally, with resulting public concerns being focused on them.

The air pollution and land use impacts from energy development on individuals are immediate, direct, and personal. The impacts themselves are obvious motives for citizens to join in exerting environmentalist pressure; no ulterior motives need be ascribed, although some may exist. On the other hand, the hazard aspects and the local ecology effects associated with energy sources cause concerns that are remote and more difficult to demonstrate. While they are legitimate matters of concern, that concern must finally be about whether established authority will deal competently with them before they rise in scale and impact to the level of many present air pollution and land-use problems.

These concerns are not limited to individuals who oppose the "establishment;" and it cannot always be assumed that environmental pressures are exerted only by chronic social critics. The highly motivated and articulate but smaller groups will lead the less organized, impacted public in specific opposition or reform projects. Therefore, the DoD can expect continued, searching scrutiny and environmentalist intervention on all its activities that have environmental impact--including its use of fuel and electric power. The degree to which such intervention can affect these activities will be a measure of the effectiveness of programs to mitigate environmental impacts of energy development and use by the DoD.

B. State of the Art

The DoD is exposed to these energy-related pressures as target in three major roles that illustrate the state of the art:

- As a fuel user and thereby, polluter
- As a priority consumer of energy in short supply
- As a holder of fuel reserves.

In a fourth role, the DoD can be an environmental problem-solver.

A relatively conspicuous fuel consumer-polluter is DoD aircraft operations. In the vicinity of urban bases where they operate at low altitudes, the noise and visible exhausts from aircraft will affect the air quality conditions more or less as their contribution to the surrounding air is more or less obviously polluted. Attention will be attracted to the nitrogen oxide (NO_x) emissions of these aircraft--especially in urbanized air basins where photochemical smog is a principal ingredient of the urban haze. In general--and until at least 1980, by which time significant numbers of NO_x-controlled automobiles are projected to have entered the population--the aircraft contribution to the total pollution load will be small; and the DoD portion of this will be still smaller.

Automobiles are, and will continue to be, the source of most of this pollutant; electric power plants and industrial combustion rank close behind. But the fact that DoD operations are controllable by ordor will expose them to increasing pressure for actions to control pollution from these sources. There are obvious approaches that DoD may use to respond to these situations. From the standpoint of technology, it is clear that DoD support of technological developments leading to improved smokeless engines and low NO_x combustors is also indicated.

It will be important to establish the basic facts concerning the question of NO_x emission in the stratosphere. This concern--that depletion of ozone through the very rapid reaction, $NO + O_3 \rightarrow NO_2 + O_2$, would strip away part of the atmosphere's ultraviolet absorption--was a factor in the SST debate. Until it is resolved, it will remain as a member of that class of phenomena--such as nuclear power plant disasters, and certain chemical pesticide uses--around which scenarios can be constructed that, through a converging chain of events, lead to ecological catastrophe. The DoD, as with other government agencies, will be obliged to investigate the elements of such scenarios no matter how improbable they may appear to be. Analyses of alternative actions are required as part of the Environmental Impact Statements--prepared in compliance with the National Environmental Policy Act. Such analyses can be valuable in determining whether significant use can be made of exotic fuels--pentaborane, for example--or in advance of the development of aircraft that will operate significantly higher than the altitudes at which much experience has been gained.

DoD land installations are being required to adhere rigorously to the emission standards for air and water pollution that govern the surrounding community. Particularly in reference to energy matters, the emissions of heating plants, local power generating plants, fuel storage, and transfer equipment will be points of scrutiny. Defense installations should be prepared to make early installations of pollution control equipment as it becomes commercially available. It is to be expected that boiler stack gases and, possibly, stationary diesel exhausts, will be required to be scrubbed of particulates, SO_2 and NO_x. Equipment for the former is widely available, since SO_2 removal is approaching commercial utility, while NO_x removal is still in the laboratory. These requirements could significantly increase operating costs of the plants affected.

Similar pressures will be applied to vessels in port. Here the pressures already felt to prevent oil emissions to the water will intensify as the oil-spill problem is intensified by growth of oil imports. Already much improvement has been noted in the previously used practices of fuel transfer and tank cleaning. Information on other activities of pollution control is presented below.

C. Present Activities Relative to the Status of Environmental Information

The environmental aspects of energy development constitute a complex set of secondary or higher order effects that are caused by (or related to) primary activities for stages of the process by which energy is produced and used. In short, they are what economists term "technical externalities," those that have been outside the market calculation of the energy scene until recent years.

