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FINAL REPORT

on

A SUMMARY OF THE  
DARPA ENERGY AND MATERIALS SHORTAGES  
PROGRAMS,  
FISCAL YEARS 1972-1976  
(Report No. A-4825, Task No. 69)

by

James O. Frankosky, Charles Ravitsky,  
and Frank Milner

Sponsored by

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY  
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents a summary of the several research efforts by DARPA during fiscal years 1972-1976 for investigations in the fields of energy and materials shortages. It is essentially a summary program completion report. It presents an overview, broken down into four major areas: Energy Availability and National Security Considerations, Alternate Sources of Energy at Military Installations, Energy Alternatives in Propulsion, and Potential Materials Shortages and Their Implications for National Security. The overview is supported by the appendices, each addressing a separate area of investigation.		

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## FOREWORD

The research and analysis reflected in this report was funded through the Tactical Technology Center of Battelle's Columbus Laboratories. The project was supported by the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense and was monitored by the U. S. Army Missile Research and Development Command, Redstone Arsenal, Alabama, under Contract No. DAAH01-72-C-0982.

This report presents a summary of the several research efforts by the Defense Advanced Research Projects Agency during fiscal years 1972-1976 for investigations in the fields of energy and materials shortages. In essence it is a summary program completion report.

The summary report presents an overview, broken down into four major areas of interest to the Department of Defense; Energy Availability and National Security Considerations, Alternate Sources of Energy at Military Installations, Energy Alternatives in Propulsion, and Potential Materials Shortages and Their Implications for National Security. This overview is followed and is supported by ten appendices, each addressing a separate area of investigation.

The programs summarized in this report were monitored by Mr. Rudolph A. Black, Director, DARPA Technology Assessments Office (TAO), until his departure in June 1975 and by Dr. Stanley Ruby. Dr. Francis Niedenuhr, successor Director of TAO, initiated and monitored this report effort, and his timely guidance and assistance are gratefully acknowledged.

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## DISCLAIMER

The views and conclusions contained in this report are those of the authors and should not necessarily be interpreted as representing the official policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the U.S. Government.

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION. . . . .	1
OBJECTIVES. . . . .	2
TECHNICAL APPROACH. . . . .	4
CONDUCT AND RESULTS OF RESEARCH PROGRAM . . . . .	4
Energy Availability and National Security. . . . .	6
Alternate Sources of Energy at Military Installations. . . . .	12
Energy Alternatives in Propulsion. . . . .	22
Potential Materials Shortages. . . . .	27
TECHNOLOGY UTILIZATION AND TECHNICAL INFORMATION TRANSFER . . . . .	34
Energy Availability and National Security Considerations . . . . .	34
Alternate Sources of Energy at Military Installations. . . . .	35
Energy Alternatives In Propulsion. . . . .	37
Potential Materials Shortages and Their Implications for National Security . . . . .	38
CONCLUSIONS . . . . .	39
RECOMMENDATION. . . . .	39
FUNDING SUMMARY . . . . .	40
REFERENCES. . . . .	41

APPENDIX A

ENERGY AVAILABILITY AND NATIONAL SECURITY . . . . .	A-1
---	-----

APPENDIX B

DOD ENERGY REQUIREMENTS, PLANNING AND CONSERVATION. . . . .	B-1
---	-----

APPENDIX C

DEFENSE ENERGY INFORMATION SYSTEM (DEIS). . . . .	C-1
---	-----

APPENDIX D

ENERGY APPLICATIONS AT MILITARY INSTALLATIONS . . . . .	D-1
---	-----

APPENDIX E

THE USE OF GEOTHERMAL ENERGY AT MILITARY INSTALLATIONS. . . . .	E-1
---	-----

TABLE OF CONTENTS (continued)

	<u>Page</u>
APPENDIX F	
STORAGE OF SOLAR ENERGY IN SMALL RINGS . . . . .	F-1
APPENDIX G	
SYNTHETIC PETROLEUM FOR DEPARTMENT OF DEFENSE USE . . . . .	G-1
APPENDIX H	
SUPERCONDUCTING SHIP PROPULSION . . . . .	H-1
APPENDIX I	
HYDROGEN AS A MILITARY FUEL . . . . .	I-1
APPENDIX J	
NATIONAL SECURITY IMPLICATIONS OF POTENTIAL MATERIALS' SHORTAGES IN ADVANCED TECHNOLOGIES. . . . .	J-1

A SUMMARY OF THE  
DARPA ENERGY AND MATERIALS SHORTAGES PROGRAMS  
FISCAL YEARS 1972-1976

by

James O. Frankosky, Charles Ravitsky, and Frank Milner

INTRODUCTION

As part of the DARPA mission to explore the frontiers of defense-relevant technology and to initiate actions that might be required to prevent the erosion of our national security, the Director of DARPA initiated an energy research program in the fall of 1971.<sup>1</sup>

After a brief survey of energy research in DoD and in the Services, which verified the need for a program in this area, DARPA initiated a number of contract efforts to make a more thorough study of the nature and extent of the energy problems which might affect DoD and the United States, particularly in view of the world energy situation. DARPA's basic interest was to identify potential DoD problems, and to investigate and establish possible technological approaches which might help solve these problems. As early as December 1971, an existing DARPA Order was amended<sup>2</sup> to direct the Air Force Office of Scientific Research (AFOSR) to have a contractor (Informatics, Inc.) include geothermal power as an optional subject area in the investigation of Soviet and Chinese research and development in geophysics. This study of Communist R&D was expanded in September 1972 to include energy technology (geothermal, solar, synthetic fuel systems).<sup>3</sup> DARPA initiated the program to investigate the potential for DoD use of geothermal power in April 1972, when AFOSR was directed to negotiate contracts with two universities (Southern Methodist University and the University of California at Riverside) for an exploratory investigation of geothermal power in the United States.<sup>4</sup>

Also, in order to establish a framework for a realistic technology assessment, DARPA conducted investigations of the broad U.S. policy issues, and their ramifications, as part of the research on the energy problem. Under existing contracts with the Defense Supply Service-Washington<sup>5</sup> and the Army Missile Command,<sup>6</sup> on-going research programs at two contractors were modified to include the examination of the national security impact of potential energy problems (by RAND Corp.) and of the petroleum supply and distribution (by Battelle Memorial Institute). This DARPA energy research program revealed the potential danger to the U.S. national security inherent in the substantial and increasing reliance on imported petroleum to meet the DoD fuel needs. The Director of DARPA gave a briefing to the State Department in May 1972 on the energy supply problem. This covered the foreign sources of the U.S. supply of fuels, the importance of fuel to DoD (as the largest fuel consumer in the U.S.), and the problems that would be created should there be an embargo on petroleum exports to the United States.<sup>1</sup>

In August 1972 the Office of Naval Research was directed<sup>7</sup> to have a broad, in-depth investigation conducted (by Stanford Research Institute) of DoD Energy Problems; in December 1972 the Rome Air Development Center was directed<sup>8</sup> to expand the investigation to include the energy resources and programs of the USSR and Eastern Europe (by Stanford Research Institute), and the energy resources and requirements of Japan (by Science Applications, Inc.); and, in December 1973 the latter contractor was directed to carry out an analysis of the global supply and distribution of energy for DoD.<sup>9</sup> This contractor produced a study of the energy supply and demand of Western Europe. The DARPA program thus expanded to become world-wide in scope, and appropriate organizations of the three military Services were brought into the program to help monitor it.

#### OBJECTIVES

At the inception of the DARPA energy program in 1971 the objectives were to identify and evaluate specific DoD energy problems, and their potential implications for national security. Most important was the investigation of the DoD petroleum supply problems, in relation to the current and projected world-wide production, distribution and consumption of petroleum.

Included, therefore, were studies of the energy needs of the countries of Western Europe, of the Soviet bloc, and of Japan.

DARPA also initiated studies with objectives concerning energy applications at military installations, and of alternative energy sources to decrease reliance on petroleum. These studies included the use of wastes for generating energy, and the use of geothermal energy at bases containing or close to geothermal sources. The use of solar energy was investigated with energy storage directly in the isomers of organic ring compounds which have high heats of formation, or in energy plantations where selected plants would be grown specifically for use as fuel. In looking at alternative sources, DARPA conducted studies of the possible use by DoD of synthetic crude oil derived from coal, and of the conversion processes which would best meet the DoD needs. Another alternative fuel studied was hydrogen. DARPA investigated the technical, economic and operational feasibility of utilizing hydrogen as a primary fuel for Navy use in stationary power, ship propulsion, and vehicular applications. DARPA also examined the possibility of fuel savings by using electric power for ship propulsion, through the use of a superconducting motor.

As the energy program developed it became apparent that precise data were needed on DoD supplies and consumption of energy, especially of petroleum fuels. Accordingly, DARPA added as an objective the conceptual design of a computerized energy information system to support the solution of energy related problems. In January 1973 the Army Construction Engineering Research Laboratory was directed<sup>10</sup> to initiate such a program (at the Stanford Research Institute). After the Arab oil embargo was declared, the Assistant Secretary of Defense (Installations and Logistics) instituted an emergency procedure in December 1973 under which all DoD activities were required to submit weekly reports showing the status and actual and anticipated use of selected fuels. As the Defense Supply Agency, which listed these data, had no software capability to perform statistical analyses of the data, the objective of this DARPA program was changed, to require the development of the detailed design characteristics of an Energy Information System for DoD, including the hardware, software, communications and staff organization.

The evident success of the DARPA energy program in anticipating DoD energy problems led to the initiation of a similar program to identify and evaluate potential shortages of materials critical for advanced technologies.

as they would affect DoD weapons systems design and fabrication. This DARPA program was directed at identifying methodologies and conducting assessments to improve forecasting tools, as well as knowledge of possible future demands for potentially critical materials.

#### TECHNICAL APPROACH

To meet these objectives, research was undertaken in four areas of primary interest to DoD:

- Energy availability and national security considerations.
- Alternate sources of energy at military installations.
- Energy alternatives in propulsion.
- Potential materials shortages and their implications for national security.

In managing this research effort from its inception in the fall of 1971, DARPA utilized the management philosophy which is followed in most of its research programs. The most appropriate DoD establishment was selected to act as the DARPA agent in administering each research task, and the DoD laboratory, university, non-profit organization or industrial contractor best qualified for each task was selected to carry out the necessary research. The DARPA program manager provided the overall technical direction for the research program, both through the DARPA agent and by direct coordination of the current and planned program with the contractor, and by periodic reviews of the status and accomplishments of the project.

#### CONDUCT AND RESULTS OF RESEARCH PROGRAM

DARPA initiated each task and provided technical directions to the DARPA agent involved through individual DARPA Orders, which provided the funds and described the research to be carried out. Detailed descriptions of the separate research programs and of their results are given in the ten appendices to this report. The overall purposes and the results of the research in each of the four areas of interest to DoD are given below, together with

the names of the DoD monitoring agents and of the contractors. The funding for each area is also given. The total cost to DARPA of the energy research program and of the critical materials shortages program was over \$5,000,000.

Research areas supported by DARPA. It was found that \$1,500,000 during the last fiscal year starting in 1972. The DoD contracting agencies for this program are listed below, together with the names of the contractors involved.

- Army Corps of Engineers (Research Research Institute)
- Army Missile Command (Research Research Institute)
- Defense Supply Agency - Washington (The RAND Corp.) (Research Institute)
- Office of Naval Research (Research Research Institute)
- Rome Air Development Center (Research Research Institute, Inc.) (Research Research Institute)

It will be observed that 21 DoD agencies were represented, with each agency being selected as most appropriate for the particular task. The results of each research task were immediately available for use by the agencies.

The objectives of this research program were:

- To identify problems and issues for the U.S. in general, and more particularly for DoD, arising from depletion of U.S. and world fossil fuel resources and increasing U.S. dependency on foreign sources.
  - To identify likely world (especially Allied) energy problem areas and their impact on U.S. foreign and defense policies.
  - To identify DoD energy requirements and to assist in the preparation of DoD plans and requests to ensure these requirements are met.
  - To identify technological approaches to solving DoD's energy problems, pointing the way towards an appropriate energy system.
  - To conceptualize and carry out a future energy information system (DEIS) and to update the DEIS information and establishment plans of DEIS as appropriate.
- Using the ARPA/DoD computerized information system, it is possible to

Energy Availability and National Security  
(refer to Appendices A, B and C)

This program was the largest and most important of the four research areas investigated by DARPA. It was funded at \$1,888,000 during the four fiscal years starting in FY1972. The DoD contracting agencies for this program are listed below, together with the names of the contractors involved:

Army Corps of Engineers (Stanford Research Institute)  
Army Missile Command (Battelle Memorial Institute)  
Defense Supply Service - Washington (The RAND Corp.)  
(Hudson Institute)  
Office of Naval Research (Stanford Research Institute)  
Rome Air Development Center (Science Applications, Inc.)  
(Stanford Research Institute)

It will be observed that all three Services were represented, with each agency being selected as most appropriate for the particular task. The results of each research task were thus immediately available for use by the Services.

The objectives of this research program were:

- To identify problems and issues for the U.S. in general, and more particularly for DoD, stemming from dwindling U.S. and world fossil fuel resources and increasing U.S. dependency on foreign sources.<sup>7</sup>
- To identify likely world (especially Allied) energy problem areas and their impact on U.S. foreign and defense policies.<sup>5</sup>
- To identify DoD's energy requirements and to assist in the preparation of DoD plan and measures to ensure those requirements are met.<sup>5,6</sup>
- To identify technological approaches to solving DoD's energy problems, pursuing the more promising to an appropriate extent.<sup>11</sup>
- To conceptualize and design a Defense Energy Information System (DEIS) and to undertake the data collection and establishment phases of DEIS as separate efforts, using the ARPANET computerized information network, if possible.<sup>12</sup>

The portion of the DARPA Energy Program discussed here deals with national security policy implications and energy availability and demand projections. Therefore, the usual DARPA emphasis on advanced technologies is missing, and no advances in the state-of-the-art were attempted in the performance of these studies. On the other hand, DARPA personnel and others involved gained improved knowledge and understanding in making these projections, particularly as they relate to DoD needs. At the time that these projections were performed (in most cases prior to the general awareness of an impending energy shortage), the making of energy supply and demand projections was much less well developed and these studies were considered to have been instrumental in bringing about improved understanding of the field.

The studies can be grouped as follows:

Program Planning Studies. These studies were performed in 1973<sup>13,14,15</sup> in order to help structure the overall DoD and DARPA energy programs: as a National Defense Planner, and as an Energy Consumer. Research programs were recommended to deal with: (1) energy management, (2) energy supply, demand and price, (3) energy conservation and environmental impact, (4) vulnerability of energy systems, (5) energy transportation and (6) material requirements.

Energy Availability Studies. These studies resulted in five reports.<sup>16,17,18,19,20</sup> One concluded that DoD cannot be assured that other Federal agency or private sector solutions will necessarily be timely or effective for satisfying DoD's energy requirements, and makes the following recommendations: (1) develop domestic sources of substitute liquid petroleum from oil shale and from coal, (2) improve the efficiency of piston and turbine engines, and (3) develop strategies for military use of hydrogen as an alternate fuel.<sup>16</sup>

The study on Energy and Security<sup>17</sup> presents a prespective on how energy needs impinge on U.S. national security now and for the next two decades and discusses major issues in detail. These deal with energy supply, security and independence, criteria for choosing options, supply interruptions, alternative energy sources, differing import needs of the U.S. and its allies, heightened security in energy, and the effect on U.S.-Soviet relations. The study principally recommends further research in the areas of: nuclear materials safeguards, U.S.-Soviet energy transactions, feasibility of energy self-sufficiency, economic tradeoffs between importing oil and the costs of developing U.S. resources, programmatic energy conservation, and R&D priorities for energy alternatives.

The study of the Energy Demand and Resources of Japan<sup>18</sup> identified oil as the major energy source for Japan through 2000, although a decreasing proportion of the supply after 1985. Demand for coal, LNG and electricity will continue to grow; after 1985 almost all new electrical generating capacity will be nuclear. The great dependence of Japan on oil imports, and resultant geopolitical implications were examined. Opportunities for technology transfer to Japan (in order to help her reduce reliance on oil include: (1) coal gasification, (2) high temperature gas reactors for direct process use of nuclear energy, (3) geothermal energy systems and (4) fusion power production.

The Analysis of the Energy Resources and Demands of Western Europe<sup>19</sup> examined energy demand through 1985. Attention was devoted to the impact on demand of the rapid rise in the cost of oil, and the prospects for development of alternative (indigenous) sources of supply. The study concluded that a marked decline in consumption will be felt through 1980 as a result of the price increases triggered by the 1973 oil embargo. Western Europe will continue to depend heavily on OPEC oil, but a potential exists for increasing imports of oil from the Eastern Bloc as an alternative. Technology transfer from the U.S. offers little short term potential for improving the energy picture in Western Europe.

The Analysis of Energy Resources and Programs of the Soviet Union and Eastern Europe<sup>20</sup> dealt with energy resources and their development with projections to 1990. The study concluded that the energy resource base of the USSR is sufficient to continue exports to Eastern Europe, and with development, the very large Siberian fuel resources could also contribute petroleum and natural gas exports to the rest of the world. The West could supply technologies in return for gas and petroleum in a barter arrangement with the USSR. The USSR and Eastern European countries will continue to import small amounts of oil and gas from OPEC.

National Security Policy Studies. Studies in this category deal with alternate scenarios related to energy denial on a global and regional basis,<sup>21</sup> with U.S. and allied responses to denials,<sup>23,24,25</sup> historic reviews of past energy crises,<sup>22</sup> petromoney, and economic security and threats to it posed by energy scarcity.<sup>26</sup> Some of the energy availability studies<sup>18,19</sup> also address geopolitical aspects of the energy issue.

The role of advanced research in addressing energy problems is becoming increasingly important for DoD and, indeed, for the nation at large. Specific aspects of the energy problem were selected for examination in these DARPA studies, with the following among the conclusions:

- a. "Low-energy" materials such as glass and plastic should be substituted for "high-energy" materials such as steel and copper wherever possible.<sup>27</sup>
- b. Energy transformation, distribution and storage capabilities could be enhanced by development of stronger materials with improved mechanical and chemical properties, and by improved fabrication techniques.<sup>27</sup>
- c. New research is needed regarding geothermal resources, oil shale recovery, materials properties, energy relationships to materials production, chemical fuels, integrated LNG usage, and waste heat from energy production processes.<sup>27</sup>

Further, the studies:

- d. Arrived at only tentative conclusions regarding the amount of energy consumed in support of DoD expenditures in the six leading DoD contracting states.<sup>29</sup>
- e. Developed methodology for estimating the amount of energy required by industries in filling DoD's needs for goods and services. (The methodology developed is based on the Input/Output technique and inherits the shortcomings of that technique.)<sup>28,30,31,32</sup>
- f. Designed a computer model which can be used to project future energy needs of the U.S. Air Force.<sup>33,34</sup>
- g. Concluded that re-engining of U.S. Air Force aircraft is technically feasible and would significantly and favorably influence fuel consumption.<sup>35</sup>
- h. Concluded that colloidal mixtures of coal in oil offer sufficient potential for cost reduction and energy conservation that their use should be explored further by DoD, particularly for marine propulsion and land-based military installations.<sup>38</sup>
- i. Concluded that the Brayton-cycle gas-turbine engine has the greatest potential for fulfilling future propulsion requirements.<sup>37</sup>
- j. Identified, reviewed and assessed approximately 1000 energy-related R&D programs of which about 50 percent appeared to have some energy conservation connotations. Observations rather than conclusions were made since

additional research, analysis and discussion would be needed prior to drawing firm conclusions.<sup>40</sup> For example, it was observed that:

- (1) DoD and all three services are continuing to advance turbine engine technology in significant on-going and proposed programs but that specific energy conservation objectives need to be added.<sup>40</sup> DoD should aggressively pursue work related to engines for light-duty military applications with good fuel economy using lower grade or multifuels, and to diesel and stratified charge engines.
- (2) It appears that DoD should await further technology advancements in the more general research areas of hybrid and compound engines, solar energy, total energy conversion, MHD energy conversion, building design/construction, geothermal energy, power train components, but that certain specific military aspects and applications appear appropriate and should be pursued.<sup>40</sup>

The scope of the effort required to develop and implement an effective Defense Energy Information System (DEIS) became larger and grew more complex as the study progressed. It was evident that the potential needs of the various users required a total systems approach. However, final design of a system was not achievable because of constraints on budget and time.

Even the organizational levels that the DEIS would serve and the way in which it would interface and interact with non-DOD energy data bases had not been decided by the time scheduled for DARPA input to the Defense Energy Task Group's (DETG) report. Furthermore, the international and domestic situation, and its impact on DoD, kept changing during the conduct of this effort.

A portion of the preliminary study for a DEIS was included with the DETG recommendations.<sup>41,42</sup> The preliminary study included recommendations that:

- DEIS should immediately be implemented with available information and procedures.
- DEIS should have a standardized reporting format for all Services.
- Additional personnel and computer capability should be made available.
- A master plan should be prepared for the evolutionary development of the full system capability.

The final study report<sup>43</sup> includes a short summary of the progress achieved, and sections on System Planning and Development, the Pilot Defense Energy Information Services (PDEIS), and the Initial Module Design and Implementation Plans. Also included is a summary outlook for system modular development beyond the initial module.

Techniques and procedures recommended were state-of-the-art, such as on-line computer access to DEIS data and information. Detailed analyses were performed to determine where and what information was currently available and how it could be coordinated. Recommendations were to utilize existing hardware and software including the ARPANET computer network, MULTICS computer system at MIT, and the software package in place in MULTICS (consistent system and JANUS). As a part of the study, a prototype version of the initial DEIS module called PDEIS was implemented and two Energy Problem Analysis Centers were established, (EPAC's)--one in Menlo Park, California, and one in Washington, D.C., to assist in maintaining liaison with potential users of DEIS.

Alternate Sources of Energy at Military Installations

(Refer to Appendices D, E and F)

A fundamental part of the DARPA energy studies was concerned with energy needs at military installations, representing about 40% of total DoD energy demand.<sup>42</sup> As in the case of civilian energy utilization, there has been a definite trend toward increased energy use by bases and facilities of the military. A related aspect of concern was the fact that nearly all U.S. military installations met their energy need through procurement from off-site commercial supplies.

The combined cost of this program was \$1,580,000 between FY1972 and FY1976. The work was contracted through and monitored for DARPA in individual tasks by a number of DoD agencies, and some of the tasks were carried out in-house at the Army Engineer Power Group, the Naval Civil Engineering Laboratory, and the Naval Weapons Center. The contracting agencies and the contractors were:

Air Force Office of Scientific Research (Informatics, Inc.)  
 (Southern Methodist University)  
 (University of California at Riverside)

Army Construction Engineering Research Laboratory  
 (Stanford Research Institute)

Army Corps of Engineers (Inter Technology Corporation)  
 (R&D Associates)

Army Missile Command (Battelle Memorial Institute)

Defense Supply Service-Washington (Informatics, Inc.)  
 (RAND Corporation)

Naval Civil Engineering Laboratory  
 (Booz, Allen and Hamilton, Inc.)

Naval Intelligence Support Center (Informatics, Inc.)

Naval Weapons Center (University of Texas)

Office of Naval Petroleum and Oil Shale Reserves  
 (Tetra Tech, Inc.)

Office of Naval Research (Boston University)

The objectives within the four areas of technology studied were:

a. Total Energy Concepts and Systems

- (1) To analyze the total energy concept, in terms of technologies ranging from those currently available to such advanced technologies as geothermal, solar, and nuclear energy conversion, for supplying the energy requirements of fixed military installations.<sup>10</sup>
- (2) To identify and systematically evaluate methods for managing the energy flow network on military bases and installations, to include identification of R&D and other measures for more effective and efficient energy use.<sup>44</sup>
- (3) Experimental System. To design, build and test an experimental total energy system, at Ft. Belvoir, Virginia consisting of electrical heating, air conditioning, domestic hot water, sewage treatment, water purification, and solid waste incineration.<sup>45</sup>

b. Waste-to-energy Conversion Technologies

- (1) Workshop. To conduct a workshop for the purpose of identifying those techniques within the waste-to-energy conversion technology which have significant potential for DoD utilization and the key issues associated with implementing those techniques at such bases.<sup>11</sup>
- (2) Pyrolysis-Synthesis Process. To develop a small, very rapid pyrolysis process that produces sulfur-free synthesis gas suitable for selective catalytic reaction to a desired energy product. Determine and evaluate candidate fuels and their attendant processes for conversion of solid waste to a higher-grade fuel.<sup>46</sup>
- (3) Fission-Waste Source. To study the feasibility and develop a conceptual design of a plant to meet baseload requirements through generating hot water or steam from the heat energy in a modular fission-waste source.<sup>45</sup>

c. Solar Energy

- (1) Technology Assessment. To provide a comprehensive review of present major developments and future planning in various fields of applied solar engineering.<sup>3</sup>

- (2) Remote U.S. Bases' Alternatives. To examine some of the energy resource and technology alternatives for remote U.S. bases to include solar radiation, wind, and ocean waves as potential substitutes for petroleum fuel.<sup>5</sup>
- (3) Energy Plantation Concept. To assess the feasibility of supplying solid and gaseous fuels at Army bases, for other than mobile equipment purposes, by generating the required fuels from energy plantations, the growth of vegetable matter purposely for its fuel value.<sup>45</sup>
- (4) Energy Storage Research. To investigate the possibilities for solar energy storage in organic ring compounds through the tautomerization of isomers with high heats of formation.<sup>47</sup>

d. Geothermal Energy

The overall objective was to determine the feasibility of developing hot-water geothermal systems for military installations as a potential energy source, and to identify key problem areas. Areas of primary interest were:

- (1) Review of Soviet and Chinese research in and utilization of geothermal energy.<sup>2,3,48,49</sup>
- (2) Assessment of hot-water geothermal resources.<sup>50</sup>
- (3) Assessment of the potential for utilization of energy from the Coso Springs Area geothermal sources at and for the China Lake Naval Weapons Center.<sup>6,46,51</sup>
- (4) Investigation of overpressured reservoirs.<sup>50</sup>
- (5) Investigation of ultra-deep drilling for geothermal sources.<sup>52</sup>
- (6) Studies of problems of corrosion connected with use of geothermal energy sources.<sup>46</sup>

Much of the early DARPA work focused on identifying feasible technical approaches for energy applications at military installations. The later work then addressed selected approaches in order to identify the state-of-the-art and their economic soundness in competing with fossil fuels as potential energy sources.

a. Total Energy Concepts and Systems

The results are embraced in four separate reports, the first on concepts for total energy systems, the remaining three covering the strategies for conserving energy and the identification of total system development approaches.

- (1) Concepts. The two most promising total energy systems include solar energy used for heating and cooling, and nuclear power. Utilization of solid wastes for heating should also be developed.<sup>53</sup> The study recommends that a program be undertaken for application of solar energy of heating and cooling on military installations. A development program for nuclear power plants for use on military installations is also recommended. A system requirements study is needed to provide a basis for such a development program.
- (2) Systems. The two Naval bases selected for an in-depth survey of energy consumption patterns were the Great Lakes Naval Training Center (people-oriented training facility) and Pensacola Naval Air Rework Facility (industrial-oriented facility). Near-term strategies would result in energy savings of approximately 11 percent of CONUS use at Navy facilities, would pay for themselves within 5 years on the average, and would not require R&D expenditures.<sup>54</sup> Advanced strategies would result in significant energy savings on CONUS Navy bases prior to 1990. However, the breakeven point for some of the strategies would likely occur after 1990 since large R&D investments would be required.<sup>55</sup>
- (3) Assessment of Applications (Total Energy [TE] Systems).<sup>56</sup> The principal finding is that there has been little research devoted specifically to the optimization of total energy system efficiency in the past. Except for the Sundstrand TE System, advanced research relevant to TE is limited to components improved for other market applications. A number of key findings are detailed. The principal recommendation is that a concerted research program be initiated to advance the overall technology of total energy systems. Specific recommendations are made for the support of research which holds promise of very significantly expanding the range of total energy feasibility in the near future.
- (4) Experimental System. When the Department of Housing and Urban Development withdrew its support

for technical reasons in May 1975, the project was terminated after completion of the design phase.<sup>57,58</sup>

b. Waste-to-energy Conversion Technologies

The results are covered in three separate reports, one for each subject area.

- (1) Workshop. In a review of current and advanced waste-to-energy technology, 33 representatives of government and industry met in an ARPA-sponsored workshop<sup>59</sup> to consider whether or not a cost effective operation could be realized in waste-to-energy processing of only 20 to 80 tons per day of solid waste.

Of the various technologies, the one with the most likelihood of cost effective operation in the use of fuel made from refuse is to burn it in an existing boiler to generate process steam.

DoD should continue to monitor progress in more advanced technologies such as pyrolysis and fluidized bed for possible future applications.

Laboratories of the three Services have an increasing knowledge and data base to evaluate individual military installations for possible applications of waste-to-energy technology.

- (2) Pyrolysis-Synthesis Process. As part of the Naval Weapons Center's Total Energy Community (TEC) Program, the solid waste conversion effort involved exploring processes for recovering energy as liquid fuels from solid waste which would be practical and economical on military bases.<sup>60</sup> Preliminary process flow sheets indicated that an energy conversion efficiency of 66% for polymer gasoline and 58% for methanol could be achieved.

Preliminary cost analyses and effects of population and energy market value on fuel costs were studied, and a nominal 10-pound-per-hour pyrolysis system was constructed and put into operation using a shredded-paper feed.

- (3) Fission-Waste Source. Utilizing the decay energy of solidified, mixed fission-products a study<sup>61</sup> was made of the feasibility of developing a conceptual design of plants which would produce 5 MW or 350°F, 120 psi steam at military installations.

A first 5-MW thermal output steam plant could become operational on the solidifiable wastes from the discharge of the U.S. civilian nuclear power industry by about 1980. By the year 2000, ~40 5-MW plants could operate on the wastes from U.S. nuclear power reactors.

A 5-MW steam plant appears competitive with equal-output burners of 33 cents per gallon fuel-oil, if RSSF-type receipts (for high-level waste storage services) are realized. 60 million gallons of fuel oil per year could be saved in the U.S. by the year 2000.

c. Solar Energy

The results are covered in four separate reports. The first assessed the solar energy research and exploitation to identify potential avenues for research. The second addressed energy resource and technology alternatives for remote bases. The remaining two addressed the technical feasibility of two advanced research approaches in solar energy--one to grow vegetable matter for its fuel value, and the other basic research into storing solar energy in organic ring compounds.

- (1) Technology Assessment.<sup>62</sup> In areas where a grid exists to connect power stations in industrial and urban centers to guarantee continuity of supply, solar energy may be unimportant unless it can provide energy at competitive rates. In areas where isolated power stations meet at least part of the most urgent power requirements, solar energy might well be a useful supplementary source in view of otherwise high fuel and generating costs. In a third type area where electricity is totally, or almost totally, lacking, which is the most typical in underdeveloped countries, solar energy may well be the only source for power supply.

Though interest is accelerating, solar energy is a "new" power source and contributes only an insignificant share of the total world energy production. With the exception of solar water heating and for high temperature research furnaces, applications are still in the R&D stage. With present state-of-the-art, a solar plant would cost about three times more than conventional systems.

- (2) Remote U.S. Bases' Alternatives. The study uses a power system model to evaluate the relative effectiveness of the three indigenous energy sources in satisfying remote base power requirements in five geographic locations. The model

solves for energy collector size, storage requirements, and conventional power inputs.<sup>63</sup>

A conclusion of the study is that there are sufficient indigenous energy sources at many remote bases to be of practical value. The drawback of total indigenous energy systems is the high initial cost, due in part to the large storage system required. The mixed use of a conventional fuel system with an indigenous energy system would markedly reduce initial cost. For example, a combined solar system and conventional system appears to represent a good mix for Diego Garcia, whereas a combined wind and conventional system is better for Adak. However, for all ranges of parameters examined, the initial cost of the combined conventional and indigenous energy system exceeds the cost of a conventional system by at least a factor of three.

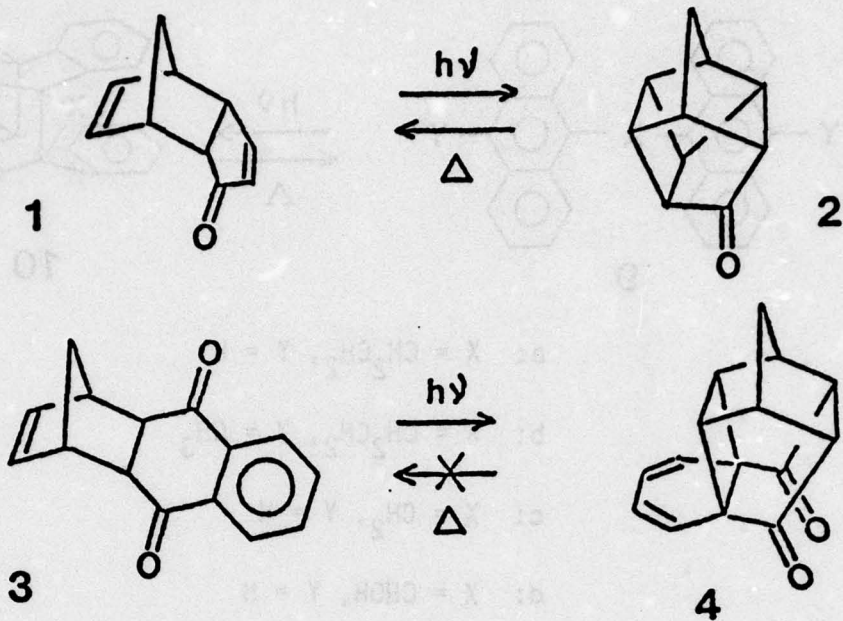
- (3) Energy Plantation Concept. A thorough investigation of the possibility of "home-grown" perpetually renewable fuel generated on U.S. Army bases from plant material, especially at Forts Benning and Leonard Wood, has been made.<sup>64</sup>

Energy Plantations are feasible for meeting the fuel needs for fixed facilities in at least fifteen large army bases in the eastern and central time zones. The cost of solid fuel produced would be about one dollar per million Btu, and the cost of SNG would be between about \$3.10 and \$4.20 per thousand standard cubic feet.

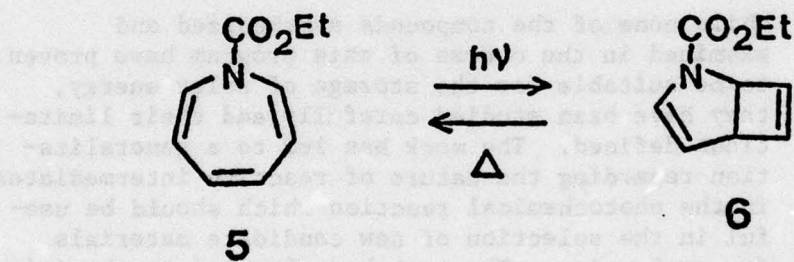
Plant species which are most suitable for "Btu Bushes" at the army bases have been identified. Immediate steps to study the remaining open questions and to commence Energy Plantation system design should be taken.

- (4) Energy Storage Research. Four classes of valence isomerization systems were examined in the course of the program. The structures of the compounds involved are presented in one study along with a brief assessment of the status of each system.<sup>65</sup>

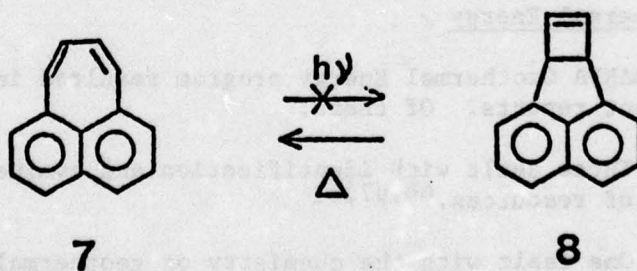
o Dicyclopentadiene Derivatives

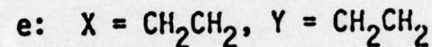
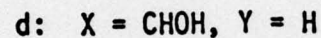
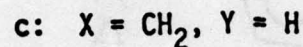
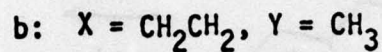
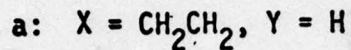
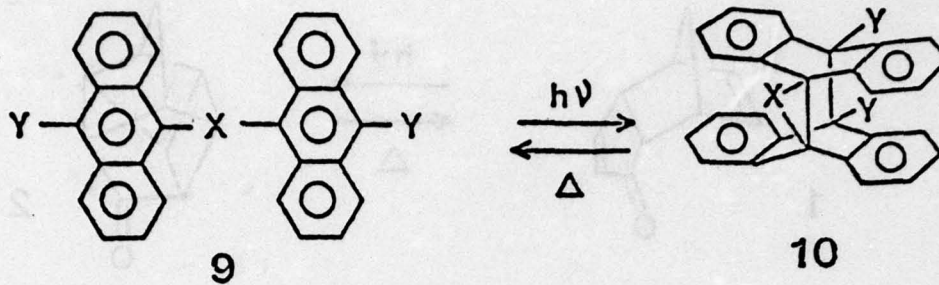


o N-Ethoxycarbonyl-1H-azepine



o Pleaidiene



o Linked dianthracene derivatives

While none of the compounds synthesized and examined in the course of this program have proven to be suitable for the storage of solar energy, they have been studied carefully and their limitations defined. The work has led to a generalization regarding the nature of reactive intermediates in the photochemical reaction which should be useful in the selection of new candidate materials for evaluation. The work has also led to the initial development of a promising new technique--photocalorimetry--which could provide direct measurements of the energy storage capacity of any solution-phase photoisomerization system during irradiation.

d. Geothermal Energy

The DARPA Geothermal Energy program resulted in six project reports. Of these:

- (1) Three dealt with identification and evaluation of resources.<sup>66,67,68</sup>
- (2) One dealt with the chemistry of geothermal fluids, in particular with corrosion and scaling.<sup>69</sup>

- (3) One covered the critical problem of drilling for geothermal resources.<sup>70</sup>
- (4) One presented a review of the current state-of-the-art.<sup>71</sup>

An energy model developed by Stanford Research Institute for DARPA provided the means for evaluating the technical and economic feasibility of all energy sources to supply the energy needs of military installations. The model was used to study potential geothermal energy systems, and indicated that the costs of installing and operating a geothermal energy system appear to be competitive with fossil fuel systems. Further study shows that at thirty-six military installations in CONUS and ten U.S. sites outside of CONUS geothermal sources exist either on or near those installations.<sup>66</sup>

As a result of these studies, two target areas have been identified as prime candidates for development of geothermal energy at military installations; the Coso Hot Springs, on the Naval Weapons Center at China Lake, California, and the Marine Corps base at Twenty-nine Palms, California. In addition, two test sites are proposed in southern Texas for research and development of geopressed systems.<sup>66,67</sup>

Energy Alternatives in Propulsion  
(refer to Appendices G, H and I)

DARPA conducted three separate studies on alternatives to the use of liquid fuels derived from petroleum, for ship and vehicular propulsion. The largest of these studies was of the possible use of hydrogen as a primary fuel for Navy use, and included its technical, economic and operational feasibility. DARPA sponsored a second study to provide guidance to DoD for action that might be taken to encourage production of synthetic crude oil from coal. The third study was an evaluation of a superconducting electric power transmission for ship propulsion. The combined cost of these three programs was \$1,003,000, during FY1974 and FY1975. The contracting agencies are listed below, together with the names of the contractors involved:

Air Force Office of Scientific Research  
(University of Denver)

Mobility Equipment Research and Development Command  
(Brookhaven National Laboratory)

National Science Foundation (University of Miami)

Naval Ship Research and Development Center  
(General Electric-TEMPO)  
(Stevens Institute of Technology)

Office of Naval Research (Bradford Computer and Systems, Inc.)

Rome Air Development Center (Stanford Research Institute)

Again, all three Services were represented.

The objective of the synthetic petroleum program was:

- To provide guidance to DoD for action that might be taken to encourage production of syncrude from coal so that the civilian economy might be relieved of some or all of the military's liquid fuel demands and that an assured supply of these fuels, critical to national security, would be available.<sup>72</sup>

The objective of the superconducting ship propulsion program was:

- Evaluation of electric power transmission for ship propulsion, specifically for DD-963 class vessels.<sup>73</sup>

The objectives of the program on the use of hydrogen as a military fuel were:

- Examination of the feasible methods of producing hydrogen in quantity, to focus on the efficiency of the production processes.<sup>74</sup>
- Investigation of chemical forms for storing and transferring hydrogen.<sup>74</sup>
- Evaluation of performance of the major naval energy conversion prime movers using gaseous hydrogen as the fuel; with performance, size, weight, efficiency, and costs to be enumerated.<sup>74</sup>
- Determination of how well hydrogen can serve as a fuel for surface, submarine, and airborne equipment when operated in "typical" naval missions.<sup>74</sup>
- Evaluation of preliminary gas turbine combustor performance when operated on gaseous hydrogen.<sup>74</sup>
- Development of techniques for evaluating hydrogen containment materials and their embrittlement behavior.<sup>74</sup>
- Investigation of ternary alloys as hydrogen storage hydrides, including development of exploratory data relating to pressure-temperature-alloy composition.<sup>75</sup>
- Investigation of the potential, and test of the feasibility of employing unstable metallic hydrides to store hydrogen, to include binary as well as ternary systems.<sup>76</sup>

The use of synthetic petroleum by DoD investigations began with an analysis of DoD consumption of petroleum derived fuel. More than half the demand is for JP-4, which cannot exceed 25 volume percent of aromatic constituents. Most coal derived liquid fuels are very high in aromatic content and are more suitable for motor fuel than for JP-4. The suggestion in the DARPA work statement that a syncrude might best be refined together with natural petroleum which is low in aromatic content was thus quite appropriate.

Various of the coal conversion processes were briefly reviewed and the H-coal process was selected for detailed study, as the syncrude it produces is suitable for refinery processing and little or no char or heavy ends are formed. The H-coal conversion process utilizes catalytic hydrogenation of coal, typically done on a coal in oil slurry, producing a desulfurized liquid product mix which can be varied in composition depending upon operating conditions. The study:<sup>77</sup>

- Alerts the Services to the need for constant review of their fuel requirements and the mix of fuel products needed since coal conversion process selection will be influenced by these factors.
- Cautions against expectation that supplementing DoD fuel requirements by use of coal derivatives can be achieved on a short term basis.
- Indicates the need for constant awareness on the part of DoD of the emerging developments in syncrude production technology.

There is much to be done before any single process can be chosen with confidence as preferable to the others. While H-coal can provide a product more directly applicable (i.e. without subsequent treatment) to conventional refineries, it cannot yet be called a proven process.

The superconducting ship propulsion program<sup>78</sup> evaluated electric power transmission for ship propulsion, specifically for DD-963 class vessels. Baseline for the study was the typical gas turbine, gear, shafting, and controllable reversible propeller (CRP). Primary technical interest was comparison of the superconducting electric transmission with various mechanical transmission arrangements. Using test results supplied by NSRDC, the study confirmed that the electric transmission would provide not only greater fuel efficiency but would also provide for a lighter weight, quieter, more maneuverable propulsion system. The study concluded that the electric drive system makes possible a 25 percent improvement in fuel economy over a standard mission profile, and a 19 percent extension of endurance range because of higher system efficiency and reduction in the overall propulsion system weight. In addition, the electric drive system provides for more efficient space utilization.

The possible use of hydrogen as an alternate, non-petroleum-derived, fuel for naval applications was another DARPA-directed investigation. The program included assessment of the state-of-the-art of hydrogen production processes, storage, transmission or transport, and conversion. It also covered analyses of operational performance, and capital and operational costs, of hydrogen-fueled vessels in typical Navy missions, and examined ship configuration revisions required for use of cryogenic hydrogen.

- Overall, the program indicates that until the cost or availability of hydrocarbon fuels changes to a markedly

adverse extent, there appears to be little impetus for further serious consideration of hydrogen as a naval fuel. If, however, hydrocarbons from whatever source become undesirable for whatever valid reasons, the options for ship powering become nuclear or chemical, and liquid hydrogen becomes the chemical fuel of choice.

- Results indicate that it is technically feasible to operate naval fleet missions using cryogenic hydrogen as a fuel, provided by a conjectured nuclear-powered liquid hydrogen factory ship manufacturing hydrogen by electrolysis of purified sea water, and utilized by ships and aircraft reconfigured for and equipped to handle cryogenic hydrogen.<sup>79,80,81</sup>
- Overall, ships and boats could approach or exceed representative mission performances using cryogenic hydrogen fuel as compared with petroleum fuel, while aircraft operating on liquid hydrogen would suffer about 10 percent range reduction.<sup>79</sup>
- The use of a single fuel for aircraft and ships of all types would negate the need for various marine fuels, and would provide a very considerable logistical advantage.<sup>79</sup>
- There would be adverse problems associated with use of hydrogen as a naval fuel, and while the information provided by this program is not sufficient for basing firm plans, it does indicate support for demonstration of performance of hydrogen fueled boats and, eventually, ships and aircraft.
- Metallic-hydride storage of hydrogen is in the early stages of investigation. To date, hydrides comparable with liquid hydrogen in energy storage suffer great weight penalties (up to 50 times heavier), although offering anticipated lower operating costs. The weight problem has provided the impetus for current searches for more effective hydride compositions.<sup>83,84,85</sup>
- Compression-ignition hydrogen-fueled engines offer small promise, except possibly as dual-fuel engines employing pilot charges of hydrocarbon fuel. Conventional spark-ignition engines could operate satisfactorily at low output power levels by means of lean-burning and power-control through mixture-ratio variations.<sup>86</sup>
- In general, hydrogen should offer no fundamental problems when used as a fuel for gas turbines, but would require solution to a number of practical problems, none of fundamental nature (except safety), but all requiring significant engineering development.

- For investigation of the effects of possible hydrogen embrittlement of materials a technique for evaluation was proposed and experimentally validated--the modified wedge-opening-loading (WOL) fracture specimen.<sup>88</sup>

and liquid hydrogen...  
 results indicate that it is...  
 representative...  
 The use of a...  
 There would be...  
 Metallic-hydrogen...  
 Compression...  
 In general, hydrogen...



- To assess DoD's dependence on catalytic processes and materials, now and in the future; and to formulate a research program responsive to DoD needs. (By R&I Associates)<sup>94</sup>

In order to provide a perspective for identifying possible future shortages of critical materials, the early DARPA work focused on identifying national security policy implications and research programs to address, from the DoD perspective, the consequent issues and problems. In this process four basic issues were identified which established a basis for DARPA research addressing potential materials' shortages in advanced technologies:<sup>89</sup>

- Determination of military resource independence. In order to understand the impact on DoD of the changing U.S. raw materials position on the world scene, there is a need to identify and project DoD demand for materials viv-a-vis an overall data base which accurately describes current world and U.S. demand and supply plus development of a basis for making future projections.
- Impact of new technological and economic factors. The DoD interest in its resource dependence should also consider possible effects of technology change to include identification of alternatives to alleviate shortages.
- Weapon system/force structure implications. Resource availability will affect the nature of research towards new systems as substitutes are sought for scarce and expensive materials. These considerations, in turn, could impact on force structure determinations.
- Soviet analogue. An important consideration in determining the effects on national security of the declining U.S. self-sufficiency in raw materials is the Soviet resource position vis-a-vis that of the U.S. A study in this regard could be useful.

Addressing all of these issues fully would, of course, be somewhat beyond the DARPA charter. However, as can be seen by the remaining results these issues had a bearing on the formulation and the conduct of the DARPA programs in the materials' shortages area.

- a. Key Dependencies of the DoD for Products Potentially Critical in the Event of Material Shortages<sup>95</sup>

The principal scientific report in this effort embraced a material consumption and flow analysis of 17 critical materials to estimate the amount of each consumed by

U.S. industry to supply DoD final demand, and to describe their direct and indirect flow through industry. The results are shown in Table 1.<sup>96</sup>

Table 1 indicates, for example, that indirect consumption is a major factor in total aluminum requirements, also in tungsten and energy sources. On the other hand, direct consumption is a major factor in requirements for lead, titanium metal and zinc castings. It is also notable that DoD is a major consumer of titanium metal.

The second part of the study investigated economic impacts of shortages of material and energy resources. The consequent major recommendations and conclusions were:

- (1) Among the resource shortages analyzed, the economic impacts of energy shortages are particularly adverse. The availability of these resources deserves continuing priority attention by DoD.
- (2) Among the material resources studied, chromium, aluminum, and tin are commodities for which a stockpile for economic purposes may be desirable. Platinum is also a candidate for an economic stockpile or alternative measures to assure supply. Additional analysis of measures to protect against adverse impacts of shortages of these materials is recommended.
- (3) A framework has been established to guide DoD advance planning for shortages. One example of the results of applying this framework is that DoD is likely to experience supply problems for ammunition products during an aluminum shortage. Indicators of other potential DoD supply problems can be derived for 17 material and energy resources from information presented in the report and the appendix to the report.

Additional extensions of the resource shortage model are recommended to explicitly treat substitution and price effects that occur during shortages.

b. Potential Criticality of Materials in New Technologies for Advanced Weapon Systems

- (1) The results are embraced in three reports. One, concerning future requirements for materials used in military optical devices, concluded that germanium may be in short supply in the near or immediate future. Substitute materials sacrifice

TABLE 1. CONSUMPTION PERCENTAGES FOR 17 MATERIALS (1972)

Material	Percentage of Consumption that is Direct*		DoD Consumption as a Percentage of U.S. Total
	U.S.	DoD	
Aluminum	37%	53%	6%
Chromium	31	42	5
Coal	35	18	3**
Cobalt	12	11	5
Copper	42	46	5
Lead	48	64	8
Natural gas	39	32	3**
Nickel	43	57	8
Petroleum	37	45	4**
Platinum	31	36	4
Silver	42	31	3
Tin	4	4	4
Titanium metal	67	72	41
Titanium pigment	15	8	3
Tungsten	34	34	9
Zinc castings	68	69	4
Zinc galvanizing	22	8	4

\*Direct consumption is that which goes from raw material to final demand products without any intermediate consumption of the product.

\*\*The energy resources have significant sales directly to final demand which are not included in these figures. Thus, while only 4 percent of petroleum is consumed by industry for DoD, approximately 5 percent of total U.S. petroleum is consumed by DoD.

something in optical, mechanical, or thermal properties.<sup>97</sup>

- (2) A second study, summarizing initial findings for a DoD workshop in January 1974, stated that consideration should be given to expanding the domestic supply of germanium.<sup>98</sup>
- (3) A third study summarized that:<sup>99</sup>
  - A case study of high temperature gas turbine engines circa 1990 indicates that chromium is potentially an increasingly significant risk. Action should be taken to maintain chromium stockpile objectives based on revised system production requirements as necessary.
  - Ceramic technology as a substitute for chromium in high temperature gas turbines has the lowest risk of present candidates.
  - Three other materials are potentially critical--cobalt, columbium, and tungsten in applications such as superconducting systems and lightweight structures.

c. Critical Materials Needs in U.S. Emerging Technologies in the Civil Sector

The results are covered in a single report.<sup>100</sup> The initial phase of the research was a screening study which identified some 57 emerging technologies in 15 U.S. industries as possible candidates for further study. Six of these technologies were selected for in-depth analysis to identify possible future criticalities in material availabilities or production capacities.

- (1) Of the six technologies studied in depth, two face potential problems in available raw materials--
  - Platinum for fuel cells.
  - Helium, niobium, copper, nickel and chromium for superconductors.
- (2) Five face potential production capacity shortages--
  - Electroslog remelted (ESR) steels.
  - Graphite and boron fibers for fiber-reinforced composites.
  - Fiber optics for lasers.

- Silicon nitride for high temperature gas turbine engines.
- Superconducting alloy wire.

(3) This report provides a methodology for periodic review of key emerging U.S. technologies.

d. Materials Requirements for Advanced Energy Systems--  
New Fuels

This study sought to identify materials-critical aspects of the use, production, transportation, and storage of new fuels derived from nonfossil sources. Hydrogen was the principal new fuel studied; hydrogen-derived fuels considered were ammonia, hydrazine, boranes, silanes, carbon monoxide, and methyl alcohol. The materials implications of the use, transportation, and storage of oxygen (produced as a by-product in hydrogen generation) and of the use of active metals in batteries were also examined during the study. The principal study results were:<sup>101</sup>

- (1) Of the four program areas--use, production, transportation, and storage--the materials requirements related to hydrogen production were considered the most important. It was considered that the electrolysis of water was the most likely route by which hydrogen could be produced in the quantities required. However, the efficiency of electrolyzer systems is highly dependent on advances in electrocatalyst materials, materials for electrode structures and electrolyte matrices, and electrolyte materials.
- (2) The use of hydrogen as a fuel in a wide variety of equipment did not appear to pose any insurmountable obstacles, although extensive materials research, development, and testing programs would be required to ensure maximum safety, reliability, and efficiency in hydrogen-using equipment. It is in the area of use that materials projects of highest relevance to DoD were found.

e. DoD's Dependence on Catalytic Processes

In the course of the workshop deliberations, held over a two-day period in Santa Monica, California, it was determined that DoD was already supporting catalyst research on a small scale but that such research was limited because the material science of catalysis was not sufficiently developed to facilitate the production of alternate fuels, nor supplementary fuels, nor easy

interconversion of fuels. It was determined, however, that industry could probably invent the catalytic technology necessary to produce new fuels for military use, if given sufficient incentive. The principal conclusions and recommendations were:<sup>102</sup>

- (1) The security-of-supply problem for energy and for catalysis is a national more than a DoD problem. Present industrial trends in fuel and petrochemical production imply increased reliance on catalyzed processes. The DoD should be aware that these trends may result in a dangerous dependence on foreign suppliers of catalysts and may require increasing national stockpiles of catalytic materials such as platinum.
- (2) Sponsoring basic catalysis research in areas not covered by industry is a desirable task for the DoD. Research in heterogeneous catalysis is likely to produce knowledge that can also be applied to fuel cells, photography, corrosion, lubrication, adhesion and membranes--all of which have important military applications.

In a later report,<sup>103</sup>

- (3) Experimental research programs directed toward reaching a basic understanding of catalysis of importance to DoD are required since industry is principally motivated to commercialize new catalytic processes rather than to explore theory, with the result that basic understandings are not enhanced.
- (4) Theoretical research programs are important to DoD's capitalization on the energy benefits which catalysis can provide. In the field of applied research it is important to DoD to develop improved catalytic technology in connection with the use of catalysis in the production of solid and liquid propellants.

TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

A review of technical results versus the research objectives of these DARPA programs indicates the objectives were essentially met. The tangible results, as far as the effectiveness of technology utilization and technical information, are summarized below. However, it should be appreciated that there are less tangible outcomes which also benefit the scientific and government community, particularly for those studies which were of broad scope or policy-related. Those which were more hardware-oriented have in many cases provided tangible results in achieving the state-of-the-art for the benefit of not only DoD, but also other federal agencies.

When, in subsequent decisions, the Federal Energy program was concentrated in two other agencies--the technical program in the Energy Research and Development Administration (ERDA) and the Environmental Protection Agency (EPA), and policy aspects in the Federal Energy Administration--not only was the policy-oriented effort of DARPA transferred to these agencies; but, as will be noted, some of the more hardware-oriented work was picked up by ERDA or EPA as well as military Services. The on-going DoD efforts, for the most part, are limited to specific military aspects and applications.

Energy Availability and National Security Considerations

The early studies helped fashion the technical parts of the DARPA Energy Program. The overall efforts within this broad research area became a major resource to the Defense Energy Task Group (DETG), which was formed in September 1973. The DARPA program manager, Mr. R. A. Black, was assigned as the DARPA member of DETG to assist in its work. He also represented DoD on the Interagency Committee on the International Aspects of Energy R&D. Dr. C. H. Church of DARPA also became a member of the Interagency Panel on the Terrestrial Applications of Solar Energy. Thus, the early findings and results of the DARPA program were transferred to the appropriate DoD and government organizations by the direct participation of the DARPA staff members in related DoD work.