The diversity of these environmental effects and their causes greatly complicates the formulation of remedial measures on the development of technology that will contribute less environmental impact at the outset. A number of considerations that bear on this problem are discussed in the sections that follow.

1. Intermedia Impacts of Pollution Control Strategies

a. Introduction

The characteristics of the physical environment are such that each component is intimately interrelated with every other component. As a result, present and potential environmental problems in a number of categories facing the nation are interrelated through their effects on the adjacent environment. A prospective solution to any one environmental problem must take cognizance of impacts on other activities and other aspects of the environment to avoid contributing to different but equally unacceptable problems. A central factor is that all developments (and modifications to them) represent perturbations to the environment, acting at a pace, on a scale, and in a manner different from those that nature would impose.

Recognition of the interrelationships and cross influences among environmentally important activities is vital to the planning necessary to prevent adverse environmental consequences. In short, it will not do to "solve" a problem in air pollution if the solution leads to impaired water quality or accentuates solid waste disposal problems. Rather than considering separate environmental categories such as air, water, solid waste, or the like, real progress toward improvement of environmental quality requires viewing the environment in its entirety.

b. Discussion of the Problem

In response to public concern, the federal government has moved to deal with problems of air pollution, water pollution, management of solid wastes, and other aspects related to environmental quality. Recent activity in dealing with environmental problems has emphasized individual categories of the environment, and organizational emphasis has been given to this approach.*

No technical reason is apparent for dividing the physical environment into such categories. In fact, from a scientific standpoint, they represent a return to the description of the physical world in terms of four "elements"--air, water, earth, and fire. Only the latter element is lacking from the present fragmented approach to environmental problems exemplified by current program patterns.

Perhaps the major drawback in the present approach is that it does not reflect the technical knowledge accumulated in the centuries since the original scientists contemplated the physical world. Actually, it appears to result from a rapid institutional response to deal constructively with expressed public desire to improve environmental quality; this is entirely logical, and represents an encouraging factor at a time when many criticise government for being unwieldy or unresponsive.

The present arrangement of organizations to deal with environmental quality appear to be related to the legislation that established the programs for dealing with pollution in a particular medium, although the legislation may not specify organizational aspects. The creation of the EPA allows for internal reorganization to deal most effectively with environmental problems. The organizational units that execute legislative intent provide the public an opportunity to see that the legislative will is being carried out, and they also facilitate accounting of funds that are appropriated so as to perform the required programs.

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* For example, the Environmental Protection Agency (EPA) has an Air Pollution Control Office and a Water Quality Office to deal with pollution problems in these media.

However, while the present approach provides for simple accounting, it is less efficient in achieving accountability for progress in maintaining or improving environmental quality in any given category because of the interrelationships of environmental media. Although it is important to keep close account of public funds used for environmental purposes, it is even more important that the funds be used in such a fashion to achieve their public purpose. Uncoordinated programs that may be able to achieve individual environmental objectives could have their "success" obviated through the consequences of other programs. In short, environmental discharges cannot be dealt with in a piecemeal fashion; the environment by definition comprises an array of interlocking factors, and governmental programs for environmental quality must reflect this basic principle.

2. Water Pollution Control

a. Introduction

Federal expenditures for water pollution control have increased substantially in recent years as the government has moved to meet the growing concerns of the public for positive actions to safeguard the quality of the nation's water resources. However, in spite of the recent attempts to control water pollution and rising budgets for such programs, many waterways remain significantly polluted. With a long agenda for important social needs and limited funds to address these needs, the public is understandably questioning whether it is receiving benefits commensurate with costs in the water pollution control field.

In the environmental area, it is often possible to measure costs and benefits through an inferential process that relies heavily on data that are of uncertain reliability. Although it is possible to determine costs of projects or facilities and to calculate benefits in savings of effort, a complete balance sheet of environmental costs and benefits cannot be constructed because of the important role of intangible values placed on environmental aspects by individuals or societal groups. Furthermore, it must be recognized that pollution control projects that suggest net benefits in terms of environmental quality may prove to result in net costs to society when considered with economic or other social aspects. In short, it can be and has been shown that all water pollution control projects do not necessarily result in increased benefits to society.

b. Discussion of the Problem

Water pollution from any source is a perturbation to the natural environment. In many areas of the nation, polluted waters have persisted for extended periods of time, while in other areas the present degree of pollution is a relatively recent development. Water pollution is particularly important, since water is the medium for transmitting pollutants to other elements of the environment or to other areas that are not now affected.