Utilizing DARPA inputs, the Director of Defense Research and Engineering (DDR&E) assigned to the Services lead, participate, incentivize or monitor

responsibilities in energy-related R&D areas as shown in the matrix of Figure B-1, Appendix B. The Secretary of Defense approved the recommendations in its Phase II Defense Energy Resources Report containing this matrix, which recommended (in part) that action be taken to:<sup>42</sup>

- Focus the energy-motivated R&D Program on DoD missions.
- Make energy effectiveness a consideration in weapon system development.

As for the studies associated with the DEIS, they were considered useful because they focused attention on the information problem, identified requirements, and provided goals and design information to implement a DEIS. Thus, the studies provided an important impetus to longer range efforts and stimulated an awareness that the DoD could and should coordinate energy information more systematically not only as a defense preparedness measure, but also to facilitate conservation.

#### Alternate Sources of Energy at Military Installations

Certainly by initiating its program in 1972, DARPA through its state-of-the-art assessments and early research programs had designed, by the time of the late 1973 oil crisis, a preliminary DoD road map for technological alternatives to petroleum-derived energy at its installations. Its continuing work through 1975 not only refined the road map but also advanced the state-of-the-art, as is evident in the follow-on actions of the Military Services and other federal agencies.

- Several hundred copies of the report on the Assessment of Total Energy Systems have been distributed, with a large demand from the Services.<sup>53</sup> Additionally, the Naval Facilities Engineering Command has had the contractor studying R&D measures for solid waste energy conversion systems.
- The recommended Near-Term strategies for energy conservation and utilization of the Alternative Strategies reports<sup>54,55</sup> are being recommended/implemented at Naval installations. Certain of the recommended Advanced strategies (e.g. solar, total energy systems, heat recovery) are being studied for applications where they would have economical benefit to the Naval installations involved.

- The design of the experimental Ft. Belvoir total utility plant is being applied in the planning for a similar plant at Ft. Benning.
- The technical information and findings of the workshop report on Waste-to-Energy<sup>54</sup> have been pertinent to recent refuse-derived-fuel experiments conducted by the Air Force at Wright-Patterson AF Base, Ohio, and those being conducted and further planned by the Navy at Norfolk, Va.
- The project on Pyrolysis-Synthesis Process<sup>60</sup> has continued at the Naval Weapons Center with FY75 and subsequent year funding by the Environmental Protection Agency.
- The Army is currently working jointly with the Energy Research and Development Agency to arrive at a mutually acceptable form of fission-waste elements to be used as a heat source at military installations. The Mixed Fission Product report<sup>61</sup> has served as a baseline for these later studies.
- Although it would be difficult to associate the assessment of Solar Energy Technology directly with any follow-on work, the report<sup>62</sup> has been widely distributed and accepted. It would therefore appear to have contributed usefully to the knowledge for solar energy applications at military installations. It is interesting to note that all three Services are either conducting solar energy experiments or are planning/constructing facilities utilizing solar as an energy source.
- Although it would be difficult to associate specific actions by any of the military Services with the report on Remote U.S. Bases Alternatives,<sup>63</sup> it has been widely circulated.
- The report on the Energy Plantation Concept<sup>64</sup> provided a base of technology for later work by the contractor with the American Gas Association to estimate the potential for deriving synthetic natural gas from plant material. It also relates to a current research project sponsored by the Energy Research and Development Agency to study a photo-synthesis Energy Factory.
- As for the geothermal work, the DARPA research resulted in a considerable extension of the understanding of geothermal energy, of capabilities for and limitations of its uses, and of problems that may be encountered. Follow-on work toward the development of geothermal energy is being conducted by ERDA, US Geological Survey, the Naval Weapons Center, and other government agencies.

As of the beginning of FY77, the Coso Geothermal Site is under active exploration and development with research funding from ERDA.

- The task of devising a suitable photochemical solar energy storage system is an exceedingly difficult one, and it is not likely to be solved by a single group working with limited funding for a few years. The DARPA program has advanced the state-of-the-art with regard to the specific compounds and procedures, and has served to stimulate interest and activity in this small, but growing, area of research. The Office of Naval Research (ONR) which monitored the program for DARPA in FY74, took over sponsorship for FY75 and FY76, and the program has been recommended for continued ONR support in FY77.

#### Energy Alternatives In Propulsion

The DARPA research in this area has been timely and useful. The state-of-the-art was well enough assessed to identify the most reasonable alternatives in current technologies.

- The study of Synthetic Petroleum for DoD use alerts the Services to the need for constant review of their fuel requirements and mix of products needed since coal conversion process selection will be influenced by these factors. It cautions against expectation that supplementing DoD fuel requirements by use of coal derivatives can be achieved on a short term basis, citing the need for additional process development work, augmented coal supplies, long lead time for specialized equipment and other factors. The report sets the stage for continuing study of the problem by DoD since ERDA's objectives do not wholly coincide with those of the military.
- Information contained in the study on Superconducting Ship Propulsion was supplied to NAVSEA/NSRDC and confirmed the direction of the Navy program. NSRDC considered the information in the study to be technically significant and has used the information supplied by the study in its continuing effort to develop the superconductive homopolar motor and generator.
- The Hydrogen as a Military Fuel project resulted in a considerable extension of verification of the State-of-the-art, and what can be possible without visualizing future "break-throughs." It tied the operational implications to the technical aspects of the problem. The Navy has attempted to capitalize upon the DARPA-supported research in their in-house follow-on developments. These studies

indicate technical feasibility; economic feasibility is probable; and necessity may be a certainty. Brookhaven National Laboratories is continuing study of hydride storage under ERDA support. DARPA joined the National Science Foundation in sponsoring the "Theme Hydrogen Conference" in Miami in March, 1974, and presentations of material from the studies from this project were made.<sup>104,105</sup>

Potential Materials Shortages and Their  
Implications for National Security

These DARPA-sponsored studies have improved the state-of-the-art in identifying and anticipating critical materials' shortages and identifying potential avenues to meet the resulting technical challenges for the benefit of DoD and the scientific community. They contributed directly to the reviews held for the DoD Materials Shortages Workshop among government and industrial representatives during January 1975 in Washington, D.C.<sup>96,98,100</sup> Results are also currently reflected in the continued representations by the Department of Defense in Government interagency coordination for actions to be taken to:

(1) Review and update U.S. stockpiling measures, (2) Provide early warning of shortages of materials necessary to meet production needs for DoD hardware (beryllium, asbestos, chromium, etc.), and (3) Identify substitute materials and processes.

- This research effort has also developed methodologies which are available to be used by DoD to: (1) illuminate, based on current consumption data, key dependencies of the DoD on industrial sectors of the economy for final demand products which would become critical in the event of material shortages,<sup>96</sup> and (2) analyze U.S. technologies for possible future criticalities to the U.S. and the DoD in material availabilities and production capacities.<sup>100</sup>
- The DARPA work on ceramics for high temperature gas turbines is being increased, pointing towards an engine demonstration in FY77. Fifty percent of the FY77 funding and 100 percent of the FY78 funding for continued research of the automotive propulsion aspects of the DARPA program is being transferred to ERDA.
- The methodology used and the results of the studies<sup>95,96</sup> to illuminate key dependencies of the DoD on materials which are potentially critical have been briefed to the Federal Preparedness Agency, the Department of Commerce,

and the Bureau of Mines (Department of Interior). It was also the basis for a presentation to the American Institute of Mining, Metallurgical and Petroleum Engineers in a symposium in Arlington, Virginia on November 11, 1975, which was later published by the National Science Foundation.<sup>106</sup>

### CONCLUSIONS

It is plain that these programs, conceived and executed as early as they were, placed DARPA in the forefront, not only in DoD but among Federal agencies, in being concerned with assessing and addressing the problems of energy and materials shortages. The "head-start" provided by DARPA studies in the field of energy concerns proved to be of great value in the critical days of late 1973 and early 1974.

In reviewing the results of these DARPA programs, the following broad conclusions emerge:

- The programs and their specific projects were, for the most part, timely and useful, not only to DoD but other Federal Agencies concerned with problems associated with shortages of energy and critical materials.
- Many research projects of a follow-on nature can be identified both within DoD and in other Federal agencies.
- Essentially, at this point in time, DARPA can consider it has completed its work in assessing the situation from a DoD point of view, and in advancing the state-of-the-art in selected research projects within the Energy and Critical Materials areas.

### RECOMMENDATION

Recognizing the importance and significance of what it has already contributed, it is recommended that DARPA continue to monitor research progress in these areas, particularly looking for advanced research concepts which have a potential for enhancing the efficiency and effectiveness of energy utilization in military applications.

DARPA ENERGY/MATERIALS RESOURCES PROGRAM FUNDING SUMMARY

Appendices	FY72	FY73	FY74	FY75	FY76	Total
Energy Availability and National Security	178K	427K	115K	100K		820K
DoD Energy Requirements, Planning and Conservation		102K	225K	138K		465K
Defense Energy Information System		67K	276K	260K		603K
DoD Energy Applications at Military Installations		328K	500K	76K		904K
Use of Geothermal Energy	95K	55K	196K	250K	25K	621K
Storage of Solar Energy in Small Rings			55K			55K
Synthetic Petroleum for DoD Use			50K			50K
Superconducting Ship Propulsion			36K			36K
Hydrogen as a Military Fuel			474K	443K		917K
National Security Implications of Potential Materials Shortages in Advanced Technologies		187K	49K	309K	100K	645K
TOTAL	273K	1166K	1976K	1576K	125K	5116K

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APPENDIX A

ENERGY AVAILABILITY AND NATIONAL SECURITY

## APPENDIX A

### ENERGY AVAILABILITY AND NATIONAL SECURITY

#### OVERALL PROGRAM

In early 1972 ARPA recognized that if worldwide energy supply and demand were to continue to increase at the rates then prevailing, an acute shortage in energy supply (particularly in hydrocarbon fuels) would be likely to occur. Such a shortage would likely have deleterious effects on U.S. national security, in particular in economic, political and military terms. ARPA responded to this recognition by undertaking a broadly-based program which sought to establish the dimensions of the overall problem and to investigate technological opportunities for its alleviation. The portion of the program covered in this section deals with planning studies and studies addressing energy availability and the national security implications of the energy problem, so that the following objectives could be met:

- Determine the implication of the energy crisis for DoD. 1,2,3 4
- Identify and evaluate specific DoD energy problems. 1,2
- Conduct preliminary R&D toward obtaining solutions. 1,2,3,4

At the inception of the ARPA program, relatively little information existed on energy availability. Information on the U.S.--much of it in the form of projections of energy consumption based on recent growth rates--was more plentiful than on other allied or Soviet-bloc countries. At about the same time that ARPA began sponsoring studies of energy availability, OASD (ISA) initiated one program which included the development of projections of energy availability to 2030, and ARPA and OASD (ISA) jointly funded an additional study which also contained estimates of energy availability. However, there was little prior effort which supported such projections, and which recognized the national security implications of the incipient energy crisis.

ARPA's Program included studies which examined policy alternatives available to DoD for meeting its energy requirements under conditions of constrained supply. Five contractors were involved in this effort utilizing

existing information as well as developing original energy supply and demand projections. In the case of three contractors, technical direction of their effort was performed directly by ARPA, while different contracting agencies were employed to administer the contracts. Two contractors' efforts (covering three study contracts) were monitored by the Rome Air Development Center of the Air Force Systems Command. Monitoring for these contracts included technical, as well as administrative and fiscal oversight, so that in these instances technical guidance from ARPA passed through an RADC technical monitor who participated in the direction of the effort.

In addition to performing studies, some contractors also prepared brief ad hoc contributions on specific topics, in response to the needs of the ARPA staff.

## SCIENTIFIC AND TECHNICAL RESULTS

The portion of the ARPA Energy Program which is discussed here differs considerably from the type of research which is generally associated with ARPA, in that it deals with national security policy implications and energy availability and demand projections. Therefore, the usual ARPA emphasis on advanced technologies is missing. In the same vein, no advances in the state of the art can be discussed, since none was attempted in the performance of these studies. On the other hand, ARPA personnel involved, as well as those of the several contractors, can be said to have gained improved knowledge and understanding in making projections of energy demand and supply. At the time that these projections were performed (in most cases prior to the general awareness of an impending energy shortage), the making of energy supply and demand projections was much less well developed and these studies are considered to have been instrumental in bringing about improved understanding of the field.

The studies reviewed here can be grouped as follows:

Program Planning Studies. These studies were performed in 1973 (by Rand Corporation)<sup>5,6,7</sup> in order to help structure the overall DoD and ARPA energy programs. They suggested that DoD could assume two roles in relation to energy programs: as a National Defense Planner, and as an Energy Consumer. Research programs were recommended to deal with: (1) energy management, (2) energy supply, demand and price, (3) energy conservation and environmental impact, (4) vulnerability of energy systems, (5) energy transportation and (6) material requirements. These program recommendations were generally followed.

Energy Availability Studies. These studies included work by four contractors (Battelle Columbus Laboratories, Hudson, SAI, and SRI.)<sup>8,9,10,11,12</sup> One study of DoD energy requirements concluded that, since the problems of the national energy economy directly affect DoD, and since the rest of the Federal Government and the private sectors of the economy will direct their efforts toward the solution of energy-related problems in the civil sector, the DoD cannot be assured that these solutions will necessarily be timely or effective in terms of the special nature of DoD's energy requirements. The study makes the following recommendations for DoD/ARPA: (1) develop domestic sources of substitute liquid petroleum from coal shale, (2) develop domestic

sources of substitute liquid petroleum from coal, (3) improve the efficiency of piston and turbine engines, and (4) develop strategies for military use of hydrogen as an alternate fuel.<sup>8</sup>

The study on Energy and Security<sup>9</sup> presents a perspective on how energy needs impinge on U.S. national security now and for the next two decades. In so doing, it identifies major issues which are discussed in detail. These deal with energy supply, security and independence, criteria for choosing options, supply interruptions, alternative energy sources, differing import needs of the U.S. and its allies, heightened security in energy, and the effect on U.S.-Soviet relations. The study recommends the following topics for further research:

- The interrelationships of nuclear proliferation, terrorism, and nuclear materials safeguards.
- U.S.-Soviet energy transactions.
- The general feasibility of energy self-sufficiency (and Project Independence).
- The economic tradeoffs between the costs of importing oil and the costs of developing U.S. resources.
- The economic impact of programmatic energy conservation.
- R&D priorities, especially as affected by the security impact of nuclear fission, and by the potential of alternatives such as solar and geothermal energy.
- The defense of energy supply lines abroad.
- The financing of Western payments for oil.
- Alternative Mid-East futures.

The study of the Energy Demand and Resources of Japan<sup>10</sup> identified oil as the major energy source for Japan through 2000, although it will provide decreasing proportion of the supply after 1985. Demand for coal, LNG and electricity will continue to grow; after 1985 almost all new electrical generating capacity will be nuclear. The great dependence of Japan on oil imports, and the geopolitical implications of this dependence were examined. Opportunities for technology transfer to Japan (in order to help her reduce reliance on oil) include: (1) coal gasification, (2) high temperature gas

reactors for direct process use of nuclear energy, (3) geothermal energy systems, (4) fusion power production and (5) transfers in energy-related fields.

The Analysis of the Energy Resources and Demands of Western Europe<sup>11</sup> examined energy demand through 1985. Attention was devoted to the impact on demand of the rapid rise in the cost of oil, and the prospects for development of alternative (indigenous) sources of supply. The study concluded that a marked decline in consumption will be felt through 1980 as a result of the price increases triggered by the 1973 oil embargo. Western Europe will continue to depend heavily on OPEC oil, since the development of the North Sea oil fields has been hampered by rising prices. In addition to obtaining oil from this area, the potential exists for increasing imports of oil from the Eastern Bloc as an alternative to reliance on oil imports from OPEC nations. Technology transfer from the U.S. offers little short term potential for improving the energy picture in Western Europe.

The Analysis of Energy Resources and programs of the Soviet Union and Eastern Europe<sup>12</sup> dealt with the energy resources and their development in the USSR, Bulgaria, Czechoslovakia, East Germany, Hungary, Poland and Romania. Also studied were electric power development, supply-demand balance, and reserve-production comparisons in these countries. Projections were made to 1990. The study concluded that the energy resource base of the USSR is sufficient to continue exports to Eastern Europe into the foreseeable future. If the very large Siberian fuel resources are successfully developed, the USSR could also contribute significant amounts of petroleum and natural gas exports to the rest of the world as well. The USSR and Eastern European countries will continue to import small amounts of oil and gas from OPEC; these imports are not expected to cause significant competition with other importers of OPEC fuels. Alternative policies are suggested in the event that the Siberian resources are not developed in the required time scale. These include substitution, limits on exports and domestic consumption, and expansion of imports from OPEC. The West could supply technologies in return for gas and petroleum in a barter arrangement with the USSR.

National Security Policy Studies (by Rand and Hudson).<sup>13,14,15,16,17,18</sup>  
Some of the energy availability studies (by SAI)<sup>10,11</sup> also address geopolitical aspects of the energy issue. Studies in this category deal with alternate scenarios related to energy denial on a global and regional basis,<sup>13</sup> with U.S.

and allied responses to denials,<sup>15,16,17</sup> historic reviews of past energy crises,<sup>14</sup> petromoney, and economic security and threats to it posed by energy scarcity.<sup>18</sup>

The analysis of the energy resources and demands of the world... examined energy demand through 1985. Attention was devoted to the... demand of the rapid rate in the cost of oil, and the prospects for... short of alternative (indigenous) sources of supply. The study... a marked decline in consumption will be felt through 1980 as a result of the... price increases triggered by the 1973 oil embargo. Western Europe will con... these to depend heavily on OPEC oil, since the development of the North Sea... oil fields has been hampered by rising prices. In addition to discussing oil... from this area, the potential exists for increasing the use of oil from the... Eastern bloc as an alternative to reliance on oil imports from OPEC nations... Technology transfer from the U.S. offers little short-term potential for im... providing the energy picture in Western Europe.

The analysis of energy resources and programs of the Soviet Union... and Eastern Europe dealt with the energy resources and their development in... the USSR, Bulgaria, Czechoslovakia, East Germany, Hungary, Poland and Rumania... Also studied were electric power, gas, and other energy-related matters, and... resource-production comparisons in these countries. The study was also... 1980. The study concluded that the energy resource base of the USSR is suf... sufficient to continue exports to Western Europe into the foreseeable future... If the very large Siberian fuel resources are successfully developed, the... USSR could also contribute significant amounts of petroleum and natural gas... exports to the rest of the world as well. The USSR and Eastern bloc countries... areas will continue to import small amounts of oil and gas from OPEC; these... imports are not expected to cause significant competition with other suppliers... of OPEC fuels. Alternative policies are suggested in the report that the... Siberian resources are not developed to the potential size scale. There is... a wide selection, limits on exports and domestic consumption, and expansion... of imports from OPEC. The West could supply technologies in return for gas... and petroleum in a barter arrangement with the USSR.

National Security Policy Studies (by Paul and Barbara) 11-10-77, 11-17-78  
11-11-77  
Some of the energy availability studies (by Paul) also address geographically... aspects of the energy issue. Studies in this category deal with... economic related to energy demand on a global and regional basis, with U.S.

TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

The portion of the ARPA Energy Program reviewed here had pervasive results in ARPA, DoD, and the Federal Government. On the direct level, these studies helped fashion the technical parts of ARPA's energy program. On a more indirect basis, the studies dealing with energy availability and national security aspects of the energy problem were valuable to the Defense Energy Task Group (DETG), and to other, non-DoD agencies. The results of some of the studies were briefed both by ARPA and contractor personnel to a number of Government agencies.

It is worth emphasizing that at the inception of the ARPA Energy Program in 1972, there was very little activity in DoD (and not much elsewhere in the Federal Government) dealing with the policy and technical aspects of the energy problem. ARPA played a pioneering role in its early recognition of the problem, by initiating studies which, on the one hand provided a better understanding of the dimensions of the problem and the policy implications of energy scarcity, and on the other hand initiated programs aimed at energy conservation and lessened dependence on foreign petroleum in the DoD. When, in subsequent decisions, the Federal energy program was concentrated in two other agencies--the technical program in the Energy Research and Development Administration (ERDA), and policy aspects in the Federal Energy Administration (FEA), the policy-oriented energy effort at ARPA was transferred to these agencies.

ENERGY AVAILABILITY AND NATIONAL SECURITY

## FUNDING SUMMARY

	<u>FY72</u>	<u>FY73</u>	<u>FY74</u>	<u>FY75</u>
BCL	\$48K			
Hudson		\$30K	\$50K	\$100K
RAND	130K	150K		
SAI		72K	65K	
SRI		<u>175K</u>		
TOTALS	\$178K	\$427K	\$115K	\$100K

Overall Total: \$820K

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Mr. J. F. Schneider, Principal Investigator  
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APPENDIX B

DOD ENERGY REQUIREMENTS, PLANNING  
AND CONSERVATION

APPENDIX B

DOD ENERGY REQUIREMENTS, PLANNING  
AND CONSERVATION

OVERALL PROGRAM

ARPA initiated this program in August, 1972, well before the 1973 petroleum crisis, because of concern within DOD about potential energy shortages and the increasing dependency of the United States on foreign sources of petroleum. Abundant domestic supplies of low-cost energy could no longer be taken for granted in the United States to meet projected demands, and the range of choice regarding energy sources was narrowing. ARPA's basic interest was to assess energy and resource needs of DOD, considering the world situation, and to identify possible research programs to resolve potential problems.

Although responsible for less than two 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 over-simplified conclusions pro or con. In accomplishing its mission in an energy shortage situation, DOD requires 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.

During fiscal years 1972 through 1975 ARPA directed and supported research by three contractors which addressed the national security implications of the potential shortages and the increasing costs of petroleum based fuels. The research program also examined current and proposed DOD R&D efforts which appeared to have a potential impact on energy conservation within the Defense establishment. The work was contracted through and monitored for ARPA by separate contracts from the Office of Naval Research,<sup>1</sup> the Defense Supply Service--Washington,<sup>2</sup> and the Army Missile Command.<sup>3,4</sup> Technical control was retained by ARPA on all of the contracts. The technical objectives of this research were:

- a. To identify the national security issues arising from changes in energy supply and demand in the U.S. and the world markets for fuel and energy.<sup>1</sup>



## SCIENTIFIC AND TECHNICAL RESULTS

The role of advanced research in addressing energy problems is becoming increasingly important for DOD and, indeed, for the nation at large. Specific aspects of the energy problem were selected for examination in these ARPA studies, as follows:

- a. Principal energy problem areas of importance to DOD and suggestions of advanced research directed toward their solution.<sup>1</sup>
- b. Definition of DOD's role in the changing U.S. energy situation.<sup>2</sup>
- c. Identification of required research programs.<sup>2</sup>
- d. Development of methodologies for projecting DOD energy demands.<sup>2</sup>
- e. Projection of military technological options.<sup>2</sup>
- f. Energy, Defense Resources, and Related Technologies research efforts.<sup>3</sup>
- g. Ongoing, programmed, proposed and potential R&D which might lead to enhancement of DOD's energy situations.<sup>4</sup>

As the results of these studies became available, they were used in guiding the on-going ARPA program. Many of the study recommendations require implementation by other parts of the Defense Department, or by the separate military departments. The studies concluded that:

- a. "Low-energy" materials such as glass and plastic should be substituted for "high-energy" materials such as steel and copper wherever possible.<sup>5</sup>
- b. Energy transformation, distribution and storage capabilities could be improved by developing<sup>5</sup>
  - (1) structural materials of improved strength and toughness,
  - (2) high temperature materials with improved mechanical properties and greater resistance to physical and chemical degradation,
  - (3) environment resistant materials that withstand stress for long-term service,
  - (4) improved conductors,
  - (5) improved primary and secondary fabrication techniques.
- c. Chemical fuels such as ammonia, hydrogen, carbon monoxide, methanol, and alkali metals should be developed.<sup>5</sup>
- d. Significant effort is already underway in addressing<sup>5</sup>

- (1) Coal gasification and liquefaction
  - (2) Oil shale and tar sand recovery
  - (3) Secondary and tertiary petroleum recovery
  - (4) Liquid fuel transportation and storage
  - (5) Energy data management
  - (6) Vulnerability of energy systems
  - (7) Energy conversion by nuclear reactors
- e. New research is needed regarding<sup>5</sup>
- (1) Environmental impacts of energy development and use
  - (2) Geothermal resources
  - (3) Oil shale recovery
  - (4) Materials properties
  - (5) Energy relationships to materials production
  - (6) Chemical fuels
  - (7) Integrated LNG usage
  - (8) Waste heat from energy production processes
- f. High capacity rapid excavation technology could enhance oil shale development and should be pursued.<sup>5</sup>
- g. An integrated plant concept might help extensively in capitalizing on the potentialities of waste as a source of energy.<sup>5</sup>
- h. DOD may need to consider alternatives to its past reliance on ad hoc energy committees to ensure an adequate fuel supply.<sup>6</sup>

Further, the studies:

- i. Arrived at only tentative conclusions regarding the amount of energy consumed in support of DOD expenditures in the six leading DOD contracting states.<sup>7</sup>
- j. Developed methodology for estimating the amount of energy required by industries in filling DOD's needs for goods and services. (The methodology developed is based on the Input/Output technique and inherits the shortcomings\* of that technique.)<sup>6,8,9,10</sup>

\*Input/Output data are subject to inaccuracies due to lack of complete coverage of an industry, restriction of information for proprietary reasons, and use of different time periods for different kinds of data.

- k. Designed a computer model which can be used to project future energy needs of the U.S. Air Force but because of inadequate data and limitations in terms of time and funds was compelled to conduct only a preliminary analysis in connection with the development of a comprehensive, computerized model of energy consumption by the U.S. Army. RAND efforts in connection with a similar model for the U.S. Navy were apparently seriously handicapped.<sup>11,12</sup>
- l. Concluded that re-engining of U.S. Air Force aircraft is technically feasible and would significantly and favorably influence fuel consumption.<sup>13</sup>
- m. Determined that the energy conservation measures practiced most commonly by ARPA-funded contractors were:<sup>14,15</sup>
  - (1) Lowering of heating temperatures
  - (2) Reducing lighting
  - (3) Establishing car pools
  - (4) Raising cooling temperatures
  - (5) Restricting official travel
- n. Found that, with regard to waste-to-energy technology:<sup>15</sup>
  - (1) Of the various technologies, the one with the most likelihood of cost effective operation is to burn waste in an existing boiler to generate process steam to be fed into existing installation heating/electric loads.
  - (2) Other possibilities such as new boilers or system augmentation with small package boilers also have promise, but there are also limitations and restrictions.
  - (3) The DOD should continue to monitor progress in more advanced technologies such as pyrolysis and fluidized bed for possible future applications.
- o. Concluded that colloidal mixtures of coal in oil offer sufficient potential for cost reduction and energy conservation that their use should be explored further by DOD, particularly for marine propulsion and land-based military installations.<sup>16</sup>
- p. Concluded that expectations that significant quantities of critical materials, other than those presently extracted, will be recovered from seawater in the foreseeable future are totally unrealistic.<sup>17</sup>
- q. Concluded that the Brayton-cycle gas-turbine engine has the greatest potential for fulfilling future propulsion requirements.<sup>15</sup>

r. Identified, reviewed and assessed approximately 1000 energy-related R&D programs of which about 50 percent appeared to have some energy conservation connotations. Observations rather than conclusions were made since additional research, analysis and discussion would be needed prior to drawing firm conclusions.<sup>18</sup> For example, it was observed that:

- (1) DOD and all three services are continuing to advance turbine engine technology in significant on-going and proposed programs but that specific energy conservation objectives need to be added.<sup>18</sup>
- (2) Reliance by DOD on the U.S. automobile industry for research related to internal combustion engine technology is understandable, but that DOD should aggressively pursue work related to engines for light-duty military applications with good fuel economy using lower grade or multifuels.<sup>18</sup>
- (3) There appears to be very little on-going DOD effort in the technology of external combustion engines, though EPA and industrial interests are exploring it; DOD should pursue more efficient and further developed engine approaches such as diesel or stratified-charge engines.<sup>18</sup>
- (4) It appears that DOD should await further technology advancements in the more general research areas of
  - o Hybrid and Compound engines,
  - o Solar Energy,
  - o Total energy conversion,
  - o MHD Energy conversion,
  - o Building design/construction,
  - o Geothermal Energy,
  - o Power Train components,

but that certain specific military aspects and applications appear appropriate and should be pursued.<sup>18</sup>

TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

It is noted that ARPA's decisions in connection with energy-related research efforts were quite timely. In several cases, they preceded the actual energy crisis by months. Had ARPA not initiated its undertakings in such a timely fashion, the DoD and the U.S. would have been less able to meet the 1973 energy crisis. The ARPA energy research program, the only such program in DoD, became a major resource to the Defense Energy Task Group (DETG), which was formed in September 1973. The ARPA program manager, R. A. Black, was assigned as the ARPA member of DETG to assist in its work, and, after the embargo began, he represented DoD on the Interagency Committee on the International Aspects of Energy R&D. ARPA also assigned C. H. Church to work with DETG, and he also became a member of the Interagency Panel on the Terrestrial Applications of Solar Energy.<sup>19</sup> Thus, the findings and results of the ARPA program were transferred to the appropriate DoD and government organizations by the direct participation of the ARPA staff members involved.