While all pollution is a perturbation to the environment, since it involves materials, quantities, and processes that differ from those of nature, it is not often recognized that remedial measures to counteract pollution are further perturbations to the environment, so that not every action achieves its intended result. For example, coal mining has led to acid mine drainage in much of the Appalachian region and adverse effects on ecological and solid factors in that area. However, attempts to neutralize acid waters by addition of limestone have resulted in precipitation of iron hydroxide ("yellow boy") that poses even more difficult problems for pollution control and rehabilitation. The lesson to be learned from this experience and similar activities is that the remedy can be as costly as the malady unless its ramifications are thoroughly understood. Progress in dealing with water pollution control requires clarity in definition of the nature of pollution and the means for its control, comprehension of the benefits as well as the costs from such control, and identification of the parts of society that will enjoy such benefits and that will bear the costs: the two groups are not likely to be entirely identical.

Furthermore, it is necessary to consider several environments, each of which is interrelated:

- The physical environment, which governs the relations of factors and processes.
- The socioeconomic environment, which comprises the actions of man relative to water pollution.
- The institutional environment, which is the system developed by man to regulate his activities.

3. Interrelationships of Land Use Planning and Control to Water Quality Management Planning

a. Introduction

The importance of land use considerations to problems of advance planning in water quality management is a relatively new concept. Unfortunately, the few previous attempts to relate water quality data to land use planning resulted in specialists from both disciplines "talking past but not communicating with" one another. Each group has needs for basic, applied, and interpretative data. A review and evaluation is needed to focus on the work of pertinent water management agencies and major land use planning groups. The aim of such work is not merely to produce a scholarly review and critique of water quality data but also to define the scope and character of information about water resources that land use planning agencies require, according to their needs. It will be especially important to identify the planner's views on the manner and format in which water quality data are compiled, presented, and disseminated. These data will be essential in preparing an outline of features desired in water quality reports for use in land use planning programs. Also, the degree of change of format suggested will be necessary to estimate likely costs of any changes, as well as the time to accomplish improvements.

b. Discussion of the Problem

The recent levels of public concern over environmental quality have led to significant legislation and funding for national programs dealing with pollution control. An especially important program administered by the EPA provides construction grants and loans to qualified local agencies to support installation of improved water pollution control and abatement activities as a part of comprehensive area plans. The program is projected to commit about $2.2 billion in fiscal 1973 and even larger sums in subsequent years.*

The Federal Water Pollution Control Act of 1970 provides for federal grants in aid of municipal facilities for waste treatment and pollution control. To qualify for these grants, applicants must show that their proposed facility is consistent with a comprehensive river basin, regional, or metropolitan plan for water quality management. These plans must be approved by the EPA according to established guidelines before funding can be authorized for individual facilities. The exacting conditions under which these funds can be allocated have led to some difficulty in keeping grants abreast of the planning work and have presented significant difficulties to many applicants. It is said that in at least one region, few applications have been approved recently because federal authorities were not satisfied on the points in question.

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* This program is described in the "Guidelines for Water Quality Management Planning," prepared by the U.S. Environmental Protection Agency in January 1971 in response to 18 CFR 601.32-33 dated 2 July 1970.

In this regard, it is important to bear in mind that water does not pollute itself. Pollution is introduced to waters as a consequence of activities and patterns of use of lands occurring adjacent to waterways. Therefore, meaningful progress in improvement (or even maintenance) of water quality can be accomplished only if the influence of land use is included in the planning process for water quality management. Although necessary, the consideration of interrelationships of land use practices, together with water quality management, represents a break with tradition and could be construed as a threat to important interests. Defining, describing, and explaining the salient elements of the overall planning process will be required to achieve a better understanding of the benefits and problems resulting from this integrated approach on the part of those responsible for day-to-day activities in the land use and water quality area. These elements will be incomplete unless related and interdependent technical, operational, and institutional factors that govern or affect planning can be displayed and clarified to assist responsible officials at all levels in the conduct of action programs for achieving national environmental quality goals.

These considerations suggest that it will be increasingly important to deal with the environmental aspects of energy development to satisfy the mission responsibilities of the DoD. This topic is considered in greater detail in the section that follows.

D. Implications for DoD

As a priority consumer of scarce energy supply, DoD will attract additional scrutiny. Domestic operations planning must take account of the possibility that electric utility service reliability may be locally reduced as demands rise faster than equipment is emplaced to serve them. Several metropolitan utilities have contingency plans for load-shedding during peak demand periods that may have to be implemented. Military installations will be pressed to conserve power use and to avoid on-peak loading of utility systems. If the severity of the energy shortage reaches the stage at which it is necessary to ration civilian consumption of electric power, or gasoline, or both, the immediate impact of priority energy use will be extended to a wider population; and the opportunity to exploit such impact from the standpoint of dissent will be materially enhanced.

The environmental impact of the energy consumption of DoD material suppliers will also come under review. Some of these supplies, such as the aluminum industry, use very large amounts of electric power directly. Other materials of which the DoD is a major consumer--e.g., reactive metals--depend ultimately on electric power for their reduction via an electrowave reducer such as magnesium or calcium. A total environmental analysis of defense procurement, inventorying the air and water emissions and the land uses that result from this production, would be useful to isolate other such areas in which DoD procurement has large, indirect impact. Then a review of procurement specifications--for necessary purity requirements that inhibit scrap recycle, for nonsubstitutable use of high-energy-cost materials, for opportunities to use other substitutions that would reduce the emissions of pollutants or the energy consumption of overall use of material--would assist in planning actions responsive to national needs for mitigation of adverse environmental impacts on the public.

There will be continuing need to take environmental factors into account as the Alaskan oil and oil shale reserves are developed. Holdings of some of these reserves such as Naval Petroleum Reserves and Naval Oil shale Reserves will require the DoD to practice environmental management in their development and, in doing so, to comply with the intent of Environmental Impact Statements prepared for the actions. The decision to develop reserves from which production has not already begun will be a "major federal action" within the meaning of the National Environmental

Policy Act. The release of restrictions on the national fuel supply and, therefore, on economic growth will be held by some as an adverse rather than a beneficial environmental impact.

Sites will be needed for both nuclear and fossil-fuel power plants that allow separation from population centers for absorbing environmental hazard and impact. Land holdings of the DoD--some of which are almost the only remaining open spaces in the midst of urban development--will be sought for these purposes; in the process, DoD will need to justify its use of these lands vis-à-vis other potential public uses.

E. Recommendations for Further Studies

The DoD can be an effective contributor in the role of environmental problem solution. A broad intersection of military and civilian interest in technology is related to energy production, conversion, and transmission. For example, early military interest in spark-ignition engines has already contributed to the stratified-charge engine technology that probably is the basis of eventual solution to automotive air-pollution. The intersection is much broader. Defense-sponsored basic research in combustion is closely related to the root of one serious pollution problem--NO_x. Defense materials technology will be useful in a number of ways in the new fuel conversion plants that may be built to convert the large western deposits of lignite and oil shale to clean, concentrated fuels. Fuel-use and high-energy-density battery needs of DoD and of the civilian sector are very similar. Some scenarios of future urban development see the expulsion of combustion-powered vehicles from big, densely populated urban cores and their replacement with combinations of mass transport systems and utility vehicles powered by yet-to-be developed electrochemical systems. Defense interest in package-power systems may aid in breaking through the technology structure that gives immense economy-of-scale advantage to very large plants and that, in consequence, leads to environmentally objectionable transmission lines and intense local concentrations of pollutant emissions.

The above are examples; a systematic inventory of possibilities would have extensive scope.

An outline for such an inventory would be based on the principal energy-related, environmental problems:

- SO_2--This pollutant, emitted from combustion of both fuel oil and coal primarily, is a major air pollution problem. Solutions entail chemical stripping from stack gases, removal from fuels, and conversion of oil and coal to methane and lighter hydrocarbons with removal of sulfur in process. High temperature, high pressure process technology, heat transfer technology, control, and measurement have high transfer potentials.
- NO_x--This is formed in combustion processes using air. DoD combustion research, engine development, and gas analysis methods are potential contributions.
- Particulate-Smoke--This is associated especially with energy conversion plants using low Btu coal, and locally could be a serious adverse environmental factor.
- Heat--Adverse environmental effects result from emission of waste heat to waterways or to air via evaporative cooling towers. Processes to use low-grade waste heat would be of use in environmental protection as well as in resource conservation.
- Fuel handling and distribution--Essentially the need is for care and foolproof, no-spill equipment design and development, as well as improved technology to clean up spills that do occur and rehabilitate affected areas.
- Underwater operations--Underwater oil well completions, perhaps drilling, would offer advantages to development of offshore oil reserves, increased protection from storm and collision damages, and possibly aid in extending the search for fuel reserves to deeper waters.