Although some of the contractual findings are more pertinent to non-DoD agencies and activities, the DoD is quite interested in monitoring and being informed of technological progress in areas which could lead to new energy sources. For example, the U.S. Navy is very interested in technological progress related to surface mining and in the rapid excavation process because of its potential application in the development of oil shale. However, the U.S. Navy's own R&D focus has been on the applicability of fuel derived from oil shale to U.S. Navy requirements. The U.S. Army is pursuing development of a lightweight engine for military applications, and also which consumes less fuel.

Utilizing inputs from ARPA based on the contractual efforts described in this summary, the Director of Defense Research and Engineering (DDR&E) assigned to the Services lead, participate, incentivize or monitor responsibilities in energy-related R&D areas as shown in the matrix of Table 1. The Directorate of Energy in the Office of the Assistant Secretary of Defense for Installations and Logistics made additional refinements and assignments.<sup>20</sup>

The Secretary of Defense approved the recommendations in the Phase II Report<sup>20</sup> containing the matrix, which recommended (in part) that action be taken to:

- Focus the energy-motivated R&D Program on DoD missions
- Make energy effectiveness a consideration in weapon system development.

The majority of U.S. energy research and development is now being undertaken under the control and monitorship of the United States Energy Research and Development Administration (ERDA). That agency has issued Volume 1 of a National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future, and ERDA is currently engaged in the preparation of Volume 2. The direct DoD efforts, for the most part, continue to be limited to specific military aspects and applications.

Table B-1. DoD Energy-Motivated R&D Participation Guidelines

	<u>Operations</u>	<u>Research</u>	<u>Exploratory Development</u>	<u>Advanced/Engineering Development</u>
<b>I. <u>Aircraft Operations - Air Force Lead</u></b>				
A.	Improved Propulsion Aircraft Turbines with Reduced Specific Fuel Consumption	Lead	Lead	Lead
B.	Improved Aerodynamic Drag Reduction	Lead	Lead	Lead
C.	Multifuel Capability	Lead	Lead	Lead
D.	Alternate Fuel for Aircraft Operations			
1.	Syncrudes	Incentivize Monitor	Incentivize Monitor	Incentivize Monitor
2.	Hydrogen and Methane			
E.	Improved Aircraft Operational Procedures	Lead	Lead	Lead
<b>II. <u>Ship Operations - Navy Lead</u></b>				
A.	More Efficient Ship Propulsion			
1.	Improved Efficiency Conventional Power Plants: Diesel and Steam	Lead	Lead	Lead
2.	Advanced Gas Turbines	Lead	Lead	Lead
3.	Advanced Topping Cycle Such as Supercritical Carbon Dioxide Brayton Cycle	Monitor	Monitor	Monitor
4.	Turbine Driven Superconducting Generator Motor Propulsion Driven Systems	Lead	Lead	Lead
5.	Nuclear Ship Propulsion (Less Reactors)	Lead	Lead	Lead
B.	Multifuel Capability	Lead	Lead	Lead
C.	Burn Less Critical Fuels			
1.	Syncrude Fuels	Incentivize Monitor	Incentivize Monitor	Incentivize Monitor
2.	Other Alternate Fuels			
D.	Combined Chemical Dash Power and Nuclear Cruise Power Systems	Lead	Lead	Lead
E.	Reduction in Non-Propulsive Energy Consumption-Improved Conversion Efficiency			
1.	Total Energy/Waste Heat Recovery Systems	Participate	Participate	Monitor
2.	Integrated Energy/Waste/Water Management System	Participate	Participate	Monitor
<b>III. <u>Installations and Buildings - All Services &amp; ARPA</u></b>				
A.	Optimum Utilization of Technology & Equipment			
1.	Conduct Analyses of DOD Buildings and Installations To Determine the Optimum Way To Invest Available DOD Energy Conservation Dollars To Maximize BTU Saved Per Dollar	Monitor	Monitor	Monitor
2.	Conduct Further Performance and Economic Analyses on Primary and Supplementary Heating and Cooling; Provide Buildings for Trial Use	Monitor	Monitor	Monitor
3.	Total Energy Systems That Recover and Use Waste Heat	Participate	Monitor	Monitor
4.	Improve Efficiency Base and Building Energy (Heating and Cooling) Distribution Systems	Incentivize	Incentivize	Incentivize
5.	Optimum Location of New Buildings and Site Placement	Incentivize	Incentivize	Incentivize
6.	Energy Independence for Remote Bases	Lead	Lead	Lead

**Table B-1. DoD Energy-Motivated R&D Participation Guidelines**

(Continued)

	<u>Operations</u>	<u>Research</u>	<u>Exploratory Development</u>	<u>Advanced/Engineering Development</u>
<b>III. <u>Installations and Buildings (Continued)</u></b>				
<b>B. Advanced Technology</b>				
1.	Advanced Power Plants of Improved Efficiency That Are Convertible to Substitute Fuels Such as Coal and Syncrude	Monitor	Monitor	Monitor
2.	Advanced Methods of Energy Storage and Distribution	Monitor	Monitor	Monitor
3.	Alternate Energy Sources and Fuels (e.g., Solar, Geothermal, Nuclear)	Monitor	Monitor	Monitor
<b>IV. <u>Ground Operations - Army</u></b>				
<b>A. Vehicles</b>				
1.	Stratified Charge Gasoline Engines	Participate	Participate	Participate
2.	High-Performance High-Speed Diesel Engines with Good Efficiency over a Wide Load Range	Participate	Participate	Participate
3.	Open-Cycle Gas Turbines with Recuperators To Increase Efficiency	Participate	Participate	Participate
4.	Multi-Speed Lockup Transmissions with High Efficiency and Smooth Operation	Participate	Participate	Participate
<b>B. Mobile Electrical Power Systems</b>				
1.	Stirling Engine - Generators	Lead	Lead	Participate
2.	Small Fuel Cells	Lead	Lead	Participate
3.	Efficient Turbo-Alternators	Lead	Participate	Participate
<b>C. Multifuel Capability</b>				
		Lead	Lead	Lead
<b>D. Advanced Fuels and Power Systems</b>				
1.	Refined Syncrude Fuels	Incentivize	Incentivize	Incentivize
2.	Hydrogen	Monitor	Monitor	Monitor
3.	Closed Brayton Regenerative Gas Turbines	Participate	Participate	Participate
4.	Fuel Additives (e.g., Methanol)	Participate	Participate	Participate
5.	Nuclear Energy Systems Such as Nuclear Powered Total Energy Depots and Radioisotope Power Generators	Participate	Participate	Participate

- **Lead.** DOD is the major source of R&D funding
- **Participate.** DOD provides a share of the necessary funding in conjunction with other Federal Agencies and/or private industry
- **Monitor.** DOD does not fund hardware development directly but observes progress closely, makes DOD's needs known, and provides resources, analyses, and indirect support (e.g., building insulation test facilities) for specific military adaptations
- **Incentivize.** DOD does not fund hardware development directly but may provide appropriate incentives (e.g., guarantee a market for syncrude subject to the availability of funds), resources, and analyses for specific military adaptations.

DOD ENERGY REQUIREMENTS, PLANNING AND CONSERVATION

**FUNDING SUMMARY**

	<u>FY73</u>	<u>FY74</u>	<u>FY75</u>
RAND	\$50K	\$150K	\$90K
SRI	52K		
BMI		75K	48K
<hr/>			
Totals:	\$102K	\$225K	\$138K
Overall Total:	\$465K		

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APPENDIX C

DEFENSE ENERGY INFORMATION SYSTEM (DEIS)

## APPENDIX C

### DEFENSE ENERGY INFORMATION SYSTEM (DEIS)

#### OVERALL PROGRAM

When this program was initiated in 1973, there was a critical need to undertake research in alternate sources of energy to support both domestic and DOD needs. Along with this critical need to conduct research, there were also very important requirements to control both technical information and fuel supply information; especially within the DOD. The DOD had to know at any given time what fuel suppliers were available and where they were available in order to plan and support operational needs of the Military Services.

In addition, whereas most types of fuel used to be relatively inexpensive and a small part of the overall DOD budget, fuel prices started to increase during this time period.

It therefore became imperative that the DOD coordinate all energy information. Thus, ARPA initiated a series of research activities to investigate the conceptual design of an Energy Information System. The original ARPA objectives and plans were:

1. To conceptualize and design the DEIS but undertake the data collection and establishment phases of DEIS as separate efforts.<sup>1</sup>
2. To utilize the ARPANET<sup>1</sup> computerized information network, if possible.

These DEIS design studies were performed by the Stanford Research Institute, Menlo Park, California.<sup>2</sup> The final report on the study was the Defense Energy Information System - Design and Implementation Plan, June 1974.<sup>3</sup> This report contained the salient information from supporting studies in this program such as the preliminary analysis<sup>4</sup> and conceptual design.<sup>5</sup>

At the DOD level, a Defense Energy Task Group (DETG) was formed in the Fall of 1973 to make recommendations for better management of Defense energy resources.<sup>6</sup> An area of interest in the DETG program was in planning an immediately available energy information system. The SRI group, already involved in ARPA conceptual design studies for an energy information system, assisted the DETG in their energy information system program planning.<sup>7</sup>

The DETG report<sup>8</sup> also identified a major requirement in DOD for an Energy Information System. The existing fragmented approach to energy data management in the DOD often resulted in limited, and in some cases, entirely missing information on energy supply, technology and economics. The DETG stated a need for an energy information system as a key requirement in managing DOD energy resources.

Work has been earlier initiated with SRI under AO 2408 to investigate the feasibility of creating an Energy Information System to support the solution of energy related problems. This work considered the conceptual design<sup>5</sup> of an Energy Information System and addressed the definition of the character of available energy data and the determination of user requirements for a DOD Energy Information System.

The SRI conceptual design study<sup>5</sup> of a DOD Energy Information System recommended that, in consideration of the large number of existing data bases, internal and external, to DOD storing large quantities of energy related data, any implemented system should avoid duplication of existing data storage and utilize the ARPANET to provide for remote access of existing data bases where possible. The conceptual system was further defined to be flexible, facilitating adaptation to shifting energy requirements and programs of DOD components that would use the data regularly.<sup>4,5,7,</sup>

Because of the critical need for immediate sources of energy information, the conceptual system was designed to be produced in an evolutionary, phased approach. An initial energy information system was to have been required so as to provide a basic problem solving capability as soon as possible in 1974, yet to have been able to grow in an orderly fashion with additional capabilities to respond to changing needs and requirements.

As an emergency measure, the ASD (I&L) instituted in December 1973 a weekly report from all Defense Department activities showing the status and the actual and anticipated usage of selected fuels. Reports were received from 1200 reporting elements (DEIS-1). These data were collected in the DSA-155 computer where only a limited capability was available to list each week's data. There was no capability in the software to perform statistical analyses of weekly reports. These analyses were needed to identify potential fuel shortage areas and fuel usage trends. SRI was to investigate the applications of advanced information processing techniques to these problems including the ARPANET, the SRI NLS text manipulation system, and the MIT MULTICS data manipulation system.

The principal objectives of the SRI study were to provide pilot information services and to develop the detailed design characteristics of an Energy Information System for the Defense Department. This was to include the system components -- hardware, software, communications and staff organization. It would provide a problem solving capability to energy-related questions. A specific additional objective was to develop a pilot capability to perform analyses of the weekly DOD energy consumption/status report.

## SCIENTIFIC AND TECHNICAL RESULTS

That the scope of the effort required to develop and implement an effective Defense Energy Information System (DEIS) would be large and the effort complex became increasingly clear as the study progressed. It was evident that to meet the potential needs of the various users required a total systems approach. However, final design of a system was not achievable because of constraints on budget and time.

Even the organizational levels that the DEIS would serve and the way in which it would interface and interact with non-DOD energy data bases (e.g., Department of the Interior and DOD command and control systems) had not been decided by the time scheduled for SRI to complete its input to the Defense Energy Task Group's report. Furthermore, the international and domestic situation, to include its impact on the DOD energy problem, kept changing during the conduct of this effort.

A portion of the preliminary SRI study for a DEIS was included with the DETG recommendations.<sup>4,8</sup> The preliminary study included recommendations that:

- DEIS should immediately be implemented with available information and procedures
- DEIS should have a standardized reporting format for all Services (to include classified and unclassified information)
- additional personnel and computer capability should be made available to assist personnel already involved in similar functions
- a master plan should be prepared for the evolutionary development of the full system capability

The final report<sup>3</sup> covers work done during the period of January 1974 through June 1974 and also updates previous work done under this contract started in May 1973. The final report includes a short summary of the progress achieved by SRI, and sections on System Planning and Development, the Pilot Defense Energy Information Services (PDEIS), and the Initial Module Design and Implementation Plans. Also included is a summary outlook for system modular development beyond the initial module.

Techniques and procedures recommended in the study were state-of-the-art such as on-line computer access to DEIS data and information. Detailed analyses were performed to determine where and what information was currently available and how it could be coordinated. SRI included recommendations that would utilize existing hardware and software including the ARPANET computer network, MULTICS computer system at MIT, and the software package in place in MULTICS (consistent system and JANUS). As a part of the study, SRI implemented a prototype version of the initial DEIS module called PDEIS and established two Energy Problem Analysis Centers (EPAC's) -- one in Menlo Park, California, and one in Washington, D.C., to assist in maintaining liaison with potential users of DEIS.

TECHNOLOGY UTILIZATION AND  
TECHNICAL INFORMATION TRANSFER

Those who are familiar with the studies and/or were involved when the studies were conducted were generally favorable, with minor exceptions, concerning the overall impact of the studies within the DOD.<sup>9,10,11,12</sup> As far as the studies were concerned, the objectives were met without exception.<sup>2</sup> In general, the studies were considered useful because they focused attention on the information problem, identified requirements, and provided goals and design information to implement a DEIS.<sup>11</sup> Thus, the studies provided an important impetus to longer range efforts and stimulated an awareness that the DOD could and should coordinate energy information more systematically not only as a defense preparedness measure, but also to facilitate conservation. However, the studies only indirectly served the energy information crisis situation involving immediate needs of the DOD for energy information.

Following the energy crisis, the pressures eased for the immediate DOD requirement. This permitted OSD to take time to consider and act on the longer term requirement. At the present time the JCS Information System is gathering energy information and data routinely. The SRI studies are still being used as a baseline for the design of a system to meet the long-range needs of DOD. Active work is underway to improve the system to accommodate the dynamic, but clarifying scope of energy information needs within the DOD.

All of the SRI reports<sup>3,4,5,7</sup> are available through the Defense Documentation Center; although some are on restricted distribution and difficult for non-DOD personnel to obtain. The reports were also disseminated throughout various DOD branches and ARPA. The SRI reports are still being used within DOD as the basis for further re-design and implementation of the DEIS,<sup>9,12</sup> although SRI itself has not been directly involved through any follow-on projects related to DEIS.<sup>13</sup>

DEFENSE ENERGY INFORMATION SYSTEM (DEIS)

FUNDING SUMMARY

	<u>FY73</u>	<u>FY74</u>	<u>FY75</u>
SRI	\$67K	\$276K	\$260K

Overall Total: \$603K

- (1) Personal communication with Mr. Robert Lee, Director, Defense Energy Research Laboratory, July 11, 1974.
  - (2) AASA Order No. 1488, January 22, 1974, and amendments.
  - (3) A. Gages, Defense Energy Research Laboratory - A Preliminary Report, Defense Energy Research Laboratory, June 1974.
  - (4) E. Schmidt, et al., Defense Energy Research Laboratory - A Preliminary Report, Defense Energy Research Laboratory, July 1974.
  - (5) E. Schmidt, et al., Defense Energy Research Laboratory - A Preliminary Report, Defense Energy Research Laboratory, July 1974.
  - (6) Personal communication with Mr. Robert Lee, Director, Defense Energy Research Laboratory, July 11, 1974.
  - (7) E. Schmidt, et al., Defense Energy Research Laboratory - A Preliminary Report, Defense Energy Research Laboratory, July 1974.
  - (8) Department of Defense Energy Research Laboratory, Phase II Report, Department of Defense, Washington, D.C., July 22, 1974.
  - (9) Personal communication with Mr. John E. Jones, Deputy Director for Energy, Office of the Secretary of Defense (OSD), Installation and Logistics (IL), July 4, 1974.
  - (10) Personal communication with Col. (Ret.) Lawrence N. Gagan, former Director of Office of Planning and Assessment, Defense Fuel Supply Center (DFSC), July 9, 1974.
  - (11) Personal communication with Mr. Walter C. Christman, Office of the Secretary of Defense (OSD), Installation and Logistics (IL), July 28, 1974.
  - (12) Personal communication with Mr. G. E. Bailey, Office of the Secretary of Defense (OSD), Installation and Logistics (IL), July 28, 1974.
  - (13) Personal communication with Mr. A. W. Gages, Director, Defense Energy Research Laboratory, September 24, 1974.
- REFERENCES
- \* E.W. Sullivan, et al., A Study Review of the Energy Requirements of the Department of Defense, Santa Monica, California, August 1972.
  - \* M. Goussard, The Energy System and Defense, Naval Engineers Journal, Vol. 56, No. 1, pages 19-27, February 1974.
  - \* Department of Defense Energy Research Laboratory - Report of the Defense Energy Task Group, Department of Defense, Washington, D.C., November 13, 1971.

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- (1) Personal communication with Rudy Black, ARPA, June 20, 1973.
- (2) ARPA Order No. 2408, January 22, 1973, and amendments.
- (3) A. Capps, Defense Energy Information System: Design and Implementation Plan, Stanford Research Institute, June 1974.
- (4) R. Schmidt, et.al., Defense Energy Information System - A Preliminary Analysis, Stanford Research Institute, November 1973.
- (5) R. Schmidt, et.al., Defense Energy Information System - A Preliminary Analysis, Vol. I, Conceptual Design, Stanford Research Institute, January 1974.
- (6) Personal communication with Mr. Robert Igou, Battelle Energy Information Center, July 13, 1976.
- (7) R. Schmidt, et.al., Defense Energy Information System - A Preliminary Analysis, Vol. II, Special Report for the Defense Energy Task Group, Stanford Research Institute, January 1974.
- (8) Management of Defense Energy Resources, Phase II Report, Department of Defense, Washington, D.C., July 22, 1974.
- (9) Personal communications with Mr. John R. Nolan, Deputy Director for Energy; Office of the Secretary of Defense (OSD), Installation and Logistics (I&L), July 14, 1976.
- (10) Personal communication with Col. (Ret.) Lawrence W. Ogden, Former Director of Office of Planning and Management, Defense Fuel Supply Center (DFSC), July 9, 1976.
- (11) Personal communication with Mr. Walter C. Christensen, Office of the Secretary of Defense (OSD), Installation and Logistics (I&L), July 26, 1976.
- (12) Personal communication with Mr. O. L. Smiley, Office of the Secretary of Defense (OSD), Installation and Logistics (I&L), July 26, 1976.
- (13) Personal communication with Mr. A. G. Capps, Stanford Research Institute, September 24, 1976.

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- N. Soneshin, The Energy Problem and Defense, Naval Engineers Journal, Vol. 86, No. 1, pages 19-27, February 1974.
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APPENDIX D

ENERGY APPLICATIONS AT  
MILITARY INSTALLATIONS

## APPENDIX D

### ENERGY APPLICATIONS AT MILITARY INSTALLATIONS

#### OVERALL PROGRAM

In recognition of the problems for the U.S. and the DoD of growing shortages and increasing prices of fossil fuels, coupled with obvious U.S. dependence on foreign oil imports, ARPA initiated energy studies in late 1971. The purposes were to determine the energy outlook for the DoD and to identify advanced research approaches to solving the associated DoD problems. A fundamental part of the energy studies was the energy needs at military installations, representing about 40% of total DoD energy demand, principally served by petroleum as the basic resource.<sup>1</sup> As in the case of civilian energy utilization, there has been a definite trend toward increased energy use by bases and facilities of the military. A related aspect of concern was the fact that nearly all U.S. military installations meet their energy need through procurement from off-site commercial supplies.

In considering energy applications at military installations ARPA addressed need at U.S. bases located in overseas areas as well as those within the zone of the interior.

During fiscal years 1972 through 1975, ARPA directed and supported research by two Service Laboratories and thirteen contractors which provided world-wide assessments on the energy outlook at military installations and identified as well as addressed, many of the associated advanced research problems. The work was contracted through and monitored for ARPA in individual contracts by the Army Construction Engineering Research Laboratory, the Naval Civil Engineering Laboratory, the Army Corps of Engineers, the Army Missile Command, the Naval Weapons Center, the Air Force Office of Scientific Research, the Office of Naval Research, and the Defense Supply Service--Washington.

The overall research program concerning energy applications at military installations was grouped into areas of:

- Total energy concepts and systems
- Waste-to-energy conversion technologies
- Solar energy
- Geothermal energy

The technical objectives within these four areas of technology were respectively:

a. Total Energy Concepts and Systems

- (1) To analyze the total energy concept, in terms of technologies ranging from those currently available to such advanced technologies as geothermal, solar, and nuclear energy conversion, to determine the current and potential applicability of total energy systems for supplying the energy requirements of fixed military installations. (By Stanford Research Institute)<sup>2</sup>
- (2) To identify and systematically evaluate methods for managing the energy flow network on military bases and installation. Strategies for optimizing the effectiveness and efficiency of mechanisms for generating, distributing and consuming energy on military bases are to be investigated to include identification of R&D and other measures for implementing these strategies for more effective and efficient energy use. (By Booz Allen and Hamilton)<sup>3</sup>
- (3) Experimental System. To design, build and test an experimental total energy system, at Ft. Belvoir, Virginia, consisting of electrical heating, air conditioning, domestic hot water, sewage treatment, water purification, and solid waste incineration. To obtain data on the design, construction, operation, maintenance, and management of total utility plants as well as consumer usage data so that the total energy system concept can be evaluated for various types of military complexes. (By the Army's Construction Engineering Research Laboratory) (Jointly funded by the Department of Housing and Urban Development)<sup>4</sup>

b. Waste-to-energy Conversion Technologies

- (1) Workshop. To conduct a workshop for the purpose of identifying those techniques within the waste-to-energy conversion technology which have significant potential for DoD utilization at typical military bases and the key issues associated with implementing those techniques at such bases. (By Battelle Columbus Laboratories)<sup>5</sup>
- (2) Pyrolysis-Synthesis Process. To develop a small, very rapid pyrolysis process that produces sulfur-free synthesis gas suitable for selective

catalytic reaction to a desired energy product. Determine and evaluate candidate fuels and their attendant processes for conversion of solid waste to a higher-grade fuel. The process was to draw upon technology generated in the coal and municipal waste conversion programs of the Department of the Interior, but also required its own technology because of the specialized military requirements not now addressed by civilian oriented energy research. (By the Naval Weapons Center)<sup>6</sup>

- (3) Fission-Waste Source. To study the feasibility and develop a conceptual design of a plant to meet baseload requirements through generating hot water or steam from the heat energy in a modular fission-waste source. An intermediate agent (i.e. radiative transfer, transfer via a primary fluid or solid, etc.) was to be used to preclude radioactive contamination of the hot water or steam. (By R&D Associates)<sup>4</sup>

c. Solar Energy

- (1) Technology Assessment. To provide a comprehensive review of present major developments and future planning in various fields of applied solar engineering. It was to cover theoretical and experimental data on the background and state-of-the-art of applied solar research in general, with emphasis on foreign work. (By Informatics)<sup>7</sup>
- (2) Remote U.S. Bases' Alternatives. To examine some of the energy resource and technology alternatives for remote U.S. bases to include solar radiation, wind, and ocean waves as potential substitutes for petroleum fuel. (By Rand)<sup>8</sup>
- (3) Energy Plantation Concept. To assess the feasibility of supplying solid and gaseous fuels at Army bases, for other than mobile equipment purposes, by generating the required fuels from energy plantations on the bases. The energy plantation concept is based on the growth of vegetable matter purposely for its fuel value. It is therefore a means for directly harnessing solar energy in the form of a fuel by photosynthesis. (By Inter Technology Corporation)<sup>4</sup>
- (4) Energy Storage Research. To investigate the possibilities for solar energy storage in organic ring compounds through the tautomerization of isomers with high heats of formation. (By Boston University) Refer to Appendix F for a preliminary review of a basic research study of this technology in its potential application at military installations.

d. Geothermal Energy

- (1) The overall objective of these studies was to determine the feasibility of developing hot-water geothermal systems for military installations as a potential energy source. (By the Naval Weapons Center, The University of California, Southern Methodist University, The University of Texas at Dallas, Informatics, Inc., and Tetra Tech, Inc.) Refer to Appendix E hereto for an assessment of this energy area in its potential application at military installations.

## SCIENTIFIC AND TECHNICAL RESULTS

Much of the early ARPA work focused on identifying feasible technical approaches for energy applications at military installations. The later work then addressed selected approaches in order to identify the state-of-the-art and their economic soundness in competing with fossil fuels as potential energy sources. The results are enumerated below respectively by the four technological areas.

a. Total Energy Concepts and Systems

The results are embraced in four separate reports, the first on concepts for total energy systems, the remaining three covering the strategies for conserving energy and the identification of total system development approaches.

- (1) Concepts. The two most promising total energy systems include solar energy used for heating and cooling, and nuclear power. Utilization of solid wastes for heating should also be developed.<sup>9</sup>

The study recommends that a program be undertaken for application of solar energy to heating and cooling on military installations. The first step should be a study to identify and evaluate alternative concepts and means of integration of solar energy elements into the military installations. This study should be followed by a prototype solar energy system on a military base.

A development program for nuclear power plants for use on military installations is also recommended. A system requirements study is needed to provide a basis for such a development program.

- (2) Systems. The two Naval bases selected for an in-depth survey of their energy consumption patterns were the Great Lakes Naval Training Center (people-oriented training facility) and Pensacola Naval Air Rework Facility (industrial-oriented facility). Conclusions reached were divided into two time-related categories--near-term and advanced strategies.<sup>10,11</sup>

Near-Term strategies would result in energy savings of approximately 11 percent of CONUS use at Navy facilities, and pay for themselves within 5 years on the average on the basis of implementation throughout CONUS Navy shore facilities. These would not require R&D expenditures and would save the Navy over a quarter of a billion dollars, discounted

to present value, between now and 1990. The total cost estimated ranges between \$172 to \$256 million. The six strategies are:<sup>10</sup>

- Solid Waste as Energy Source
- Steam Distribution System Improvements
- Building Insulation Improvements
- Metering of Electricity for Family Housing
- Window Air-Conditioning Efficiency Improvements
- Energy Conservation in Lighting Design

Advanced strategies would result in significant energy savings on CONUS Navy bases prior to 1990. However, the breakeven point for some of the strategies would likely occur after 1990 since large R&D investments would be required. The five strategies are:<sup>11</sup>

- Solar Energy Applications (Hot Water, Heating, Cooling)
- Automated Building Control and Monitoring
- Fuel Cells
- Advanced Transportation Technology (Light Duty Diesel Engines and "Dial-A-Bus" Systems)
- Total Energy Systems

- (3) Assessment of Applications (Total Energy [TE] Systems).<sup>12</sup> The principal finding relating to overall system development is that there has been very little research devoted specifically to the optimization of total energy system efficiency in the past, and that there is presently only one major program ongoing, the Sundstrand organic Rankine cycle. There is concern that the flammability of the working fluid used in the Sundstrand system may severely inhibit market acceptance. Except for the Sundstrand TE System, advanced research relevant to TE is limited to components improved for other market applications. Other key findings based on a review of relevant TE research are as follows:

- Double effect absorption cooling is an almost perfected technology which can greatly expand TE system feasibility during critical summer operation.
- The closed Brayton cycle holds significant promise for a major improvement in prime movers for Total Energy and on-site power generation.
- Lithium bromide absorption air conditioning is the only system currently available that is applicable to heat recovery for total energy.
- More research in heat actuated air conditioning is needed if the feasibility of TE systems is to be improved.
- Stirling cycle research, although promising, is not oriented toward the development of a continuous duty, longlife engine.