- Excavation technology--Efficient underground mining methods would alleviate some environmental damage at lignite and shale developments. Tunneling technology would encourage development of efficient, environmentally desirable energy transmission systems and utility systems to make efficient distribution of central heat and refrigeration for both conservation and minimization of pollution.

Both as target and as problem-solver, the DoD's Corps of Engineers is highly visible environmentally. In its traditional role as a builder of flood control and navigation facilities on the nation's waterways, the Corps has attracted considerable environmental opprobrium. Results that once were considered to be unquestioned benefits are now considered undesirable adverse environmental impacts. Moreover, the opportunities for major benefit with minimal environmental perturbation are becoming harder to develop.

The Corps has been largely a rural construction operation. However, the opportunities for environmental improvement by construction are now mainly urban. A great variety of urban needs, ranging from advanced sewage systems to transit, can use the engineering skills represented by the Corps. Major institutional obstacles to filling these needs at present underscore the need for new modes of federal-local interaction; cooperation between private and public institutions--for new forms of utility development, for example; and project decision and planning. Rather than wait for these institutional forms to develop, it seems desirable for DoD to take the lead in institutional obstacle analysis, synthesis of practical solutions, and advocacy of them to better use its skills in meeting the urgent domestic environmental and social needs of the nation.

XX TOTAL ENERGY CONCEPTS

A. Statement of the Problem

If present trends continue unchecked into the future, severe energy shortages in the United States are likely. In such a situation--which could materialize before the end of the present decade--it would be necessary to employ stringent measures to conserve energy and to make optimum use of available energy resources. Such measures could logically emphasize a "total energy concept" in which maximum advantage of energy production would be sought in the performance of a number of integrated functions requiring energy use. The purpose of a total energy concept is to realize high overall thermal efficiency (of the order of 70 to 80 percent energy conversion)* per unit of fuel. Thus, total energy systems are defined here as those that satisfy (from the same fuel or energy source) the needs of a particular facility for electricity, space heating, cooling, process steam, or other useful applications.

The total energy concept seeks to realize conservation of both energy sources (fuels) as well as energy itself. A key factor of the total energy concept is that it is relatively independent of sources of energy as represented by various types of fuels. Rather, it is focused on the processes by which energy in all its forms is extracted efficiently from such fuels and used to the maximum degree practicable. Furthermore, the total energy concept seeks to employ this energy to fulfill an array of prospective uses instead of any single use. As such, the total energy concept requires integrated and systematic attention to multiple-purpose energy generating and distribution systems as well as to energy utilization systems that have the capability to employ particular forms of energy regardless of its source in fuel (e.g., use of waste heat from electricity generation for space heating or cooling). Additional technical factors to be considered in a total energy concept pertain to means of increasing reliability of energy generation and

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* National Petroleum Council, "US Energy Outlook: An Initial Appraisal" New Energy Forms Task Group 1972, p. 71-73

distribution, improved means to control energy losses, and enhanced efficiency of energy use. Attention also needs to be directed at the economic and institutional factors relative to the total energy concept, especially to those changes in present practice that would be required to take full advantage of the prospective benefits. In short, the total energy concept represents a strategic approach to the energy problem, one that includes a number of more conventional or tactical approaches, and attempts to integrate these to satisfy energy requirements while at the same time practicing energy conservation.

B. State of the Art

The total energy concept is fundamentally related to the efficiency of energy production; it is commonly estimated that this efficiency is on the order of about 30 to 40 percent of the total heating value of the fuel.* One useful measure of energy conversion efficiency is the average number of BTUs required to produce one kilowatt-hour of electricity, defined by the National Coal Association as the "heat rate."** Of the fossil fuels, coal has the lowest heat rate compared to oil and gas (Figure 1). In the decade of the 1960s, oil and gas experienced greater improvements (decreases) in their respective heat rates (3.9 and 5.4 percent) than did coal with 2.8 percent; this is largely because the base rate for coal was less than that of the other fuels. One reason for this is that the data are aggregates; averaging has smoothed out local differences in fuel quality; still, coal is generally lower than the others. However, the figure suggests that the best heat rate data have levelled off or increased in the late 1960s, reflecting in part limiting materials factors affecting generation equipment and operating temperatures, as well as the imposition of measures to control emissions that introduce combustion inefficiencies into the system. Clearly, a total energy concept will require attention to the prospects for returning to the trend of continued improvement in generating efficiency from existing facilities while maintaining environmental quality. In this regard, it will be necessary to explore the anticipated consequences of substitute natural gas (SNG) or substitute liquid fuels made from coal upon the energy conversion efficiency of