The principal recommendation is that a concerted research program be initiated to advance the overall technology of total energy systems. Specific recommendations are made for the support of research in components which hold promise of very significantly expanding the range of total energy feasibility in the near future.

Another section of the report examines the application of total energy systems and of heat recovery in general to the specific environment of naval shore facilities. Since the Navy owns nearly 500 large shore-based engine generators, the installation and reliability aspects of converting non-TE engines to total energy operation are emphasized. A Navy-wide analysis is made of the heat recovery potential of currently installed engines, along with an examination of a variety of the characteristics of these engines and their locations. Operator personnel recruitment and training are identified as neglected factors in total energy operation which require improvement.

The principal conclusions are that heat recovery is a practical, technically sound energy conservation measure for use by the Navy on an individual case basis, but that certainty of successful operation requires increased attention to a number of previously neglected operational factors. Numerous specific conclusions are reached with respect to implementation of total energy, to heat recovery potential in the Navy, to equipment problems, and to operator personnel.

The overall recommendation is that the Navy should exploit total energy and heat recovery as an energy conservation method. Numerous specific technical and operational recommendations are included in the body of the text.

In addition to the foregoing investigations based on recommendations presented in Volume II of this series a study was conducted, because of specific interest within the Navy, to determine whether the use of ships in port to provide electrical power to shore facilities is a viable energy conservation approach. Technical and cost analysis is applied to information about existing naval equipment, resulting in the conclusion that steaming of ships in port to provide shore power is undesirable from operational, cost, and energy conservation standpoints. It is recommended that no further action be taken on this approach.

- (4) Experimental System. When the Department of Housing and Urban Development withdrew its support for technical reasons in May 1975, the project was terminated after completion of the design phase.<sup>13,14</sup>

b. Waste-to-energy Conversion Technologies

The results are covered in three separate reports, one for each subject area. The first provided the results of an ARPA-sponsored workshop to identify the most cost-effective technology of current state-of-the-art processes for military installations, the other two covering research into more advanced technologies for military applications.

- (1) Workshop. In a review of current and advanced waste-to-energy technology, 33 representatives of government and industry met in an ARPA-sponsored workshop to consider whether or not a cost effective operation could be realized in waste-to-energy processing of only 20 to 80 tons per day of solid waste--the amount of refuse which is typically disposed of daily at military installations without exploiting its inherent thermal energy.

Essentially, their findings were:<sup>15</sup>

- Of the various technologies, the one with the most likelihood of cost effective operation in the use of fuel made from refuse is to burn it in an existing boiler to generate process steam to be fed into existing installation heating/electric loads.

- Other possibilities such as new boilers or system augmentation with small package boilers also have promise. However, each installation should be individually studied since net costs or savings are highly dependent upon the local situation--fuel prices, labor costs, landfill costs, cost/load sharing with nearby communities, etc.
- The DoD should continue to monitor progress in more advanced technologies such as pyrolysis and fluidized bed for possible future applications.
- Laboratories of the three Services have an increasing knowledge and data base to evaluate individual military installations for possible applications of waste-to-energy technologies.
- Because of the potential savings in thermal energy and operating funds the DoD should encourage each military installation commander to investigate the possibilities for local application of waste-to-energy technology.

(2) Pyrolysis-Synthesis Process. As part of the Naval Weapons Center's Total Energy Community (TEC) Program, the solid waste conversion effort involved exploring processes for recovering energy from solid waste which would be practical and economical on military bases. Emphasis was placed on conversion of solid waste and development of liquid fuels for mobile power plant use.<sup>16</sup>

Two promising fuels were identified--polymer gasoline and methanol. Preliminary process flow sheets for these fuels were developed. These indicated that an energy conversion efficiency of 66% for polymer gasoline and 58% for methanol could be achieved.

Preliminary cost analyses were made for conversion facilities consisting of a front-end system for removal of metals and glass, a pyrolysis system for production of synthesis gas and a synthesis module for conversion to fuel. Effects of population and energy market value on fuel costs were studied.

A nominal 10-pound-per-hour pyrolysis system was constructed and put into operation. Checkout runs were made using a shredded-paper feed at feed rates to 10 pounds/hour.

(3) Fission-Waste Source. Utilizing the decay energy of solidified, mixed fission-products a study was made of the feasibility of developing a conceptual design of plants which would produce 5 MW of 350°F, 120 psi steam at military installations. A summary of major findings is given below:<sup>17</sup>

- A first 5-MW thermal output steam plant could become operational on the solidifiable wastes from the discharge of the U.S. civilian nuclear power industry by about 1980. By the year 2000, the total thermal-output capacity of such steam plants could grow to perhaps 200 MW (i.e., ~40 5-MW plants could operate on the wastes from U.S. nuclear power reactors at year 2000).
- A 5-MW steam plant appears competitive with equal-output burners of 33 cents per gallon fuel-oil, if RSSF-type receipts (for high-level waste storage services) are realized. Without such receipts, competitiveness requires that oil costs about 44 cents per gallon (heating oil at U.S. military installations presently falls in the 25 to 50 cents per gallon range according to Fort Belvoir). With storage receipts, a 5-MW plant might compete with 22-cent oil and with 33-cent oil without such receipts.
- Solidified fission-wastes represent a very small source of energy relative to the fission energy released by their fission-product source reactors; the ratio of the former to the latter being  $\sim 1.0 \times 10^{-4}$  (4-year-old wastes and 10-year usage assumed).
- The utilization of U.S. nuclear power fission-waste decay-energy could save some 60 millions of gallons of fuel oil per year by the year 2000 (one 5-MW thermal output plant saves  $\sim 1.5 \times 10^6$  gallons per year).
- Four-year-old wastes (solidified in the borosilicate glass form) appear economically optimum for steam plant operation. (Borosilicate-type solidification of 4-year-old wastes also promises a minimum number of canisters to accommodate the wastes from a given number of source reactors.)
- A partially water-shielded, 5-MW nuclear-waste steam plant could be built for a total of ~\$1.8M in quarter-plant sections over a 3- to 4-year period. The plant could be operated at

an annual cost of ~\$0.67 M/year, even without receipts for the 10-year interim storage of its 480 nuclear-waste canisters. With such receipts, the annual cost might be ~\$0.50 M/year. Canisters would be replaced at a rate of ~48 per year. This plant would require about a half-acre site and its inventory of radionuclides would total ~1.5 billion curies.

- A totally water-shielded design-philosophy has been noted (the "diving bell" concept) which could lead to a significantly smaller and cheaper plant than those thus far studied. Also, the operational complexity of the previously studied concepts might be simplified by an all-water shielded system.

c. Solar Energy

The results are covered in four separate reports. The first assessed the solar energy research and exploitation to identify potential avenues for research. The second addressed energy resource and technology alternatives for remote bases. The remaining two addressed the technical feasibility of two advanced research approaches in solar energy--one to grow vegetable matter for its fuel value, and the other basic research into storing solar energy in organic ring compounds.

- (1) Technology Assessment. The study concluded that, in utilizing solar energy for power supply needs, special attention has to be drawn to different energy situations which could be divided into three categories: the exceptional areas where a grid exists to connect power stations in industrial and urban centres with enough interconnected capacity to guarantee continuity of supply within a limited area, often at a level comparable to that of developed countries; the areas where isolated power stations meet, at least in part, the most urgent power requirements; and the areas-- which are the most numerous--where electricity is entirely lacking.<sup>18</sup>

Broadly speaking, for areas in the first category, solar energy may be unimportant unless cost studies can show that it could provide power and other useful energy at competitive rates. In areas of the second category, characterized by high fuel and generating costs, solar power might well be a useful supplementary source effecting fuel savings.

For many of the areas in the third category, which are by far the most typical in the underdeveloped countries and for which large-scale rural and village electrification cannot be foreseen in the near future, solar energy is the only source for power supply.

Economic developments and industrial growth of the world have accelerated the interest in research and development of other power resources, among them solar energy. The widespread interest in solar energy utilization is seen in relevant activities in basic and applied research of numerous countries throughout the world. However, with the exception of solar water heating, most possible applications of solar energy are still in the experimental and development stage and need further research in laboratories, pilot projects and field trials.

By virtue of its very nature of being a "new" source, it may be noted that solar energy contributes only an insignificant share to the total world energy production today. In industrialized countries, solar energy can be utilized for solar furnaces (for high-temperature research), solar power in space vehicles, and water and space heating. However, solar energy is likely to find its most important utilization in less developed countries, where solar energy in the near future will be a supplementary rather than a competitive source of energy, particularly in areas with favorable availability of solar energy, i.e. in the belt between latitudes 40° N and 40° S, in which most of the underdeveloped countries are located and are lacking conventional energy. However, latitudes up to 50° N and 50° S are by no means ruled out completely.

At the present state-of-the-art, a solar plant for the production of electric power would cost about three times more than conventional power, but as the cost goes up for nuclear, coal and gas systems, solar energy is bound to become more competitive. If sufficient research and development funds were provided, solar energy could become a viable economic alternative within 10 to 15 years.

- (2) Remote U.S. Bases' Alternatives. The study uses a power system model to evaluate the relative effectiveness of the three indigenous energy sources in satisfying remote base power requirements.

The model solves for energy collector size, storage requirements, and conventional power inputs. A standard remote base is positioned in five geographic locations, and the results of the simulation are compared and summarized. Initial cost comparisons are made of the several combinations of systems.<sup>19</sup>

A conclusion of the study is that there are sufficient indigenous energy sources at many remote bases to be of practical value. The state of the art of solar and wind systems is quite mature. The wave energy system, however, is not well understood, nor is it currently receiving much attention. The drawback of total indigenous energy systems is the high initial cost, due in part to the large storage system required. The mixed use of a conventional (petroleum-based) fuel system (generator-furnace) with an indigenous energy system would markedly reduce initial cost because the energy storage requirement would be reduced. For example, a combined solar system and conventional system appears to represent a good mix for Diego Garcia, whereas a combined wind and conventional system is better for Adak.

For all the ranges of parameters examined, the initial cost of the combined conventional and indigenous energy system exceeds the cost of a conventional system by at least a factor of three. Thus the indigenous energy system cannot, at present, be justified on the basis of cost for remote bases. But it does provide an energy alternative to the present situation of complete dependence on petroleum, and it may lessen the vulnerability of these bases in times of crisis.

- (3) Energy Plantation Concept. A thorough investigation of the possibility of "home-grown" perpetually renewable fuel generated on U.S. Army bases from plant material, especially at Forts Benning and Leonard Wood, has been made.

The major conclusions from the study are:<sup>20</sup>

- Energy Plantations are feasible for meeting the fuel needs for fixed facilities in at least fifteen large army bases in the eastern and central time zones;
- The cost of solid fuel produced in Energy Plantations would be about one dollar per million Btu, and the cost of SNG would be between about \$3.10 and \$4.20 per thousand standard cubic feet.

- Plant species which are most suitable for "Btu Bushes" at the army bases have been identified.
- Immediate steps to study the remaining open questions and to commence Energy Plantation system design should be taken.
- By implementing the program, several significant benefits can accrue:
  - Noise, dust and vision suppression at the perimeter of army bases.
  - Environmental and U.S. balance of payments advantages.
  - Natural-gas shortages and eventual unavailability would not affect continued operations at the army bases.
  - U.S. Army technological leadership in adaptation to future energy-tight conditions would be clear.
  - Essential military training and readiness would not be totally dependent on fossil-fuel supplies and in competition with civilian needs.

(4) Energy Storage Research. Refer to Appendix F for results of this basic research effort.

d. Geothermal Energy

Refer to Appendix E for results of studies conducted in this area of technology.

TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

In reviewing the technical results of the ARPA studies on Energy Applications at Military Installations it would appear that the research objectives were well served. Certainly by initiating its program in 1972, ARPA through its state-of-the-art assessments and early research programs had designed, by the time of the late 1973 oil crisis, a preliminary DoD road map for technological alternatives to petroleum-derived energy at its installations. Its continuing work through 1975 not only refined the road map but also advanced the state-of-the-art, as is evident in the follow-on actions of the Military Services and other federal agencies. Highlights of such actions are summarized below.

a. Total Energy Concepts and Systems

- (1) Several hundred copies of the report on the Assessment of Total Energy Systems have been distributed, with a large demand from the Services.<sup>9</sup> Additionally, the Naval Facilities Engineering Command has had the contractor studying R&D measures for solid waste energy conversion systems.<sup>21</sup>
- (2) The recommended Near-Term strategies for energy conservation and utilization of the Alternative Strategies reports<sup>10,11</sup> are being recommended/implemented at Naval installations. Certain of the recommended Advanced strategies (e.g. solar, total energy systems, heat recovery) are being studied for applications where they would have economical benefit to the Naval installations involved.<sup>22</sup>
- (3) Experimental System. The design of the Ft. Belvoir total utility plant is being applied in the planning for a similar plant at Ft. Benning.<sup>23</sup>

b. Waste-to-Energy Conversion Technologies

- (1) Workshop. The technical information and findings of the report<sup>15</sup> have been pertinent to recent refuse-derived-fuel experiments conducted by the Air Force at Wright-Patterson AF Base, Ohio, and those being conducted and further planned by the Navy at Norfolk, Va.<sup>24,25</sup>

- (2) Pyrolysis-Synthesis Process. The ARPA technical project<sup>16</sup> has continued at the Naval Weapons Center with FY75 and subsequent year funding by the Environmental Protection Agency. The objective has been to use the ARPA-sponsored pyrolysis experimental unit to arrive at an ethylene or other olefin product to be used in making gasoline.<sup>26</sup>
- (3) Fission-Waste Source. The Army is currently working jointly with the Energy Research and Development Agency to arrive at a mutually acceptable form of the waste elements to be used as a heat source at military installations. The Mixed Fission Product report<sup>17</sup> has served as a baseline for these later studies.<sup>27</sup>

c. Solar Energy

- (1) Technology Assessment. Although it would be difficult to associate it directly with any follow-on work, the report<sup>18</sup> has been widely distributed and accepted.<sup>28</sup> It would therefore appear to have contributed usefully to the knowledge for solar energy applications at military installations. It is interesting to note that all three Services are either conducting solar energy experiments or are planning/constructing facilities utilizing solar as an energy source.<sup>28,29,30</sup>
- (2) Remote U.S. Bases' Alternatives. Although it would be difficult to associate specific actions<sup>19</sup> by any of the military Services with this report, it has been widely circulated. In addition to the solar experiments previously noted, it should be also noted that the Air Force is erecting a 15 KW wind-powered experimental generator at F. E. Warren Air Base, Wyoming,<sup>30</sup> and the Navy has set up a 5 KW unit at Laguna Peak in California.<sup>29</sup>
- (3) Energy Plantation Concept. The report<sup>20</sup> provided a base of technology for later work by the contractor with the American Gas Association to estimate the potential for deriving synthetic natural gas from plant material. It also relates to a current research project sponsored by the Energy Research and Development Agency to study a photo-synthesis Energy Factory.<sup>31</sup>

ENERGY APPLICATIONS AT MILITARY INSTALLATIONS

## FUNDING SUMMARY\*

	<u>FY73</u>	<u>FY74</u>	<u>FY75</u>
SRI	\$164K		
Booz Allen & Hamilton	134K	\$25K	
COE		90K	\$ 3K
BMI			23K
NWC		40K	50K
RDA		150K	
Informatics	30K	30K	
RAND		90K	
Intertechnology Corp.		75K	
<hr/>			
Totals:	\$328K	\$500K	\$76K
Overall Total:	\$904K		

\*Not inclusive of research on geothermal or organic ring compounds.

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APPENDIX E

THE USE OF GEOTHERMAL ENERGY AT MILITARY INSTALLATIONS

## APPENDIX E

### THE USE OF GEOTHERMAL ENERGY AT MILITARY INSTALLATIONS

#### OVERALL PROGRAM

Recognition of the growing shortages and increased prices of fossil fuels, and our obvious dependence on foreign oil imports, caused the Director of ARPA to direct initiation of energy studies in the fall of 1971.. A fundamental consideration was that of energy requirements for military bases and other installations, both within the U.S. and overseas; to investigate use of possible alternative energy sources for meeting those needs; to determine problems involved; and to establish possible technological approaches to help solve those problems. At that time, 1971, installation energy requirements represented 40% of the total Department of Defense energy needs, and were increasing year by year.

One alternative for providing base and installation energy perceived by ARPA for early investigation was that of use of naturally-occurring geothermal energy at those bases and installations where such use could be developed. In December, 1971, an existing ARPA order<sup>1</sup> was amended to direct the Air Force Office of Scientific Research (AFOSR) to have its contractor, Informatics, Inc., include geothermal power as an optional subject area in its investigation of foreign research and development in geophysics. This was the first of a number of ARPA contract efforts covering a wide range of energy-related and materials shortages-related areas. In 1972, ARPA initiated a multi-year program with the overall objectives of determining the feasibility of developing hot-water geothermal systems for providing energy for use at military bases and installations, selecting candidate installations for further further study, and recommending programs for investigation and for development.

During fiscal years 1972 through 1976, ARPA directed and supported research by five contractors and the Naval Weapons Center, China Lake, California. These research efforts were contracted through and monitored for ARPA in individual contracts by the Air Force Office of Scientific Research, the Office of Naval Petroleum and Oil Shale Reserves, the Naval Intelligence Support Center, and the Naval Weapons Center.

a. Primary areas that were addressed as the program developed included:

- (1) Review of Soviet and Chinese research in and utilization of geothermal energy. (By Informatics, Inc.)<sup>1,5,7</sup>
- (2) Assessment of hot-water geothermal resources. (By the University of California, Riverside)<sup>2</sup>
- (3) Assessment of the potential for utilization of energy from the Coso Springs Area geothermal sources at and for the China Lake Naval Weapons Center. (By the University of Texas at Dallas and the Naval Weapons Center)<sup>4,6</sup>
- (4) Investigation of overpressured reservoirs. (By Southern Methodist University)<sup>2</sup>
- (5) Investigation of ultra-deep drilling for geothermal sources. (By Tetra Tech, Inc.)<sup>3</sup>
- (6) Studies of problems of corrosion connected with use of geothermal energy sources. (By Naval Weapons Center, China Lake)<sup>4</sup>

b. The objectives of the program were to:

- (1) Identify geothermal resources for military installations, and
- (2) Identify key problems for development.

Geothermal energy, the natural heat of the earth, which comes from decay of radioactive materials in the earth's crust, is trapped within the earth and can be utilized by man. Temperatures in the earth increase with depth at a world average of approximately 25°C/km but vary greatly at local hot spots. Although this energy resource is essentially unlimited, most of it is located too deep to be economically extracted with current drilling technology. Drilling can reach a depth of approximately 10 km and may some day reach 20 km. However, many geothermal resources are near the earth's surface and can be economically extracted.

Recent assessment of geothermal resources in the United States estimates that 46,000 MW-centuries of geothermal energy is available with current technology from hydrothermal convection systems, and an additional 34,000 MW-centuries of energy is recoverable from geopressed systems within the U.S. Geothermal energy has been tapped for electric power generation since

1904, although only recently has there been any rapid expansion and development to current world-wide power generation of 1420 MWe in seven nations. The U.S. has only one producing field, The Geysers, which is the largest producer of geothermal electric power (520 MW). An even larger energy resource is available from lower temperature geothermal fluids that can be used for space heating, agriculture, and industrial processes. Geothermal resources could ultimately produce 5 to 10% of the nation's energy needs.

Development of geothermal resources requires:

- Exploration and discovery of resources
- Energy extraction
- Consumer utilization
- Environmental engineering
- Control of chemical properties of fluids

## SCIENTIFIC AND TECHNICAL RESULTS

The ARPA Geothermal Energy program resulted in six project reports.

Of these:

- Three dealt with identification and evaluation of resources.
- One dealt with the chemistry of geothermal fluids, in particular with corrosion and scaling.
- One covered the critical problem of drilling for geothermal resources.
- One presented a review of the current state-of-the-art.

An energy model developed by Stanford Research Institute for ARPA provided the means for evaluating the technical and economic feasibility of all energy sources to supply the energy needs of military installations. The model was used to study potential geothermal energy systems, and indicated that the costs of installing and operating a geothermal energy system appear to be competitive with fossil fuel systems. Further study shows that at thirty-six military installations in CONUS and ten U.S. sites outside of CONUS, geothermal sources exist either on or near those installations.<sup>9</sup>

As a result of these studies, two target areas have been identified as prime candidates for development of geothermal energy at military installations; the Coso Hot Springs, on the Naval Weapons Center at China Lake, California, and the Marine Corps base at Twenty-nine Palms, California. In addition, two test sites are proposed in southern Texas for research and development of geopressured systems.<sup>9,13</sup>

The objectives of the ARPA funded research projects have been accomplished in that they have:

- Successfully identified military installations where geothermal resources are known to exist and can be developed.
- Identified key problems that must be solved before development can take place.
- Joint research projects with the Energy Research and Development Administration and U.S. Geological Survey are now taking place to develop these national resources.

Much of the publicized literature and research of the past has been devoted to use of geothermal energy for generation of electric power but, significantly, much more geothermal energy capacity has been devoted to a diversity of non-electric purposes.

Figure E-1 displays nonelectric applications as a function of temperature.<sup>15</sup> This figure also illustrates the diversity of applications, most of which will become more important as the cost of fossil fuels continues to rise. Certainly in the U.S., applications have been limited by the availability of inexpensive fossil fuels, as well as a lack of geothermal technology. Other factors, such as availability of markets and transportation problems to and from geothermal sources, must also be considered. Figure E-2 displays known non-electric applications by country.

Department of Defense installations may have a particular advantage in utilization of low cost geothermal heating sources because military bases essentially function as controlled communities. Since hot water sources are very widely distributed, many DoD sites have the potential for direct utilization of geothermal fluid for heating and refrigeration.<sup>15</sup> Besides the economics in conservation of fossil fuels, utilization of geothermal sources at remote DoD sites offers the potential advantage of some independence from oil supply lines.

Air conditioning can be accomplished with cool geothermal waters (less than 15°C) by direct circulation. Heat pumps can be used effectively for both heating and cooling, using geothermal fluid as the heat source or sink. (Heat pumps are now commercially available in most industrial countries and are becoming more and more competitive economically.) To obtain industrial refrigeration with temperatures below 0°C, ammonia-water refrigeration units have been used, but geothermal fluids of fairly high temperatures (about 175°C) are required for effective operation. For temperatures above 0°C lithium-bromide machines are available which require geothermal fluid temperatures of only about 70°C. The lithium-bromide refrigeration units are being manufactured on a routine basis in Russia to meet the great demand for refrigeration in the chemical industries. Although the Russians probably lead in the application of absorption refrigeration, an interesting installation of geothermal heating and air conditioning exists at the Rotorua International Hotel, New Zealand. The system is designed for the extreme climatic temperatures from -4°C to +30°C. A 130-ton (0.39 Gcal/h) lithium-bromide absorption unit requires

Figure E-1. Geothermal Applications as a Function of Temperature

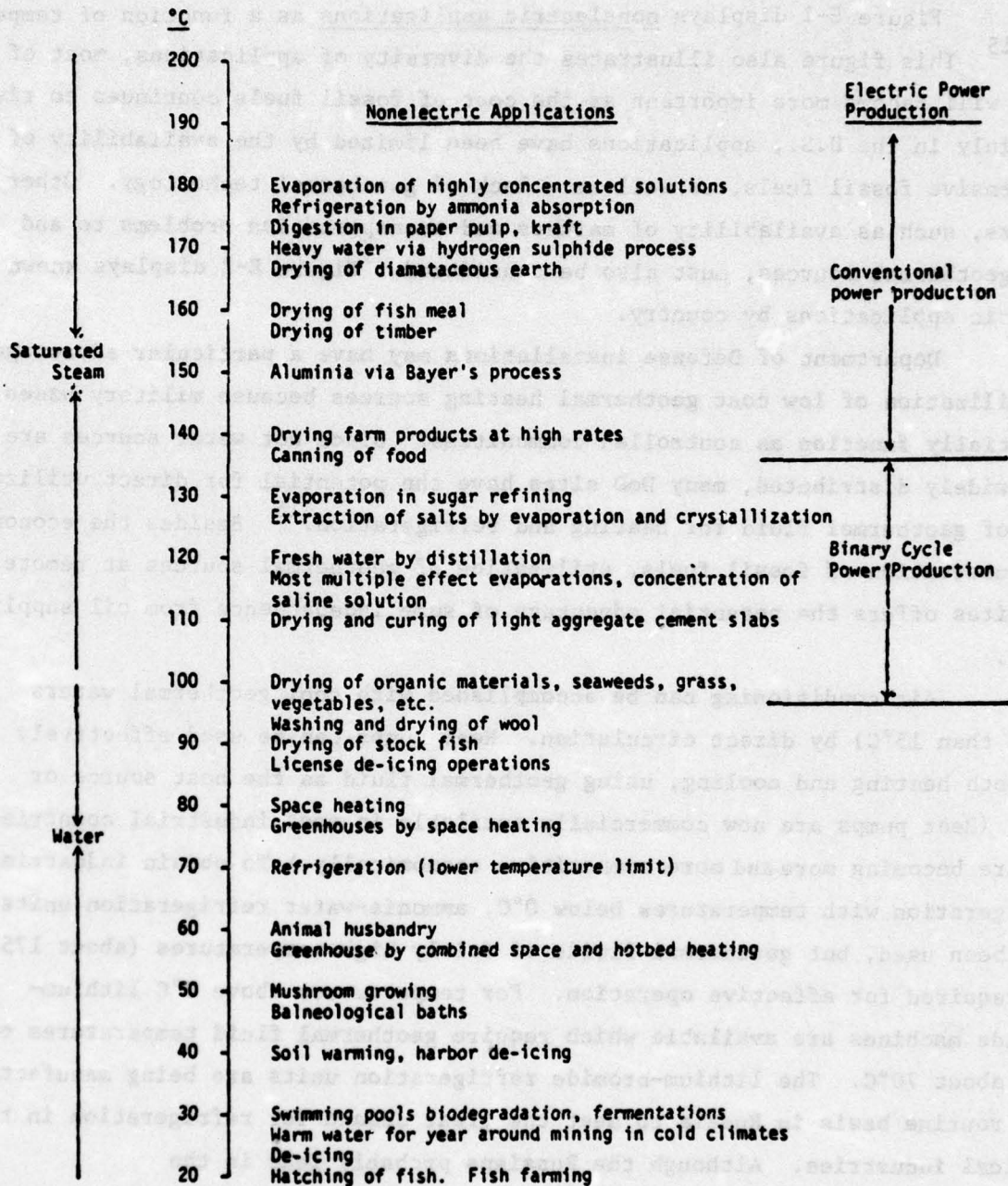


Figure E-2. Nonelectric Applications of Geothermal Energy

Country	Total Use (1975) (MW <sub>t</sub> )	Space Heating & Refrigeration	Food and Industrial Processing	Agriculture	Recreational and Health	Comments
Russia	5100	✓	✓	✓	✓	Russia started a national program in 1920 and is completing an additional 6 10,000 m of new test wells. Over 10 <sup>6</sup> T/yr of vegetables are produced.
Hungary	770	✓		✓	✓	131 wells provide district heating for 20,000 residents of Budapest and other cities. Animal husbandry and facilities heating are primary uses.
Iceland	590	✓	✓		✓	About 127,000 Icelanders' homes are heated from geothermal sources
New Zealand	100		✓		✓	The Tasman Pulp and Paper Mill at Kawerau uses geothermal process heat.
United States	16	✓			✓	Boise uses about 9 MW <sub>t</sub> and Klamath Falls about 5 MW <sub>t</sub> for residential space heating.
<b>TOTAL</b>	<b>6576</b>					

a heat input of 0.575 Gcal/h. The specific energy requirement of the absorption unit is therefore 1.47 kcal/h per 1 kcal of cooling. The Russian industrial units have approximately five times the capacity of this refrigeration unit.<sup>15</sup>

Figure E-3 shows the known world use of geothermal energy for production of electric power.<sup>15</sup> The generation of electric power from geothermal steam first began in Italy in 1904 from the Larderello Field where dry steam issues from vents in the earth. Continuous operation and growth has brought capacity to approximately 420 MW. Other geothermal fields received little attention because of the abundance of inexpensive fossil fuels. As of 1975 seven nations were producing electric power from geothermal energy sources, a total of 1420 MW. The U.S. was producing the most, though a late starter in 1960 and utilizing but one geothermal field, the Geysers in California producing 520 MW in 1975, with expansion planned to 1400 MWe by 1985.

Geothermal power plants can be somewhat arbitrarily classified according to the nature of the geothermal source. The five basic types of geothermal reservoirs listed in the order of the ease of development of electric power are:

- Vapor-dominated, where steam but little or no water comes to the surface.
- Flashed steam where water and steam must be separated at the surface.
- Hot water, not flashed (binary cycle).
- Geopressured reservoirs where both thermal and mechanical energy can be utilized.
- Dry hot rock where water must be injected to obtain steam.

The largest and most successful fields have been of the dry steam type as exemplified by the Geysers and the Larderello Fields. Flashed steam and hot water plants also are in operation but, to date, no power plants have been developed using either the dry hot rock or the geopressured systems.

The location of geothermal sources is controlled by geologic events primarily of the late Cenozoic period and tend to follow lines of tectonic activity. Other than location, the primary technical factors dictating utilization of geothermal sources are:

Figure E-3. Geothermal Power Plants of the World

Geothermal Power Plant (1975)	1975 Capacity, MWe	Number of Turbines	Reservoir Type*	Res. Temp. °C	Res. Area, sq. mi.	No. Producing Wells	Ave. Well Depth (ft)	Production Bore Diam. (in.)	Comments
The Geysers, USA	520	11	DS	250	180	88	3000	8 $\frac{5}{8}$	Growth: 1400 MWe by 1985. Generation began in 1960 at 12.5 MWe. Geology: Metamorphosed highly fractured Franciscan shale and sandstone. Disposal: Steam is condensed and reinjected. Noncondensable gases, primarily CO <sub>2</sub> and H <sub>2</sub> S, are vented to atmosphere
Larderello, Italy Monte Amiata, Italy	420	15	DS	200	150	467	3300	13 $\frac{3}{8}$	Growth: Generation began in 1904. Geology: Cavernous limestone and anhydrite with impermeable schistous clays above. Disposal: Condensate gases to natural drainage. High in boron.
Wairakei, New Zealand Kawerau, New Zealand Broadlands, New Zealand	193	7	FS	270	900	61	2500	7 $\frac{5}{8}$	Growth: 300 MWe projected. Production began in 1958. Geology: Rhyolitic pumice breccia and open jointed welded tuft, in region of volcanism and faulting. Pleistocene. Disposal: Brine is discharged into a large river. Land subsidence is occurring.
Hachimantai, Japan	10	1	?	?	?	?	3000	?	Growth: Production started in 1971. Data lacking.
Hatchobaru, Japan	50	2	FS	?	?	?	?	?	Growth: Under construction, data lacking.
Matsukawa, Japan	20	1	DS	240	*	5	3600	7 $\frac{5}{8}$	Growth: 60 MWe expected by 1980. Production started in 1966. Geology: Andesitic volcanics. Pleistocene. Disposal: Condensate discharged into natural drainage.
Onikobe, Japan	25	1	DS	280	?	12	3000	?	Growth: Construction started April 1973. Completion due 1975.
Onuma, Japan	10	1	FS	260	?	3	4500	?	Growth: Operation began in 1973 at 4.8 MWe.
Otake, Japan	13	1	FS	200	?	5	3000	7 $\frac{5}{8}$	Growth: Operation began in 1967 at 12 MWe. 60 expected by 1980
Cerro Prieto, Mexico	75	2	FS	300	10	15	4500	7 $\frac{5}{8}$	Growth: 150 MWe by 1982. Geology: Highly fractured sandstone and shale at The San Jacinto Fault Zone. Late Tertiary. Disposal: Brine follows natural drainage to Gulf of California. Condensed steam supplies potable water.
Pathe, Mexico	3.5	1	FS	150	?	12	1000	?	Growth: Experimental plant started in 1958. No expansion planned.
Namuffjall, Iceland	3.0	1	FS	260	20	4	2200	?	Growth: 3 MWe plant in operation since 1969. 60 MWe construction started in 1974.
Krafla, Iceland	60								Geology: Late Quaternary centers of dacitic and rhyolitic volcanism.
Paratunka, USSR	0.75	1	HW	82	?	8	1300	7 $\frac{5}{8}$	Growth: Binary cycle operation with Freon began in 1964.
Pauzhetka, USSR	5.0	2	FS	170	?	8	1000	?	Growth: Operation began in 1967 at 3 MWe. Expansion to 20 MWe is planned.
Makhachkala, USSR	12	?	FS	160	?		12,000	?	Growth: Under construction.

\*Reservoir type: DS = dry steam, FS = flashed steam, HW = hot water (not flashed)

- Temperature of the reservoir
- Flow rates available from the wells
- Depth of the reservoir
- Purity of the geothermal fluids.

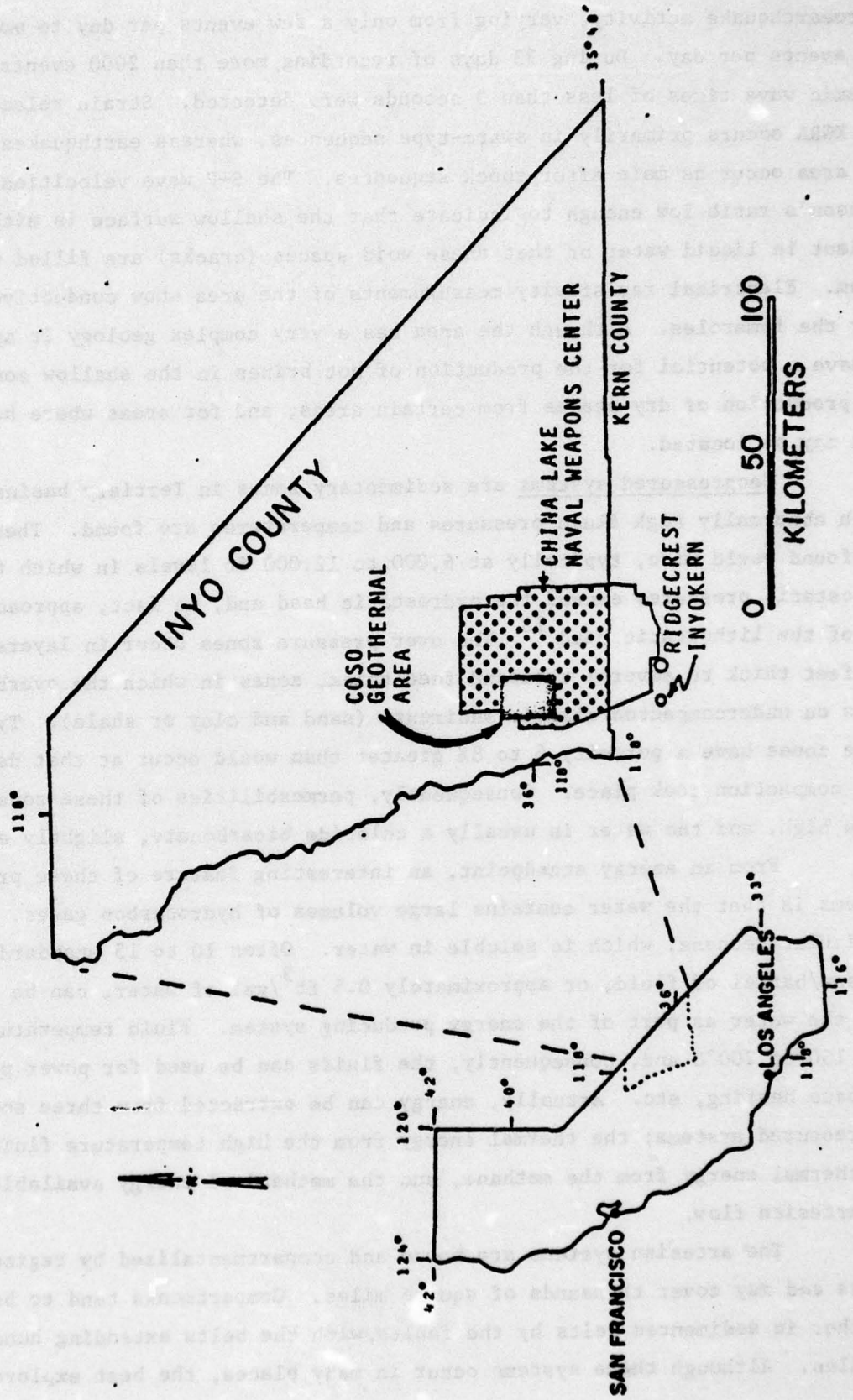
The Coso Hot Springs is identified as a prime candidate for development of geothermal energy at a military installation.<sup>8,9,10,11</sup> The Coso geothermal area, located primarily in the China Lake Naval Weapons Center, in Inyo County, California, (Figure E-4) is situated in a tectonically active area of young basaltic and rhyolitic volcanism.<sup>10</sup> In the fall of 1974 intensive study was begun including:

- Geologic mapping
- Geo-chemistry of the late Cenozoic rocks
- Geochronology of the late Cenozoic volcanic rocks
- Geochemistry of the geothermal fluids
- Further study of gravity
- Aeromagnetics
- Addition heat flow determinations
- Both active and passive seismic investigations
- Patterns of arrival times for teleseisms
- First order leveling studies
- Geodimeter trilateration
- Additional geoelectric and electromagnetic surveys

These investigations involve personnel of the USGS, Battelle Northwest Laboratories (BNW), Naval Weapons Center (NWC) and the University of Texas at Dallas (UTD).

Results show that heat flows vary from 2.0 to 16.0 heat flow units ( $\mu$  cal/cm<sup>2</sup> sec) with measured temperatures of 100°C at 200 m at the site of the first deep slim hole. During the summer of 1974, and again in 1975, seismographs installed in the Known Geothermal Research Area (KGRA) showed considerable

Figure E-4. Coso Geothermal Area, California<sup>11</sup>  
(Shaded rectangle depicts area of  
the microearthquake investigation.)



microearthquake activity, varying from only a few events per day to more than 115 events per day. During 33 days of recording, more than 2000 events of S-P seismic wave times of less than 3 seconds were detected. Strain release in the KGRA occurs primarily in swarm-type sequences, whereas earthquakes outside the area occur as main after-shock sequences. The S-P wave velocities infer a Poisson's ratio low enough to indicate that the shallow surface is either deficient in liquid water or that these void spaces (cracks) are filled with steam. Electrical resistivity measurements of the area show conductive zones near the fumaroles. Although the area has a very complex geology it appears to have a potential for the production of hot brines in the shallow zones, for the production of dry steams from certain areas, and for areas where hot dry rock may be located.

Geopressured systems are sedimentary zones in Tertiary basins in which abnormally high fluid pressures and temperatures are found. These zones are found world wide, typically at 6,000 to 12,000 ft levels in which the hydrostatic pressures exceed the hydrostatic head and, in fact, approach 75 to 90% of the lithostatic head.<sup>13</sup> The over pressure zones occur in layers from a few feet thick to several thousand feet thick, zones in which the overburden rides on undercompacted clastic sediments (sand and clay or shale). Typically these zones have a porosity 6 to 8% greater than would occur at that depth if full compaction took place. Consequently, permeabilities of these zones tend to be high, and the water is usually a chloride bicarbonate, slightly alkaline.

From an energy standpoint, an interesting feature of these pressured systems is that the water contains large volumes of hydrocarbon gases, in particular methane, which is soluble in water. Often 10 to 15 standard ft<sup>3</sup> of methane/barrel of fluid, or approximately 0.5 ft<sup>3</sup>/gal of water, can be extracted from the water as part of the energy producing system. Fluid temperatures vary from 150 to 200°C and, consequently, the fluids can be used for power production or space heating, etc. Actually, energy can be extracted from three sources in geopressured systems; the thermal energy from the high temperature fluids, the thermal energy from the methane, and the mechanical energy available from the artesian flow.

The artesian systems are bound and compartmentalized by regional faults and may cover thousands of square miles. Compartments tend to be linked together in sedimented belts by the faults, with the belts extending hundreds of miles. Although these systems occur in many places, the best explored is in

the northern Gulf of Mexico basin along a fault system about 750 miles long on the Texas and Louisiana Gulf coast. Since the 1920s, more than 300,000 wells have been drilled in search of petroleum and have penetrated geopressured zones in this basin. Known occurrences of geopressured systems<sup>13</sup> are as follows: the U.S. (Arkansas, California, Louisiana, Oklahoma, Texas, Wyoming), the Arctic Islands, Mexico, South America (Venezuela, Trinidad, Columbia, Argentina), Japan, New Guinea, Indonesia, South China Sea, Burma, India, Iraq and Pakistan, Algeria, Morocco, Nigeria, Mozambique, Austria, France, Germany, Holland, Italy, Hungary, Poland, Rumania and Russia. Department of Defense installations exist over geopressured regions in the United States, Holland, West Germany, Berlin, Italy, South China Sea, Alaska, Canada, Taiwan and Japan. Energy could be extracted from these reservoirs for DoD use but to date no such applications exist and additional R&D projects are needed. A good place to extract this energy is in the Gulf coast region of the United States because of the knowledge available from oil exploration activities.

One report<sup>13</sup> has proposed two sites in southern Texas where testing of the geopressured reservoir concept can take place. The two sites proposed are located south of Corpus Christi, Texas, near the Mexican border, as shown in Figure E-5. These sites have been proposed after consideration of both technical and environmental features, and in both cases the existence of geopressure systems has been verified by existing wells. The characteristics of the Sebastian site are summarized in Figure E-6 and the Port Mansfield site in Figure E-7. The Sebastian site is in a remote agricultural section where cotton is grown and is adjacent to scrub woodlands and a wildlife refuge. Waste waters can be disposed of by an existing drainage system and land subsidence would have a minimal effect because of the remoteness from towns and villages. The Port Mansfield site is approximately 7 miles inland from the Laguna Madre of the Gulf of Mexico, on land belonging to the King Ranch, about 3 miles northwest of the Willimar oil fields, 4 miles east of the small ranch community of El Sauz. The region is almost completely useless for crop growing because of the high salinity and frequent water logging of the soil, but it is being used for cattle range land. The particular site selected has been leased by the Federal government for a U.S. Naval Research station for satellite detection. Again, the effect of subsidence and other project activities on the environment would be minimal.

Based upon the information available at the two sites, the report<sup>13</sup>

recommends construction and operation of a pilot plant for electric power production, using water from a single well, preferably at the Sebastian site. The principal objectives of the five-year pilot project would be as follows:

- Demonstrate the feasibility of power production from thermal and mechanical energy storage in a geopressured subsurface reservoir.
- Determine the production pressure history of the well. Evaluate the contributions to production from gas drive and de-watering of the shale.
- Study the change in water chemistry with production as an indication of the change in shale composition in the reservoir.
- Develop optimum methods for converting the mechanical energy stored in the over pressured water to electrical energy.
- Investigate the use of the facility as a standby power facility. Determine the effect of shutting down the well for long periods of time.
- Determine, by use of sensitive instrumentation, the surface effects resulting from withdrawal and reinjection of large amounts of water required for power production.

The accomplishment of these objectives would require drilling of one to three deep wells, a similar number of shallower wells into normal pressured formations for reinjection, installation of a 5 to 10 MW turbine alternator system, installation of surface plumbing and well control equipment, preparations and arrangements for disposal of saline waste water, completion of legal arrangements for land use from the current owners, preparation of an environmental impact statement, and installation and monitoring of instrumentation to gather the required scientific information. Successful penetration of the geopressure reservoir is essentially assured because of data available from other wells in the region. The estimated characteristics of a typical deep well are given in Figure E-8. Under the given assumptions, each well could reasonably be expected to produce about 2.5 MW of electrical power with an estimated lifetime of 20 to 30 years.

Drilling of production wells is one of the most expensive investments for any geothermal development. It is not unusual for a well to cost \$1 million, which, when completed, will produce about 5 MW electrical, yielding a capital

Figure E-5. Texas Gulf Coast<sup>13</sup>

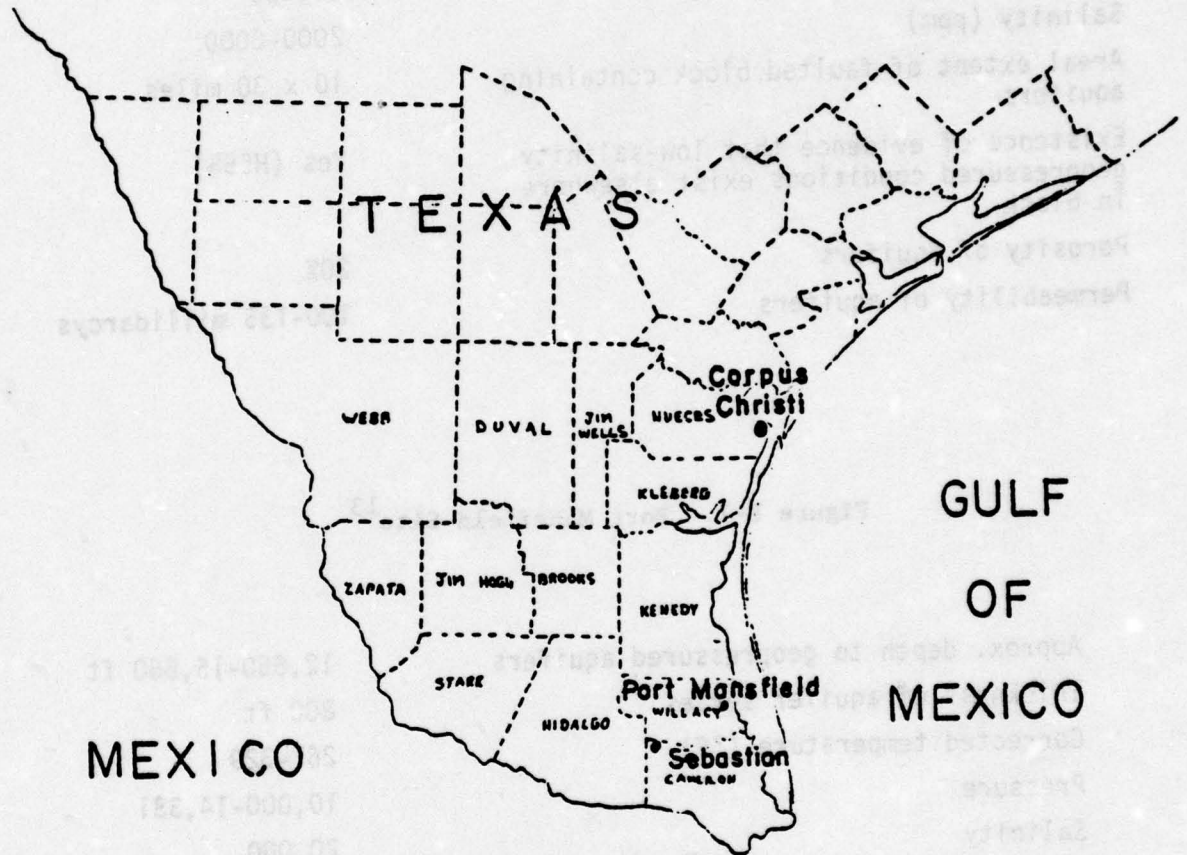


Figure E-6. Sebastian Site<sup>13</sup>

Depth to geopressed aquifers	14,300 ft
Thickness of aquifer series	700 ft
Corrected temperature (°F)	320-325
Pressure (psi)	11,600
Salinity (ppm)	2000-6000
Areal extent of faulted block containing aquifers	10 x 30 miles
Existence of evidence that low-salinity geopressed conditions exist elsewhere in block	Yes (H555)
Porosity of aquifers	20%
Permeability of aquifers	100-135 millidarcys

Figure E-7. Port Mansfield Site<sup>13</sup>

Approx. depth to geopressed aquifers	12,650-15,660 ft
Thickness of aquifer series	800 ft
Corrected temperature (°F)	267-329
Pressure	10,000-14,381
Salinity	20,000
Areal extent of faulted block containing aquifers	About same as San Sebastian
Existence of evidence that low-salinity geopressed conditions exist elsewhere in block	Yes (C-177)
Porosity of aquifers	20%
Permeability of aquifers	100-135 millidarcys

Figure E-8. Estimated Production Well Characteristics at the Sebastian Site.<sup>13</sup>

Water Viscosity		0.2 cp
Total Salinity		2000-6000 ppm
Sand Porosity		0.25
Sand Permeability	good	0.3 darcy
	average	0.05 darcy
Reservoir Pressure		12,000 psi
Well Head Pressure		5000 psi
Well Depth		14,600 ft
Bore Hole Radius		0.3 ft
Well Production		50,000 bbls/day ( $2.1 \times 10^6$ gal/day)
Well Head Temperature		325°F
Plant Discharge Temperature		212°F
Thermal Energy ( $\Delta T = 113^\circ\text{F}$ )		942 Btu/gal
Thermal Conversion Efficiency		10%
Power Production		2.5 MWe/well*

\*Thermal equivalent of recovered methane and of the mechanical energy are not included. With these factors included the energy would be about 4 MW/well.

investment ratio of \$200/kW. That cost includes drilling, casing, cementing, well completion and wellhead equipment. It does not include any of the above ground plumbing and plant costs. The cost of nonproducing wells and reinjection wells can cause drilling costs to become one of the largest single factors of geothermal development.

Historical developments of the drilling industry fall into two categories. Deep large diameter production wells are drilled with a conventional rotary drilling rig developed by the oil industry. The diamond drill rig, on the other hand, was developed by the hard rock mining industry to produce continuous core samples and not to be used in production. It appears both technologies will merge in the development of geothermal resources.

The diamond drilling, or so-called slim hole drilling, is typically done with a small drill rig mounted on the back of a truck for mobility, and is usually limited to holes less than 6 in. in diameter and 5000 ft deep. Such holes are drilled primarily to obtain information and not for the production of energy. The primary use for the slim hole drilling in geothermal energy development will be during exploration to locate and evaluate our resources.

Since slim hole drilling uses a diamond coring bit, a continuous lithological record is obtained as the drilling is done, and cores can be used for evaluation of mineralogical, chemical, and physical properties. Such operations enable mining engineers and geologists to delineate the boundaries of ore bodies and probably can be used equally effectively on geothermal reservoirs. The diamond drill bits typically run at fairly high speeds (200 to 1200 rpm), and under difficult operations may last for only about 100 ft before they are extracted and salvaged.

The drill rig is operated with a two man crew and its mud system is fairly simple. Because slim hole drilling is done with fairly small and simple drill rigs, requiring little auxiliary equipment, environmental impacts of exploratory drilling and, consequently, exploratory costs are low.

The primary disadvantages of slim hole drilling derives from the small diameter of the hole. The probability of leaving a hole due to bridging or caving is greater, and fishing for lost or damaged equipment is more difficult than in larger diameter holes. Instrumentation and blowout prevention systems are much more limited than for the rotary drilling rig. Consequently, slim hole drilling will find its place in the geothermal industry as an exploration tool

to be used with other geophysical surveys and not as a replacement for rotary drilling.

Rotary drill rigs vary in size from those not much bigger than slim hole drill rigs to the massive systems for deep ocean drilling. Hard formations are drilled with tri-cone carbide insert bits which typically run from 100 to 400 ft at less than 100 rpm with axes of the cones offset so that a skidding-rolling action crushes the rock. As with slim hole drilling, drilling fluids are pumped down the center of the drill string, and around the drill bit to cool it and remove drill cuttings.

The drill string is driven through an appropriate transmission system by 3 to 5 large diesel engines, often with a total of 2000 or more horsepower. The drill rig is operated by a crew of five or more men per shift to keep the drill rig operating on a 24-hr basis. The deepest holes currently being drilled are 30,000 to 35,000 ft with new depth records being set every year. However, the average depth is about 5500 ft for the 20,000 to 50,000 wells completed each year by the U.S. drilling industry. Most of these holes are drilled in relatively soft sedimentary formations in search of gas and oil. The drilling costs per foot under these conditions are \$30 to \$50/ft, a deceptively low cost for typical geothermal drilling. Most geothermal wells are drilled in very hard igneous formations at drilling costs 2 to 3 times the above figures.

The rotary drilling industry has had many years to mature into a highly specialized well-developed technology, largely without the support of government research. Each operation (drilling, mud preparation, logging, casing, cementing, well testing and completion) is done by companies who often specialize in only one of the operations. This has proven highly efficient since most of the specialists are needed for only a short period of time during the total drilling operation.

As the wells are drilled to greater and greater depths, the costs per foot increase exponentially because proportionally more and more time is devoted to nonproductive drilling operations associated with taking cores, changing bits, etc. For these reasons, the current technology will probably reach its economic depth limit prior to 50,000 ft.

High temperatures cause the second basic limitation with current technology. At temperatures above 250 to 300°C, the journal bearings on the drill bits do not function properly, the carbide inserts fall out (due to different coefficients of expansion), logging and downhole instrumentation

systems often fail to work, the drilling fluids break down, and cements do not harden properly. The combination of high temperatures and depths beyond 35,000 ft will prove particularly devastating as the tensile strength and compression strength of drill strings and casings are stretched beyond their limits.<sup>14</sup>

Novel drilling techniques are currently under investigation in various places around the world. Electric heating and laser techniques have been under investigation at Los Alamos Scientific Laboratory for several years, although these techniques are still confined to laboratory use.

One of the most promising new techniques is under development by M. I. Tsiferov, a Russian explosives expert, who, since 1948, has been working on an underground rocket,<sup>15</sup> now relatively well developed and registered under a Soviet patent. It is approximately 20 cm in diameter and 2 m long. It drills by releasing a stream of high pressure gas (at pressures between 500 and 2500 atm) to disintegrate the rock immediately in front of the rocket head. Simultaneously, side jets of gas cause the rocket to rotate while a flame vortex rocket engine in the rear drives the rocket forward and ejects disintegrated material. The rocket has equivalent energy of 10,000 to 50,000 hp and has produced shallow wells, 1 m diameter, approximately 17 m deep, in about 18 sec and can be recovered and refueled in 20 minutes for repeated operation. Potentially, a sequence of these rockets could be used to drill a single hole to great depths.

Chemistry problems associated with geothermal fluids are corrosion, erosion, precipitation and scaling (CEPS). All four of these problems can occur at various places in a power plant or more generally in any system that utilizes geothermal fluids.

Many geothermal fluids tend to be very corrosive because of a low pH (1.5 to 2). Corrosion may occur in a variety of forms: uniform corrosion, galvanic corrosion, pitting and crevice corrosion, fretting and erosion corrosion, intergranular corrosion, corrosion fatigue, sulphide corrosion and hydrogen embrittlement, stress corrosion cracking, and high temperature oxidation.

To date, satisfactory analytical and computer models do not exist that account for both the chemical reactions and the heat and mass transfer simultaneously. Although such models would be useful in predicting the effects of

geothermal fluids on power plants and other operations prior to construction, they are difficult to develop because of the extreme chemical complexity of geothermal fluids from site to site. This is illustrated<sup>8</sup> in Figures E-9 and E-10. These analyses come from major geothermal fields of the world for both dry steam and hot water systems and show variations in pH from 1.8 to 8.6, while the total dissolved solids vary from approximately 400 at Larderello to almost 260,000 ppm at the Salton Sea.

Each constituent in water has its own solubility characteristics as a function of pressure and temperature, and almost every phase of power plant operation is influenced by one or more. In the Cerro Prieto and Wairakei fields the water in the well tends to flash to steam in the upper third of the well, causing precipitation scaling on the casing, building up to restrict the flow, and further reducing the pressure and increasing the rate of deposition. Somewhat similar scaling and precipitation problems occur in heat exchangers where rapid temperature changes are taking place. Reinjection of cool, super-saturated geothermal fluids into the reservoir tends to plug the formation immediately around the well, reducing permeability and restricting usefulness of the well. Release of noncondensable gases, in particular hydrogen sulphide, into the atmosphere tends to corrode exposed metals and is often blamed for the failure of electrical apparatus in the immediate vicinity.