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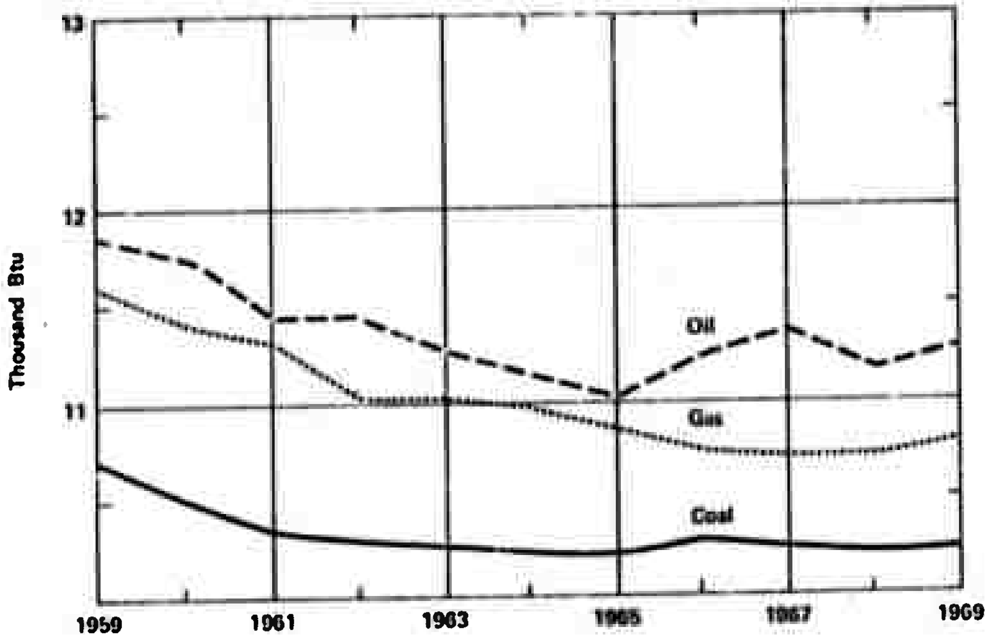
* This amount varies among individual fuels and processes.

** National Coal Association, "Steam-Electric Plant Factors," 1971 Edition, p. 103-110 existing plants. Also, the impact of waste heat utilization upon the heat rates for these plants will need to be assessed and the relative advantages determined for each type of fuel and each class of generating facility.

Figure 1

U.S. STEAM - ELECTRIC UTILITY HEAT RATE EXPERIENCE, 1959–1969

(Btu Per Kwh)



Source: National Coal Association

The total energy concept has been in existence for some time, but only limited success has been realized in actual practice. In many cases, such systems have not met their specifications or were developed in such a fashion as to prevent systematic evaluation. The achievement of a balance between the electricity and heat requirements of a particular user has been a particularly difficult problem for many prospective applications. One possible solution to this problem may be to employ a boiler system sized to meet heat and steam requirements in a closed system while allowing the electricity system to be only semi-closed (having access to other systems for times of over- or under-load conditions). This approach could improve the overall energy conversion efficiency of conventional facilities and represent a real contribution to energy supply.

Still, the dimensions of the forecast energy supply situation are such that even a return to gradual improvement in conversion efficiency or the achievement of substantial efficiency gains through new systems will probably be insufficient in satisfying long-term energy demands. Consequently, new energy sources need to be explored in the context of a total energy concept to ensure the capability to meet energy demands of the DOD. Among promising areas for further study are geothermal resources and small nuclear facilities.