Corrosion research work initiated under this program, conducted at Coso Hot Springs, has been testing a variety of metals and nonmetal products over long-term exposures to geothermal fluids under field conditions. An analysis of the geothermal fluids at Coso is given in Figures E-11 and E-12 where very wide variation in pH is noted. Corrosion arrays have been set up to test samples under both oxygen poor (anaerobic) and oxygenated (aerobic) conditions within the sample pipes. Arrays of pipes, valves, tees, and other plumbing fixtures are under test, including a variety of galvanized pipe, black iron pipe, copper pipe, PVC, transite, 6063 aluminum, stainless steel, ADS plastic, and a variety of other materials. Visual estimates of the damage to a variety of the samples is given in Figure E-13. Some materials show little failure and even some relatively inexpensive materials, such as mild steel, show encouraging results. This research is continuing.

Figure E-9. Chemical Analyses of Waters Associated with Lardarello, Wairakei and the Geysers Areas in ppm

8

Location: Water Type: System Type:	Lardarello, Italy <sup>a</sup> SO <sub>4</sub> (CO <sub>3</sub> )(Cl) hot water	Well #4 Wairakei, N.Z. <sup>b</sup> Cl hot water	Well #5 Wairakei, N.Z. <sup>c</sup> HCO <sub>3</sub> -SO <sub>4</sub> vapor dominated (1)	The Geysers, Calif. <sup>d</sup> HCO <sub>3</sub> -SO <sub>4</sub> vapor dominated	The Geysers, Calif. <sup>e</sup> Acid Sulfate vapor dominated
SiO <sub>2</sub>	...	386	191	66	225
Al	Trace	...	...	...	16
Fe	Trace	...	...	...	63
Mn	...	...	...	...	1.4
As	...	...	...	...	...
Cu	...	26	12	58	47
Mg	3.0	<0.1	1.7	108	281
Na	56.6	1,130	230	18	12
K	32.0	146	17	6	5
Li	...	12	1.2	...	...
NH <sub>4</sub>	19.0	0.9	0.2	111	1,400
B	...	...	...	...	9.5
HCO <sub>3</sub>	89.7	35	670	176	0
CO <sub>3</sub>	...	0 (?)	...	...	...
SO <sub>4</sub>	137.4	35	11	766	5,710
Cl	42.6	1,930	2.7	1.5	0.5
F	...	6.2	3.7	...	...
Br	...	...	...	...	...
NO <sub>3</sub>	...	...	...	...	...
B	13.9	26	0.5	15	3.1
H <sub>2</sub> S	...	1.1	0	0	...
Total Reported	396.2	3,750	1,140	1,330	7,770
pH	...	8.6	6.7	neutral	1.0+
Temperature, °C	300	228+	high	100	boiling (1)

<sup>a</sup>Deepest well of hot-water field on south border Lardarello's steam fields (Cataldi and others, 1989). Original analysis in ppm, supplied by R. Cataldi, 1970.

<sup>b</sup>Typical of shallow Wairakei system; 375 meters deep with maximum temperature of 245°C (Rawell and others, 1957). Analysis by Wilson; also contains 11 ppm free CO<sub>2</sub> (Wilson, 1955; quoted in White and others, 1963, p. 740).

<sup>c</sup>Western part of Wairakei field (Wilson, 1955, quoted in White and others, 1963, p. 747). Similar to some waters of vapor-dominated system; 467 meters deep, maximum 217°C at 271 meters.

<sup>d</sup>Kitchen Cauldron, White and others, 1963, p. 747, modified from Allen and Day, 1927.

<sup>e</sup>Devils Kitchen, White and others, 1963, p. 746, modified from Allen and Day, 1927.

Figure E-10. Analyses of Fluid From Wells in the Salton-Mexicali Geothermal Province<sup>8</sup>

	Salton Sea geothermal field		Cerro Prieto geothermal field	
	I.I.D. No. 1 <sup>a</sup>	I.I.D. No. 2 <sup>b</sup>	M-5 <sup>c</sup>	M-8 <sup>c</sup>
Sodium	50,400	53,000	5,820	6,100
Potassium	17,500	16,500	1,570	1,860
Lithium	215	210	19	17
Rubidium	135	70	...	...
Calcium	28,000	28,800	280	390
Magnesium	54	10	8	6
Strontium	400	440	...	...
Barium	235	250	...	...
Iron	2,290	2,000	0.2	...
Manganese	1,400	1,370	...	...
Zinc	540	500	...	...
Boron	390	390	9.1 <sup>c</sup>	15 <sup>c</sup>
Chlorine	155,000	155,000	10,420	11,750
Fluorine	15	...	...	...
Bromine	120	...	14.1	14.3
Iodine	18	...	3.1	3.2
Silica	400	400	740	770
Sulfate	5.4	...	0.0	0.0
Hydrogen sulfide	16	... <sup>b</sup>	700	...
Bicarbonate	> 150	690 <sup>b</sup>	73	890
Carbon dioxide	...	...	1,600	...
Total as reported	258,973	259,000	19,018	21,915

<sup>a</sup>White, 1968, Table 1.

<sup>b</sup>Halgeson, 1968, Table 1; HCO<sub>3</sub> calculated from total CO<sub>2</sub> of 500 ppm; total sulfur given as 30 ppm.

<sup>c</sup>Spiewak, et al, 1970, Table II; boron calculated from H<sub>3</sub>BO<sub>4</sub>.

Figure E-11. Analysis of Fluids and Alteration Products in the Coso Thermal Area<sup>8</sup>

Analysis	Location						
	Devil's Kitchen, clear pool	Resort, shallow steam well	Resort, shallow well next to fault scarp	Resort, shallow well at old steam bath	Devil's Kitchen, siliceous residue	Devil's Kitchen, green siliceous residue	Resort, red mud
	% Residue on evaporation to dryness				% of sample		
Constituent:							
Si .....	10-100	10-100	10-100	10-100	10-100	10-100	10-100
Fe .....	...	3-30	3-30	3-30	.1-1	1-10	1-10
Al .....	1-10	1-10	1-10	3-30	1-10	3-30	3-30
Ca .....	3-3	.1-1	.1-1	1-10	.03-3	.01-1	.1-1
Mg .....	.1-1	3-3	3-3	3-3	.01-1	.003-03	.1-1
Na .....	.03-3	3-3	.1-1	1-10	.01-1	.03-3	.1-1
K .....	3-3	.1-1	.1-1	3-30	...	3-3	3-3
Mo .....	...	.0003-003	.0003-003	...	...	...	...
Zn .....	...	.003-03	.01-1	...	...	...	...
Sn .....	...	...	...	.01-1	.001-01	.001-01	.003-03
Co .....	...	...	...	.001-01	...	.0003-003	...
Sc .....	...	...	...	.0003-003	...	.0003-003	.003-03
Y .....	...	...	...	...	...	.001-01	...
B .....	3-3	.03-3	...	.1-1	.01-1	.003-03	.001-01
Mn .....	.003-03	.03-3	.03-3	.1-1	.001-01	.0003-003	.003-03
Ag .....	...	...	...	...	...	...	.0003-003
Cu .....	.003-03	.01-1	.003-03	.01-1	.003-03	.003-03	.003-03
Ti .....	.03-3	.1-1	.1-1	.1-1	.1-1	3-3	3-3
Sr .....	.01-1	.003-03	.003-03	.003-03	.01-1	.03-3	.03-3
Ni .....	.003-03	.0003-003	.0003-003	.003-03	.001-01	.003-003	.001-01
V .....	.001-01	.001-01	.001-01	.001-01	.001-01	.003-03	.003-03
Pb .....	.001-01	.001-01	.003-03	.03-3	.001-01	.01-1	.003-03
Ba .....	.003-03	.01-1	.01-1	.01-1	.01-1	3-3	.03-3
Ga .....	.001-01	.001-01	.001-01	.001-01	.0003-003	.003-03	.001-01
Cr .....	.0003-003	.0003-003	.0003-003	.001-01	.0003-003	.001-01	.003-03
Zr .....	.0003-003	.003-03	.003-03	.003-03	.01-1	.03-3	.003-03
Be .....	.0003-003	.001-01	.0003-003	...	...	...	...
Total dissolved solids, ppm .....	2,500~	2,800	2,800	2,700	...	...	...
pH .....	1.5	4.5	4.5	...	...	...	...
Temp., °F .....	176	203	203	...	...	...	...

Figure E-12. Water Analysis of Samples from Coso No. 1 Drill Hole Taken at Depth of 375 Feet<sup>8</sup>

Sample 1 was taken from the well discharge (clear water) at completion of drilling after blowing the well with compressed air for over 1 hour. Samples 2 and 3 were taken after the well was idle for 7 months. Sample 2 is from the first and third bailer, and Sample 3 from the 13th and 14th bailer.

Data	Sample No.		
	1	2	3
<b>Data:</b>			
Sample taken .....	27 Jun. 67	Mar. 68	Mar. 68
Analysis .....	12 Jul. to 3 Aug. 67	16 Apr. 68	16 Apr. 68
Temp., °F .....	240	287	287
<b>Constituent, ppm:</b>			
Ca .....	72.8	359.0	74.4
Mg .....	0.5	0.6	1.0
Na .....	1,764	2,808.0	1,832.0
K .....	154	172.0	244.0
Co <sub>3</sub> .....	84	50.4	77.4
HCO <sub>3</sub> .....	134.2	0.0	0.0
SO <sub>4</sub> .....	38	216.0	52.8
Cl .....	2,790	3,621.0	3,042.0
NO <sub>3</sub> .....	7.1	trace	trace
NO <sub>2</sub> .....	...	negative	negative
SiO <sub>2</sub> .....	50	27.0	154.0
F .....	3.70	1.60	2.20
B .....	48	57.42	71.60
Fe .....	0.15	...	...
Mn .....	0.0	...	...
PO <sub>4</sub> .....	0.4 <sup>d</sup>	0.23	0.88
Cu .....	0.0	...	...
OH .....	...	76.2	1.7
Br .....	...	4.67	2.55
As .....	...	0.94	7.50
NH <sub>4</sub> .....	...	trace	trace
Hg .....	...	1.4	0.0
Synthetic detergents, apparent ABS .....	0.290	...	...
<b>Total dissolved solids, ppm .....</b>	<b>5,744</b>	<b>6,894.0</b>	<b>5,228.0</b>
pH .....	8.9	9.8	8.5
Analytical laboratory .....	Navy	Hornkohl	Hornkohl

<sup>d</sup> Ortho.

Figure E-13. Materials Tested by Thirty-Day Immersion in  
Coso No. 1 Well<sup>8</sup>

<u>Material</u>	<u>Obvious rapid failure</u>	<u>Obvious slow failure</u>	<u>No obvious chemical failure</u>
Nylon rope.....	X		
Hemp rope.....	X		
305 Stainless.....		X	
304 Stainless.....			X
Monel.....		X	
Ni resist.....		X	
Mild steel.....			X
Fiberglass (copper-loaded).....			X
Epoxy-coated shaft.....	X		
Delrin 9D9.....			X
Polyphenylene sulfide.....	X		
Polyethylene.....			X
Lexan polycarbonate.....			X (but extensive scaling)
Neoprene jacketed wire.....			X
Lead jacketed wire.....			X
Kynar insulated wire.....			X
Hypalon insulated wire.....			X

TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

The ARPA "Use of Geothermal Energy at Military Installations" program initiated the series of energy-related studies undertaken by ARPA in fiscal years 72 thru 76. This program resulted in a considerable extension of the understanding of geothermal energy, of capabilities for and limitations of its uses, and of problems that may be encountered. Its timely inception provided a framework for experimental national programs brought about by top-level governmental concern with energy shortages, and highlighted by the oil embargo of late 1973.

- A thorough overview of geothermal energy technology was completed and will serve as a useful guide to program planners and managers.<sup>15</sup>
- Particular DoD establishments where geothermal energy probably can be applied have been identified and target sites for initial projects have been proposed.<sup>9,13</sup>
- Partly as an outgrowth of the ARPA funded project, one target site is under active exploration at the Naval Weapons Center at China Lake, California. The Coso Geothermal Project is proceeding with geophysical surveys, geochemical studies, and exploratory drilling.<sup>10,11,12</sup>
- Certain key factors which will ultimately inhibit the development of geothermal energy without additional R&D have been identified. Problems of geothermal fluids chemistry and effects of corrosion, erosion, scaling and precipitation have been discussed. Field tests with geothermal fluids on selected materials have been carried out.<sup>8,12</sup>
- High costs of drilling and technological limitations of working in high temperatures are limitations that have been addressed. Some solutions have been proposed but, in general, significant R&D will be required.<sup>14</sup>

Follow-on work toward the development of geothermal energy is being conducted by ERDA, USGS, the Naval Weapons Center, and other government agencies. Since many programs under these agencies were concurrent with the ARPA research program, it is difficult to measure the amount of technical information transferred among the various researchers. However, in the cases of geopressured systems and the project at Coso, technical information developed under the ARPA programs was used by the research teams sponsored by other government agencies.

In addition, one of the sites identified under ARPA sponsorship is actively being developed. Based upon this evidence alone it is evident that the ARPA sponsored research has had an impact and ultimately can help reduce the nation's dependence on foreign energy sources.

Additional research and development is needed relating specifically to DoD needs. Because military establishments are essentially controlled communities, utilization of geothermal energy for nonelectric applications (heating, refrigeration, air field and harbor de-icing, chemical processing, etc.) can probably be explored and developed more effectively than in other areas of the American economy. Many DoD sites have been identified where such development is possible. Additional research is needed on the chemistry of geothermal fluids at specific DoD sites. Development, either for electric or nonelectric applications, cannot proceed without thorough knowledge of this subject. At certain DoD sites electric power generation is possible from known geothermal resources.

As of the beginning of FY77, the Coso Geothermal Site is under active exploration and development with research funding from ERDA. This project is budgeted at \$1.3 million for Battelle Pacific Northwest Laboratories (BNW), the prime contractor, plus \$150,000 to the Naval Weapons Center for logistics and environmental support of the project. It is anticipated that two exploration wells to approximately 4000 ft will be drilled during FY77 as the first in-depth probe of the geothermal resource.

The current Coso Geothermal Project under ERDA funding started in December 1975 at \$675K for BNW in FY76. The NWC also received \$75K in direct funding from ERDA, Division of Geothermal Energy, for their project activities in FY76. Transition quarter funding was \$500K for BNW and \$50K for NWC, and FY77 budget is \$1,300K for BNW and \$150K for NWC. Under this project an additional 18 heat flow holes (100 m deep) have been drilled, heat flows evaluated, microseismic measurements made, and drilling of the first deep hole (1200 m) has begun. During FY77 two deep slim holes are expected to be drilled, followed by two to four additional deep holes the following year.

The objectives of the Coso Geothermal Project are to:

- (1) investigate the potential geothermal resource of the Coso KGRA as part of the national resource assessment program for dry hot rock.
- (2) assess the effectiveness of the slim holed drilling (less than 15 cm diameter and up to 1500 m depth) as an exploratory tool for geothermal energy.

THE USE OF GEOTHERMAL ENERGY AT MILITARY INSTALLATIONS

## FUNDING SUMMARY

	<u>FY72</u>	<u>FY73</u>	<u>FY74</u>	<u>FY75</u>	<u>FY76</u>
Informatics, Inc. Rockville, Maryland	\$50K			\$ 50K	\$25K
Naval Weapons Center China Lake, California			\$130K		
Southern Methodist University Dallas, Texas	17K				
Tetra Tech, Inc. Houston, Texas		\$55K			
University of California Riverside, California	28K				
University of Texas at Dallas Richardson, Texas			66K	200K	
<b>TOTALS</b>	<b>\$95K</b>	<b>\$55K</b>	<b>\$196K</b>	<b>\$250K</b>	<b>\$25K</b>

Overall Total: \$621,000

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APPENDIX F

STORAGE OF SOLAR ENERGY IN SMALL RINGS

## APPENDIX F

### STORAGE OF SOLAR ENERGY IN SMALL RINGS

#### OVERALL PROGRAM

At the inception of this program in 1974, there was an evident need for research to inquire into the feasibility of using energy sources other than fossil fuels for the production of massive amounts of heat and electricity. Because the production of low-grade heat (primarily for water heating and the heating and cooling of buildings) is a major consumer of fossil fuels, and because solar energy is inherently suited to the production of low-grade heat by virtue of its low intensity, a number of agencies and organizations recognized that research and development on solar heating systems could lead to very real savings in fossil fuel consumption. This philosophy is clearly applicable to the DoD; were it possible to utilize solar heating and cooling at military bases, a significant amount of fossil fuel would be saved for use in transportation or the production of chemicals.

While a number of methods for the conversion of solar energy to low-grade heat have been developed to date, they all suffer from either low efficiency, high initial cost, or unproven reliability in use. As a possible alternative to the purely thermal or mechanical conversion of solar energy, it has been suggested from time to time since the early 1900's that it might be possible to utilize energy-storing photochemical reactions for this purpose. There was a flurry of research activity in this area during the 1950's, but no suitable photochemical systems were developed and, in the absence of continued public interest and financial support, the research efforts virtually ceased after a few years. There has been little subsequent activity in this area until recently. The photo-chemical approach still appears promising, however, because it offers not only the possibility of energy storage for relatively long periods but also potentially improved collection efficiency as compared to purely thermal solar energy collection. Several laboratories worldwide began to study this field quite actively during the past few years.

During fiscal year 1974, ARPA directed and supported research by the laboratory group of Professor Guilford James, II, at Boston University, which explored one approach to the photochemical conversion of solar energy

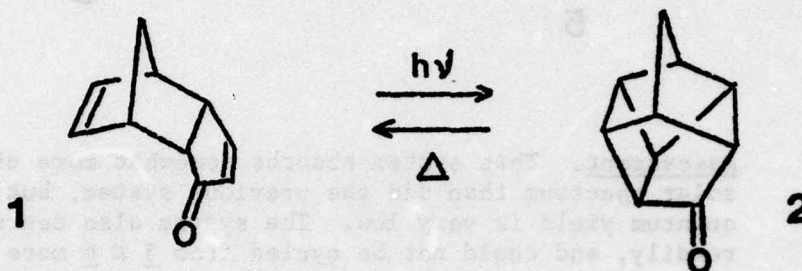
to heat. The work was contracted through and monitored for ARPA by the Chemistry Program Office of the Office of Naval Research which continued to support the research in FY1975 and FY1976. No subcontractors were involved. The research program was a feasibility study with the overall objective of determining whether or not it is possible to convert and store solar energy as the heat of formation of certain organic compounds which are produced by photochemical isomerization reactions. The specific technical objective was the synthesis of organic ring compounds which would tautomerize to isomers containing small, strained ring structures having higher heats of formation, upon the absorption of visible light, and which would release this energy as heat by catalytic reversion to the original compounds.

This was a challenging task, as most of the compounds known to photoisomerize in this way at the start of the program were responsive only to ultraviolet light (which comprises only a small fraction of the sunlight reaching the earth's surface). The compounds selected for study in this program all exhibit valence isomerization; this means that the reactant molecules and their photochemical products differ in their electronic bonding arrangements but do not differ greatly in shape. The program sought to synthesize and evaluate analogs of known valence isomerization systems which would absorb sunlight strongly, undergo the energy-storing photochemical isomerization efficiently upon exposure to sunlight, and still release appreciable amounts of energy as heat upon exposure to an appropriate catalyst. The systems and engineering considerations which would ultimately have to be addressed in the development of a working solar heating system were outside the scope of the program. The constraints on the behavior of the photochemical system are quite severe (for example, the materials must be safe, long-lasting, and relatively inexpensive in addition to the properties listed above), and the photochemical research alone constitutes a very challenging research problem at the present time. Professor Jones was well qualified to conduct this program, as he had significant expertise prior to the start of the program in the photochemistry of small-ring compounds which exhibit valence isomerization.

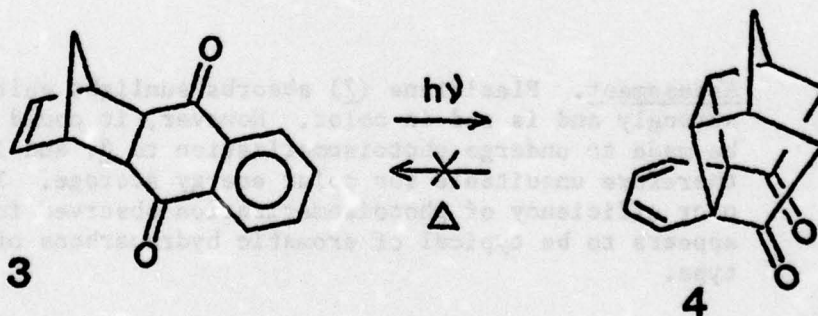
## SCIENTIFIC AND TECHNICAL RESULTS

Four classes of valence isomerization systems were examined in the course of the program. The structures of the compounds involved are presented below, along with a brief assessment of the status of each system.

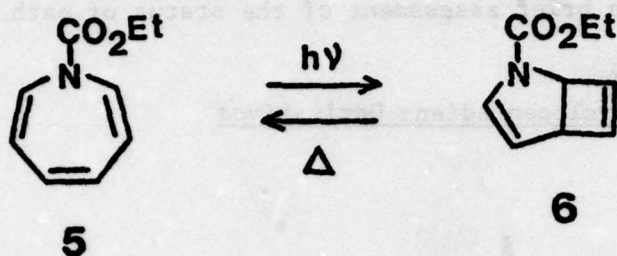
• Dicyclopentadiene Derivatives



Assessment. Good quantum yield and chemical yield of high-energy Isomer 2, also good energy storage characteristics. However, 1 absorbs very little of the solar spectrum, and is therefore a very inefficient solar energy storage material. The conversion of 2 and 1 can be achieved with the aid of certain acids or metal complexes, but the reaction is slow and leads to degradation of the catalysts. This system is therefore unsuitable for solar energy storage. Work on analogs which absorb sunlight more strongly is recommended in the summary report.<sup>(1)</sup> One such system (3) was examined briefly, but the product 4 could not be made to revert to 3 with either catalysis or heating.

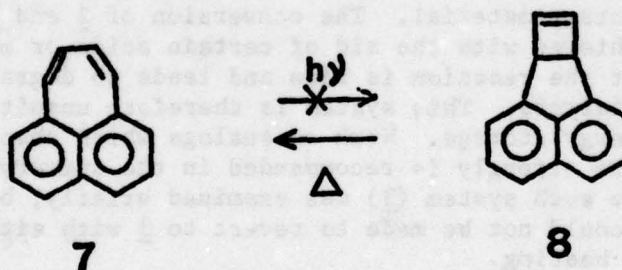


- N-Ethoxycarbonyl-1H-azepine



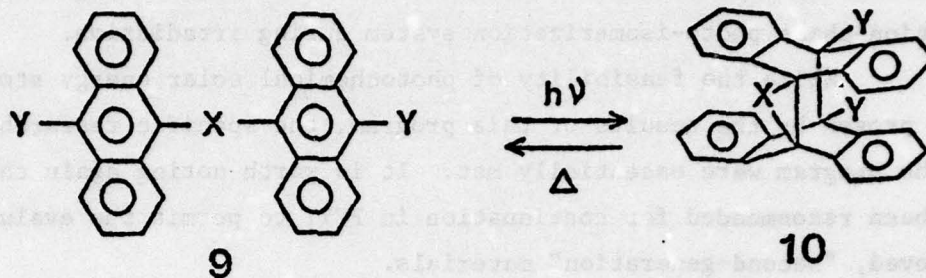
**Assessment.** This system absorbs somewhat more of the solar spectrum than did the previous system, but the quantum yield is very low. The system also degraded readily, and could not be cycled from 5  $\rightleftharpoons$  6 more than 10 times. The system is therefore not suitable for solar energy storage.

- Pleidiene



**Assessment.** Pleidiene (7) absorbs sunlight quite strongly and is red in color. However, it could not be made to undergo photoisomerization to 8, and is therefore unsuitable for solar energy storage. The poor efficiency of photoisomerization observed for 7 appears to be typical of aromatic hydrocarbons of this type.

• Linked dianthracene derivatives



- a: X = CH<sub>2</sub>CH<sub>2</sub>, Y = H
- b: X = CH<sub>2</sub>CH<sub>2</sub>, Y = CH<sub>3</sub>
- c: X = CH<sub>2</sub>, Y = H
- d: X = CHOH, Y = H
- e: X = CH<sub>2</sub>CH<sub>2</sub>, Y = CH<sub>2</sub>CH<sub>2</sub>

**Assessment.** This is the most promising class of compounds examined in the program. The various derivatives of 9 absorb relatively little of the solar spectrum (absorbance is limited to the blue and violet wavelengths) but the isomerization is modestly efficient and improved absorbance properties might be achieved with other derivatives. The products 10 store moderate amounts of energy (9-17 kcal mole<sup>-1</sup>) and are transparent to sunlight. However, degradation of the materials is a problem after about 30 successive photochemical and thermal steps. These materials represent a marked improvement over the dimerization of anthracene, which was suggested over 65 years ago for solar energy storage, but they are not useful for this purpose at their present stage of development.

In summary, while none of the compounds synthesized and examined in the course of this program have proven to be suitable for the storage of solar energy, they have been studied carefully and their limitations defined. More importantly, these results will necessarily influence and guide subsequent research in this area, not only by Professor Jones but by others in the field as well. The work has led to a generalization regarding the nature of

reactive intermediates in the photochemical reaction which should be useful in the selection of new candidate materials for evaluation. The work has also led to the initial development of a promising new technique--photocalorimetry--which could provide direct measurements of the energy storage capacity of any solution-phase photo-isomerization system during irradiation.

While the feasibility of photochemical solar energy storage has not been proven by the results of this program, the specific research objectives of the program were essentially met. It is worth noting again that the program has been recommended for continuation in FY77 to permit the evaluation of improved, "second-generation" materials.

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TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

The results of this program to date will be of most use to those researchers actively pursuing research in this field. As mentioned before, the task of devising a suitable photochemical solar energy storage system is an exceedingly difficult one, and it is not likely to be solved by a single group working with limited funding for a few years. The ARPA program has advanced the state of the art with regard to the specific compounds and procedures discussed in this appendix, and has served to stimulate interest and activity in this small, but growing, area of research. ONR which monitored the program for ARPA in FY74, took over sponsorship for FY75 and FY76, and the program has been recommended for continued ONR support in FY77.

In addition to several interim reports and the summary report<sup>1</sup> referred to previously, the results of this research have been disseminated through a number of scientific publications and presentations at scientific conferences. These are listed in the References section, below.

STORAGE OF SOLAR ENERGY IN SMALL RINGS

FUNDING SUMMARY

FY74

**Boston University**

**\$55K**

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APPENDIX G

SYNTHETIC PETROLEUM FOR DEPARTMENT  
OF DEFENSE USE

## APPENDIX G

### SYNTHETIC PETROLEUM FOR DEPARTMENT OF DEFENSE USE

#### OVERALL PROGRAM

The very large requirements of DoD for petroleum derived liquid fuels coupled with diminishing domestic production of crude and ever-increasing reliance on overseas sources, led ARPA to support this study in 1974 at Stanford Research Institute. The primary objective of the program was to provide guidance to DoD for action that might be taken to encourage production of syncrude from coal so that the civilian economy might be relieved of some or all of the military's liquid fossil fuel demands and that an assured supply of these fuels, critical to national security, would be available.

At the time the study was commissioned, there were a number of coal conversion processes, some differing from each other to a major extent, under active study in various laboratories throughout the nation. No process had been operated on even a semi-commercial scale and, in most cases not even in a fully integrated flow system, with the sole exception of the Fischer-Tropsch process. Not only do the processes vary widely but so do the products produced by them. They may be grouped in five categories:

- Fischer-Tropsch synthesis: gasification of coal followed by catalytic reduction of the carbon monoxide to produce chiefly hydrocarbons.
- Pyrolytic processes in which liquid fuel is generated by depleting a portion of the coal of its hydrogen in order to enhance the hydrogen content of the rest.
- Solvent refining from which a low melting solid product is obtained in a non-catalytic hydrogen transfer process.
- Catalytic hydrogenation of coal, typically done on a coal in oil slurry, producing a desulfurized liquid product mix which can be varied in composition depending upon operating conditions.
- Uncatalyzed hydrogenation in a fluidized bed to produce a gas and liquid fuel product mixture (Coalcon).