1. Geothermal Resources. The widespread but imperfectly known geothermal resources of the Gulf Coast region of the United States (and other areas) are promising new energy sources. The recently passed law* permitting leasing of federal lands for geothermal resource development is expected to stimulate exploration and development of such poorly known but apparently significant resources. Before benefits from this development can be realized, however, a number of complex technical, engineering, and economic problems will have to be analyzed and resolved. Furthermore, the role of geothermal resources needs to be established in perspective to the larger energy scene. Accordingly, a comprehensive assessment of the state of the art as a basis for appraisal of the potentials for geothermal development in the Gulf Coast area of the United States would be useful in terms of the total energy concept for DOD installations. On the basis of present information, some preliminary comments are offered below.

2. Occurrence of Hot Water and Overpressured Geothermal Reservoirs Coincident with Locations of Military Installations. Major known hot water reservoirs occur in the United States west of the Great Plains including the states of Hawaii and Alaska. There are probably major reservoirs elsewhere in the United States since, for example, there are warm springs in Virginia, Arkansas, and Georgia, but their significance is not known. It has been estimated that, west of the Great Plains, as much as 75% of the area is underlain by hot water geothermal reservoirs of some significance and usefulness. For example, the following major military installations are known to be located coincident with hot water reservoirs:

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* The Geothermal Steam Act of 1970, Public Law 91-581, dated December 24, 1970

Naval Weapons Center, China Lake, CA

The Port Heuneme (Naval Construction Battalion Center) and Point Mugu (Navy Pacific Missile Range) ares in Calif.

Marine Corps Base, Twenty-nine Palms, CA

The Army's White Sands Missile Range and Fort Bliss in Texas

Mountain Home AFB, ID

Elmendorf AFB and the Army's Fort Richardson near Anchorage, Alaska

Hickam and Wheeler AFBs, the Army's Schofield Barracks, and the Pearl Harbor Naval Complex on the island of Oahu in Hawaii

The locations of hot water reservoirs in other parts of the world are not as well known but major reservoirs are known to occur in Iceland (Keflavik AB) and in much of Korea, Japan, Taiwan, Philippines, Southeast Asia, many of the Pacific islands, Panama Canal Zone, and near Ankara, Turkey. Military installations are located in all of these countries and areas.

Major known overpressured reservoirs occur in the United States in the Los Angeles and Santa Barbara basins in California, in Wyoming, along the island chain and on the North Slope region of Alaska, and in a very large belt in the northern Gulf of Mexico basin about 750 miles long from the Rio Grande River in Texas to the Mississippi Sound, inland under the Coastal Plain at least 100 miles, and offshore under the Continental Shelf at least 150 miles. Locations of military installations coincident with these reservoirs are:

The Naval Stations on Adak and Kodiak Islands in Alaska

The Port Heuneme (Naval Construction Battalion Center) and Point Mugu (Navy Pacific Missile Range) area in CA

Eglin and Tyndall AFBs and Pensacola Naval Air Station in Fla.

Keesler AFB and the Naval Construction Battalion Center in the Gulfport and Biloxi area in Mississippi

New Orleans Naval Air Station, the Army's Fort Polk, and England and Barksdale AFBs in Louisiana

Corpus Christi Naval Air Station and Ellington AFB in Texas

Locations of military installations coincident with overpressured areas in other parts of the world are not presently known but it is known that overpressured areas have been encountered during oil and gas field drilling throughout the world. They are located in the Far East (Japan, New Guinea, Indonesia, Burma, India, and the South China Sea), in South America (Venezuela, Trinidad, Columbia, and Argentina), in the Middle East (Iraq, Iran, and Pakistan), in Africa (Algeria, Morocco, Nigeria, and Mozambique), in Austria, France, Germany, Holland, Italy, Hungary, Poland, Rumania, and in a number of areas in the USSR.

3. Prospective Geothermal Benefits. The potential importance of geothermal resources for these bases is the possibility to employ them for electric power generation, space heating, or (with desalination) for fresh water supply at fixed sites. This would result in savings in fossil fuel supplies that are presently employed to meet fuel requirements at these sites, and effectively increase their supply. Furthermore, the liquid fossil fuels could be freed for mobile uses of the DOD, taking further advantage of their inherent properties to fulfill mission requirements.

A further advantage of geothermal resources development is the potential to obtain auxiliary supplies of fresh water through integrated development (inherently part of the total energy concept for this resource) that includes desalination of thermal brines. Finally, geothermal resources are generally non-polluting as are more conventional, fossil-fueled plants (although the quality of geothermal waters does vary and this factor would need to be taken into account on a locality by locality basis).

4. Prospective Nuclear Benefits. The feasibility of constructing nuclear reactors for the production of heat and electricity for military applications has been demonstrated. The U.S. Army has constructed eight pressurized water, boiling water, and gas-cooled nuclear power plants ranging from 300 KW(e) to 10,000 KW (e). At present four pressurized water plants remain in operation. The first desalination plant operating on nuclear power is still in operation in Antarctica. A nuclear reactor located at Fort Greely, Alaska, provided half of the energy produced to generate electricity and the other half to steam for space heating. Designs for a 2 MW(e) high temperature gas-cooled nuclear reactor are under consideration. The concept is modular.

One prospective concept calls for a combination of nuclear energy sources with total energy and total utility concepts. "Total Energy" concept provides for the utilization of waste heat from production of electrical power for heating, air conditioning, and other uses. The "Total Utility" concept provides for the most efficient use of fuel to provide electric power, heating, and air conditioning, as above, but is extended to include potable water, sewage treatment, and waste disposal. The use of nuclear power would presumably provide an alternate energy source to petroleum, and would reduce environmental pollution.

C. Present Activities and Organizations

The total energy concept has been examined at various times by a number of agencies of the federal government, as well as by private organizations. Many of these agencies are carrying on continuing programs that pertain to the total energy concept through work in energy conservation and minimizing environmental impact. Among those known to be actively concerned with this concept at present are the DOD office of Installations and Logistics, the Army Corps of Engineers, the Army Materiel Command, the Naval Engineering and Facilities Laboratory, the Council on Environmental Quality, the Environmental Protection Agency, the National Aeronautics and Space Administration, the Office of Emergency Preparedness, the Department of Housing and Urban Development, and the Atomic Energy Commission. Obviously, this listing is incomplete, and a thorough survey of the field would be required as an early step of additional advanced research into the total energy concept.

D. Implications for the DOD

From the standpoint of the DOD, the significance of the total energy concept is that if it proves practicable for use at military installations and facilities, multiple benefits could be realized. At present all U.S. military installations derive their energy needs from off-site suppliers in the form of purchased electricity or fuels. No known bases are self-sufficient in respect to their principal energy requirements. The potential advantage of the total energy concept applied to military bases is that it could:

- relieve some of the energy load now placed on local supporting energy sources and thereby effectively increase the available fuel supply.
- use waste heat resulting from energy-related facilities for some other purpose (e.g., water treatment, space heating, etc.) to achieve greater overall efficiency and to realize lesser environmental impacts.

- provide a multiple-use energy source that, if developed on-site at military installations as with geothermal resources, would be entirely under the control of the DOD and thereby less vulnerable to prospective interruption and impairment of mission activities.

  Geothermal resources could provide further savings if developed for bases in remote regions by reducing the amount of fuel transportation required to supply fixed generating capacity.

  Geothermal resource development according to a total energy concept could allow DOD (and supporting industries located in the vicinity of these developments) to contribute positively to both the energy supply situation (by development of new energy sources to augment present supplies) and the environmental impact of energy (by use of a relatively non-polluting source in comparison to the fossil fuels).
- provide for integrated energy sources to meet normal and emergency conditions. For example, development of the nuclear-energy, total energy/total utility concept could have a significant impact in relieving DOD dependence on fossil fuels (directly and indirectly). If successful, the concept could be used for bases and camps in the U.S. and for hardened and deep underground defense systems. It could also be used for off-shore logistic support bases, and would offer several potential benefits similar to those attainable from geothermal resources, discussed above.

E. <u>Recommendations for Further Study</u>

To examine in more depth the applicability of the total energy concept to the DOD, specific areas for further investigation could logically include the following partial listing:

- smoothing out the daily demand cycle for electricity at DOD installations.

- increased use of improved architectural and mechanical designs to conserve energy through heat recovery systems (e.g., insulation, building designs, etc.)
- enhance extent and degree of recycling and reusing of energy-consuming materials
- achieve better accountability and management of energy use in routine operations
- use of waste heat in activities associated with or supportive of DOD activities
- determine the technology and engineering economics of geothermal resource development for total energy applications at DOD installations
- assessment of the degree to which geothermal resources can supplement (or substitute for) conventional fossil fuels for DOD installations
- coordinated investigation of problems associated with the use of nuclear energy in military applications such as providing total energy capabilities for particular installations in normal and emergency situations
- demonstration of the feasibility of total energy concepts for use by DOD through design, construction, and operation of full-scale prototype units at actual installations.