These various processes may be viewed as competing with each other for commercialization even though they do not all produce the same products.

They compete also with shale oil which, though outside the scope of the present study should perhaps have been included.

The problem may essentially be defined as selection from among those processes under examination, those that appear best to meet DoD needs while conforming most closely with conventional refining methods and which therefore could be most readily implemented with minimum disruptive effects. Recommendations to ARPA for further program planning were to be included and economic and institutional constraints identified.

This program was contracted for and monitored by Rome Air Development Center.<sup>1</sup> The final report is dated November 1974.<sup>2</sup>

## SCIENTIFIC AND TECHNICAL RESULTS

The petroleum derived fuel consumption of DoD was determined with respect both to fuel type and to geographic distribution. More than half the demand is for JP-4 which cannot exceed 25 volume percent of aromatic constituents. This is significant because coal derived liquid fuels are very high in aromatic content (except for Fischer-Tropsch products), which makes them more suitable for motor fuel than for JP-4. The suggestion in the task directive that a syncrude might best be refined together with natural petroleum which is low in aromatic content was thus quite appropriate.

Various of the coal conversion processes were briefly reviewed and the H-coal process was selected for detailed study. The reason for this selection was stated to be the fact that the syncrude it produced is suitable for refinery processing and little or no char or heavy ends are formed.

In addition to the technical suitability of the product, consideration might have been given to state of development of the coal conversion processes. In particular, if very early implementation of a DoD incentives program is contemplated, the Fischer-Tropsch process might have been given more careful consideration since the technology for commercialization has been demonstrated while this cannot be said for any other process under study. Fischer-Tropsch also produces little aromatic product which may have some advantage in view of DoD needs. Thus any emphasis on shortening the time period for realization of a DoD supported synthetic fuels program would strengthen the case for Fischer-Tropsch and diminish that for H-coal simply because of the relative states of technical development.

In the period since the report was prepared development work on the various processes has accelerated.

- The SYNTHOIL process has been operated in a 1.1 in. inside diameter reactor, and a 4 in. reactor is under construction at Bruceton, Pennsylvania. The principal problems facing this process are solids separation (from the product) and catalyst life and stability.
- A large pilot plant for evaluation of the H-coal process is being constructed in Catlettsburg, Kentucky. In this process also, solids separation is a major problem.
- A semi-commercial plant for evaluation of the Coalcon process is under commitment for southern Illinois.

Although it will produce gas, oil and char and is therefore not specifically designed for liquid fuel production, the operation of this plant, if successful, should move this process to the forefront in engineering technology in the U.S.

- The SRC pilot plant (50 T/day) has been operated with some success at Ft. Lewis, Washington and a larger unit is scheduled for construction in Colorado.

Information on plans for other processes, e.g. Gulf, Exxon, is not as fully available but it is clear that until a number of processes have been evaluated on a much larger scale than heretofore, no decisions can be made concerning commercial practicability. For this very reason a number of competitive processes are being scaled-up simultaneously. While H-coal can provide a product more directly applicable (i.e. without subsequent treatment) to conventional refineries, neither it nor its competitors, excepting Fischer-Tropsch, can yet be called proven processes.

The arguments concerning production, refining and transportation costs and plant siting apply in a general way also to processes other than H-coal. However, because of the relatively small scale on which these processes have been evaluated to date, extrapolation to commercial scale costs must be viewed as tentative. The constraints on commercial coal liquefaction as discussed in the report should be universally applicable.

Thus in the past two years, although research and development on synthetic liquid fuels has been actively pursued, there is still much to be done before any single process can be chosen with confidence as preferable to the others, and the basis for selecting a single process for intensive study is now much the same as then.

TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

The objectives of the study were essentially achieved within the limitations imposed. Since at that time it was not possible, nor is it today, to select a preferred process based on technological advancement, the choice of H-coal was based on product properties and compatibility with normal refining processes. The report furthermore does provide some information of general utility, applicable even if a shift of emphasis to an alternative process is necessary at a later time. Some alternatives to H-coal are cited and serve to alert the reader to the potential for other methodology for liquid fuel production from coal.

The report has served several purposes useful to ARPA:

- It alerts the Services to the need for constant review of their fuel requirements and the mix of fuel products needed since coal conversion process selection will be influenced by these factors.
- It cautions against expectation that supplementing DoD fuel requirements by use of coal derivatives can be achieved on a short term basis, citing the need for additional process development work, augmented coal supplies, long lead time for specialized equipment and other factors.
- It inferentially indicates the need for constant awareness on the part of DoD of the emerging developments in syncrude production technology. The time necessary to achieve results from a DoD production incentives program will depend greatly upon the choice of process and that choice can only be made in an intelligent way if an up to date knowledge of the relative merits of competing processes is maintained. Thus the report sets the stage for continuing study of the problem by DoD since ERDA's objectives do not wholly coincide with those of the military.

**SYNTHETIC PETROLEUM FOR DEPARTMENT  
OF DEFENSE USE**

**FUNDING SUMMARY**

**FY74**

**Stanford Research Institute**

**\$50K**

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APPENDIX H

SUPERCONDUCTING SHIP PROPULSION

SUPERCONDUCTING SHIP PROPULSION

## OVERALL PROGRAM

At the time that this study was performed in 1974 there was a need for information on the fuel economy of various ship propulsion methods. The world fuel situation that had developed at this time and the projected fuel supplies that would be available in the future made the study not only timely but essential. Future Naval ships must be designed for maximum fuel conservation if we are to reduce the consequences that even a partial oil embargo might impose on our military strength.

This program was a study to evaluate electric power transmission for ship propulsion, specifically for DD-963 class vessels. Baseline for the study was the typical gas turbine, gear, shafting, and controllable reversible propeller (CRP). The study showed that superconducting propulsion systems would provide greater fuel efficiency, lower propeller noise, elimination of gear noise, variable propeller speeds (elimination of CRP), and significant reduction in overall system weight.

At the time the program was conducted Naval Ship Research and Development Center (NSRDC) Annapolis was in 6.3 stage of development on a superconducting homopolar motor design. Design of the motor was completed and they were in the construction and testing phases of the machine. Test data had established feasibility of the design. Test results and system analysis was provided by NSRDC and was used as a basis for the study. A Standard NAVSEC destroyer mission profile was used and calculations of the efficiency of operation of a variety of proposed propulsion systems was performed.

Primary technical interest in the study was comparison of the superconducting electric transmission with various mechanical transmission arrangements. Using the test results supplied by NSRDC the study confirmed that the electric transmission would provide not only greater fuel efficiency but would also provide for a lighter weight, quieter, more maneuverable propulsion system.

## SCIENTIFIC AND TECHNICAL RESULTS

Since the study was a paper study to examine a variety of ship propulsion system configurations within the context of a modern naval vessel a direct measure of successful or unsuccessful results cannot be made. However, the usefulness of the results can be used to measure the success of the study. Those who have used the results of the study consider the study to be worthwhile. Therefore, the program must be considered successful in meeting its objectives.

The study did not lead directly to a technical advance but did provide background information and an independent evaluation of an NSRDC program that is a technical advancement in the state of the art in electrical ship propulsion. Important information resulted from the study on the economic justification and fuel efficiency to be realized from superconducting electric ship propulsion systems.

As reported in the study, up to 25 percent improvement in fuel economy over a standard mission profile are possible with electric drive systems. Endurance range may be extended as much as 19 percent. Much of this improvement over the baseline system results from higher system efficiency. A portion of the improvement is attributed to a reduction in the overall propulsion system weight. This weight reduction would be at least 38 tons. In addition to weight savings, the electric drive system provides for more efficient space utilization and reduces the turbine ducting since the turbines and generators can be located closer to topside.

Propulsion system arrangements included in the study were:

- Baseline configuration of four 20,000 hp LM-2500 gas turbines direct geared to two propeller shafts (two turbines per shaft) with controllable-reversible pitch (CRP) propellers.
- The addition of electrical alternators to the baseline. The alternators, functioning as a motor/generator set, provide a "crossover" capability by allowing transfer of power from one shaft to the other and permit cruising with a single gas turbine powering both shafts.

- The addition of 5,000 hp cruise turbines to the baseline. This arrangement allows cruising with the smaller turbines at power levels where the IM-2500 turbines are highly inefficient.
- Addition of a combination of cruise turbines and alternators to the baseline.
- Replacement of the baseline geared drive system with a superconductive electric drive system. In this system, the mechanical gears and shafting are replaced by electrical transmission lines connecting electric generators driven by the turbines to electric motors driving the propeller shafts. The electric drive system provides crossover capability and improves turbine efficiency by allowing turbine operation at speeds independent on the propeller rpm's.
- Addition of 5,000 hp cruise turbines to electric drive system.

Three versions of the electric drive systems were studied:

- Installation of the baseline configuration without changes to engine room locations or propeller shafting lengths.
- Installation with the gas turbines moved from the 15 ft. level to the 24 ft. level and elimination of 228 ft. of propeller shafting by moving the motors aft.
- Location of the cruise turbines in either deck-mounted modules or in the engine rooms.

TECHNOLOGY UTILIZATION AND  
TECHNICAL INFORMATION TRANSFER

Information contained in the study was supplied to NAVSEA/NSRDC and confirmed the direction of the Navy program. NSRDC considered the information in the study to be technically significant and the achievements of the study to be productive and effective. NSRDC has used the information supplied by the study in their continuing effort to develop the superconductive homopolar motor and generator and the other elements of an electric ship propulsion system.

As a follow-on program NSRDC, under sponsorship of NAVSEA, has contracted with Bradford Computer & Systems, Inc., and M. Rosenblatt & Sons, Inc., to perform additional studies on alternative propulsion machinery arrangements. The objective of the continued studies is to identify more efficient volume arrangements, weight reduction, and cost effectiveness.

NSRDC is using the information from the studies to aid in their development of an electric transmission test vehicle. Further, they plan to use the study information in their investigation of electric propulsion in the 40,000 hp range for larger Naval ships.

SUPERCONDUCTING SHIP PROPULSION STUDY

FUNDING SUMMARY

FY74

Bradford Computer

36 K

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Total

36 K

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APPENDIX I

HYDROGEN AS A MILITARY FUEL

## APPENDIX I

### HYDROGEN AS A MILITARY FUEL

#### OVERALL PROGRAM

At the inception of this program the increasing dependence of the United States on imported petroleum and on natural gas had become painfully apparent, and it became important for DoD to increase efforts in investigation of alternate fuels to replace these. The Defense Advanced Research Projects Agency decided to investigate the use of the hydrogen alternative, and established this R&D program to identify the state of the art and to investigate the technical, economic, and operational feasibility of utilizing hydrogen as a primary fuel for Navy use in stationary power, and in vehicles and ship propulsion applications. No naval prime movers had been operated previously on hydrogen. The feasibility of so doing needed to be investigated and demonstrated to determine performance in light of naval missions. Though there had been previous studies of operating automotive equipment and fuel cells on hydrogen, little had been accomplished in operation of gas turbines on hydrogen, and no adequate demonstration had been conducted (save for an isolated NASA effort in the late 50's). An objective of this program would be to identify problems associated with hydrogen utilization, and to identify research and development needs for their solution.

a. Primary areas that were to be covered included:

- (1) Comparison of feasible methods of producing hydrogen from non-petroleum sources, including costs.
- (2) Investigation of fuel conditioning in various physical and chemical forms for transport and storage of hydrogen.
- (3) Evaluation of the performance of various conventional and advanced energy conversion devices using gaseous hydrogen as a fuel.
- (4) Identification and addressing of special problems such as hazards and safety implications as well as materials handling and performance (e.g., hydrogen embrittlement of metal containers).

(5) Life-cycle cost analyses.

After these feasibility studies, demonstrations of the use of hydrogen as a fuel in naval prime movers were planned.

The Defense Advanced Research Projects Agency (DARPA), with the Naval Ship Research and Development Center (NSRDC), planned a multi-year jointly-funded program to conduct the majority of the necessary R&D studies and investigations under NSRDC direction employing both contract and NSRDC in-house capabilities. DARPA would also pursue some aspects of the subject through other agencies and other contractors.

During fiscal years 1974 and 1975 DARPA directed and supported the work of NSRDC and four contractors in assessing the practicability of using hydrogen as a fuel in the Navy environment. This work included assessment of the state of the art of hydrogen production processes, storage, transmission or transport, and conversion. It also covered analyses of operational performance, and capital and operational costs, of hydrogen-fueled vessels in typical navy missions, and examined ship configuration revisions required for use of cryogenic hydrogen. The activities originally planned for the third year of the program, additional laboratory and hardware investigations to pursue solutions to problems identified during the first two years, were not funded.

b. The technical objectives of the program elements were:

- (1) Examination of the feasible methods of producing hydrogen in quantity, to focus on the efficiency of the production processes. (By Stevens Institute of Technology)<sup>1,2</sup>
- (2) Investigation of chemical forms for storing and transferring hydrogen. (By Stevens Institute of Technology)<sup>1,2</sup>
- (3) Evaluation of performance of the major naval energy conversion prime movers using gaseous hydrogen as the fuel; with performance, size, weight, efficiency, and costs to be enumerated. (By Stevens Institute of Technology)<sup>1,2</sup>
- (4) Determination of how well hydrogen can serve as a fuel for surface, submarine, and airborne equipment when operated in "typical" naval missions. The trade-off options for hydrogen versus

conventional and other alternative fuels were to be refined, and capital and operating costs were to be developed. (By General Electric-TEMPO)<sup>1,2</sup>

(5) Evaluation of preliminary gas turbine combustor performance when operated on gaseous hydrogen. (By Naval Ship R&D Center)<sup>1,2</sup>

(6) Development of techniques for evaluating hydrogen containment materials and their embrittlement behavior. (By Naval Ship R&D Center)<sup>1,2</sup>

(7) Investigation of ternary alloys as hydrogen storage hydrides, including development of exploratory data relating to pressure-temperature-alloy composition. (By Brookhaven National Laboratory)<sup>3,4</sup>

(8) Investigation of the potential, and test of the feasibility of employing unstable metallic hydrides to store hydrogen, to include binary as well as ternary systems. (By University of Denver)<sup>5,6</sup>

## SCIENTIFIC AND TECHNICAL RESULTS

NSRDC was the logical choice as a partner to DARPA in planning and funding this program and in contractually managing it, since NSRDC is the Navy element responsible for fuels, and for most of its important prime movers. NSRDC participation provided a program management such that the major facets of the program plan would be focused on the target--alternate fuels for naval use, and whether hydrogen can fulfill a significant portion of the needed non-petroleum-derived fuel. This arrangement also eases the process of technology utilization and technical information transfer.

A fundamental underlying the entire program was the adoption of a conservative current state-of-the-art for the technologies involved, particularly in the case of the operational aspects. This assumption obviated the difficult if not impossible task of consistently projecting diverse technologies to some future time frame. More important, it prohibited invoking unproven capabilities which, taken together, might tend to favor new technologies over the old.

Overall, the program indicates that at present, and until the cost or availability of hydrocarbon fuels changes to a markedly adverse extent, there appears to be little impetus for further serious consideration of hydrogen as a naval fuel. If, however, hydrocarbons from whatever source become undesirable for whatever valid reasons, the options for ship powering become nuclear or chemical, and liquid hydrogen becomes the chemical fuel of choice.

Results of the program indicate that it is technically feasible to operate naval fleet missions using cryogenic hydrogen as a fuel resource with the fuel being provided by a conjectured innovative new navy vessel, a nuclear-powered liquid hydrogen factory ship manufacturing hydrogen by electrolysis of purified sea water, and utilized by ships and aircraft reconfigured for and equipped to handle cryogenic hydrogen. Overall, ships and boats could approach or exceed representative mission performances using cryogenic hydrogen fuel as compared with petroleum fuel, while aircraft operating on liquid hydrogen would suffer about 10 percent range reduction. The use of a single fuel for aircraft and ships of all types would negate the need for various marine fuels, and would provide a very considerable logistical advantage. There would be adverse problems associated with use of hydrogen as a naval fuel, and while the information provided by this program is not sufficient for basing firm

plans, it certainly indicates support for demonstration of performance of hydrogen fueled boats and, eventually, ships and aircraft.

a. The conclusion that liquid hydrogen would be the preferred fuel and electrolysis the preferred process was based upon the following:

- (1) Of six manufacturable fuels (hydrogen, ammonia, hydrazine, methane, methanol, and methylamines) studied for production at sea and their impact on ship and aircraft design, only hydrogen and methane stored as cryogenic liquids could provide ship and aircraft performance comparable to present platforms in endurance.
- (2) Diesel fuel Marine (DFM), and the two cryogenic fuels, hydrogen and methane, are calculated to produce roughly equivalent operational results in appropriately equipped vessels. For weight-limited vessels (hydrofoils and surface effect ships) low density hydrogen would be superior to DFM, while in volume-limited displacement ships DFM and hydrogen would be very similar. Liquid methane and DFM are consistently almost identical. Ammonia, hydrazine, and methanol would produce only 40-50% of the range achieved with DFM, and methylamine about 80%.<sup>8</sup>
- (3) Electrolysis of purified seawater would be the preferred production process, since it is the only presently employed hydrogen generation method that does not require feedstock materials not readily available at sea. Electrolysis cells, presently about 60-70 percent efficient, would require improvement to perhaps as much as 100 percent.<sup>8,10</sup>
- (4) The large power requirements of the electrolysis process and the process of conversion from the normal hydrogen gas produced to para-hydrogen, could be effectively satisfied by a state of the art nuclear reactor-steam generator-electric power system for production of up to 250 long tons of para-liquid hydrogen (LH2) per day.<sup>9</sup>
- (5) Manufacture of methane would require so much coal feedstock tonnage as to establish liquid hydrogen as the only logical and the preferred manufacturable fuel from a design and logistic viewpoint.<sup>8,9</sup>
- (6) Coal gasification (including use of municipal and industrial wastes) is considered a good

candidate as a "near-term source" of hydrogen. It requires, however, plants near materials sources and considerable transmission or transport of gaseous or cryogenic product, or the logistical burden of transporting large quantities of "feedstock" to the point of manufacture.<sup>8,10</sup>

- (7) Production of hydrogen by thermochemical decomposition of water may be accomplished in a simple direct chemical reaction but requires extremely high temperatures. Because heat sources capable of supplying this temperature are not readily available this appears an impractical process. Other, less direct means of decomposition have been proposed, but all are in need of extensive further laboratory research before programs of research and development can be established. Should such systems be developed they might be competitive with electrolysis and require less energy.
- b. For hydrogen storage, cryogenic and hydrided forms of hydrogen are identified as the most likely candidate storage modes on the basis of energy stored per unit volume and/or weight.
- (1) For small-scale, portable storage (land vehicles) both hydride and cryogenic hydrogen are usable, but for large-scale users (marine and air vehicles) only the cryogen is attractive.<sup>8,9,12</sup>
  - (2) Liquifaction and liquid hydrogen storage costs are high, not only in equipment and power requirements, but in losses during storage and transfer. Hydrogen liquifaction efficiency and steady-state cryogenic storage and transfer losses do not appear as high-promise areas of R&D, owing to the relatively high current state of development achieved in the space programs.<sup>12</sup>
  - (3) "Boil-off" of cryogenic hydrogen aboard ship, however, can be utilized to a considerable extent, and loss costs greatly reduced, by utilization of boil-off delivered to the ship's gas turbines by a boil-off compressor. Thus, boil-off is not vented and wasted as long as it remains below the fuel demand quantities.<sup>9</sup>
  - (4) Metallic-hydride storage of hydrogen is in the early stages of investigation. To date, hydrides comparable with liquid hydrogen in energy storage suffer great weight penalties (up to 50

times heavier), although offering anticipated lower operating costs. The weight problem has provided the impetus for current searches for more effective hydride compositions.<sup>14,15,16</sup>

- (5) Hydride research did not result in definitive technical guidance, though many pressure-temperature relationships were developed. "Mischmetal-nickel", a commercial mixture of rare earths alloyed with nickel, raised decomposition pressures markedly.<sup>14</sup> Indicated as the one system with by far the greatest possibilities for commercial application was cerium-free, Mischmetal-Ni<sub>5</sub>, because of characteristics and cost.<sup>15</sup>
- c. Investigation of means of conversion of hydrogen energy for naval use involved two major efforts, one concerned with use of hydrogen-fueled reciprocating engines, and the other with hydrogen-fueled gas turbines, these being the prime movers most likely to be available for any large-scale, near-future use for conversion of hydrogen energy.
- (1) Compression-ignition hydrogen-fueled engines would offer small promise, except possibly as dual-fuel engines employing pilot charges of hydrocarbon fuel.<sup>13</sup>
- (2) Conventional carburetted spark-ignition engines could operate satisfactorily at low output power levels by means of lean-burning and power-control through mixture-ratio variations. Such operation, however, results in decreased power output compared to a similar hydrocarbon fueled engine.<sup>10</sup>
- Only at substantial loss (about 50%) in maximum power and specific power can hydrogen be used at low NO<sub>x</sub> in simply-modified naturally-aspirated reciprocating engines.<sup>13</sup>
  - The specific power and peak power penalties are conjectured to be overcome by substantial modification to allow for direct-cylinder-injection of the hydrogen fuel during the compression stroke. Compression of the hydrogen for injection might prove troublesome.<sup>13</sup>
- (3) In general, hydrogen should offer no fundamental problems when used as a fuel for gas turbines (except, perhaps, safety and materials compatibility).

- Conventional gas turbines operated on hydrogen fuel were calculated to show modest power-output increases (approximately 5%), with a slightly decreased efficiency (1%-2%).
  - Cooling of gas-turbine hot-sections using (indirectly) the heat-sink capacity of the cryogenic fuel is considered attractive as offering the largest potential for improvement of gas-turbine engine performance, with efficiency increases of 10%-20% possible.
  - The use of cryogenic hydrogen in gas-turbine engines would require solution to a number of practical problems, none of fundamental nature (except safety), but all requiring significant engineering development, particularly for flight-weight auxiliaries for aircraft applications.<sup>13</sup>
  - Comparison of gas turbine combustor (designed for liquid fuel) when operated on gaseous hydrogen and on diesel type fuel showed comparable performance. Hydrogen consumption closely followed theoretical predictions.<sup>17</sup>
  - Some modifications of the liquid-fuel combustor would improve performance and reduce possibility of flame-out. Importantly, these modifications can be affected by removal of material (drilling, machining, etc.) from existing combustor hardware.
- d. For investigation of the effects of possible hydrogen embrittlement of materials a technique for evaluation was proposed and experimentally validated--the modified wedge-opening-loading (WOL) fracture specimen.<sup>18</sup>
- (1) The WOL specimen is self-stressed with a bolt, and is portable.
  - (2) Modified specimen shapes of titanium alloys were first subjected to fatigue crack initiation in air, and then placed under a lower but sustained cyclic stress in hydrogen to determine if crack propagation would progress as a brittle failure.
  - (3) Results were not clear-cut in that a failure mode appeared that was later identified with the residence time that the initial subcritical crack growth is exposed to the air.

TECHNOLOGY UTILIZATION AND TECHNICAL  
INFORMATION TRANSFER

The "Hydrogen as a Military Fuel" Program resulted in a considerable extension of verification of the state of the art, and what can be possible without visualizing future "break-throughs." It tied the operational implications to the technical aspects of the problem.

- The program was primarily analytical in nature, with experimentation limited to hydride storage, fracture embrittlement, and combustion performance comparison. The third year of the program experimentation did not materialize.
- The Navy has attempted to capitalize upon the ARPA-supported research in their in-house follow-on developments. These studies indicate technical feasibility; economic feasibility is probable; and necessity may be a certainty. Many technical issues associated with synthetic fuel alternatives require further research and engineering, and should be pursued.
- Brookhaven National Laboratories is continuing study of hydride storage under ERDA support.
- The contract reports in large part have distribution restricted to U.S. government agencies--this distribution should probably be widened. Several public presentations of much of the information have been, and are being made, including a summary of testimony made before a Subcommittee of the House Committee on Science and Technology.<sup>19</sup> ARPA joined the National Science Foundation in sponsoring the "Theme Hydrogen Conference" in Miami in March, 1974, and presentations of material from these studies were made.<sup>7,21</sup>
- A foundation has been accomplished upon which rational and feasible programs may be constructed in accordance with perceived needs and/or desires that may arise or be formulated.

HYDROGEN AS A MILITARY FUEL

## FUNDING SUMMARY

ARPA Funding

	FY74	FY75
Stevens Institute	\$130,000	\$130,000
GE-TEMPO	84,400	99,400
NSRDC	110,600	73,600
Brookhaven	40,000	40,000
University of Denver	98,805	99,770
NSF/University of Miami	<u>9,900</u>	<u>--</u>
	473,705	442,770

NSRDC Funding

	<u>50,000</u>	<u>40,000</u>
	\$523,705	\$482,770

Overall Total	\$1,006,475	
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APPENDIX J

NATIONAL SECURITY IMPLICATIONS OF  
POTENTIAL MATERIALS' SHORTAGES IN  
ADVANCED TECHNOLOGIES

NATIONAL SECURITY IMPLICATIONS OF  
POTENTIAL MATERIALS' SHORTAGES IN  
ADVANCED TECHNOLOGIES

## OVERALL PROGRAM

At the inception of this program in 1973 there was an evident need for research to forecast demands for critical materials, particularly as they might impact on the nation's security; and, more particularly, on the DOD needs for materials which have a potential for becoming critical. During the last several decades, the rapid increase of technological advances and their incorporation into military systems and materiel has often created unforeseen demands for raw materials. The resulting situations have sometimes been further aggravated and intensified by the onset of major military conflicts, economic rivalries among friendly as well as hostile nations, as well as motivations by principally political considerations.

In these instances, the United States has usually found it necessary to categorize certain raw materials as essential or critical. To meet U.S. security policies and to ensure adequate supplies of such materials the DOD has often, on such occasions, belatedly initiated conservation measures (including design changes), material substitute programs, and/or raw materials stockpiling. It would be most significant to the DOD if it could better anticipate the need for such measures through prior assessment and analysis of technological trends which impact on the needs for materials which could be classed as critical.

These ARPA research programs have been directed at identifying methodologies and conducting assessments to improve forecasting tools as well as knowledge of potential future demands for potentially critical materials.

During fiscal years 1973 through 1975, ARPA directed and supported research by four contractors which addressed the national security implications in potential shortages of materials vital to the technology enhancement needed to support concepts for advanced weapons systems. The work was contracted through and monitored for ARPA in individual contracts by the Rome Air Development Center, the Defense Supply Service, and the Army Missile Command. Technical control was retained by ARPA on all contracts. The technical objectives of this research were:

**Primarily,**

- a. To outline the basic issues and problem areas which arise for DOD from increasing U.S. dependence on foreign sources of material supply. (By Rand Corporation)<sup>1,2</sup>
- b. To illuminate, based on current consumption data, key dependencies of the DOD for materials which are potentially critical in the event of shortages; and to analyze the impact of such shortages on the capability of U.S. industry to meet DOD needs. (By Stanford Research Institute)<sup>3,4</sup>
- c. To detect and analyze for the DOD those circumstances wherein undue future risks could obtain in availability of materials and/or materials application technologies which support advanced weapons systems concepts. In such cases, to compare possible alternatives in achieving the needed technological advance through varied approaches in materials<sup>5</sup> technologies and availabilities. (By Rand Corporation)
- d. To analyze key U.S. emerging technologies, in the civil sector, to identify possible future criticalities in material availabilities and production capacities and any resulting, potential problems in advanced development and procurement areas for DOD. (By Battelle's Columbus Laboratories)<sup>6</sup>

**Secondarily,**

- e. To assess materials needs of advanced energy generation and conversion systems, involving the production and use of new fuels such as hydrogen, for use by DOD. (By Stanford Research Institute)<sup>7</sup>
- f. To assess DOD's dependence on catalytic processes and materials, now and in the future; and to formulate a research program in the field of catalysis which is responsive to DOD needs. (By R&D Associates)<sup>8</sup>

## SCIENTIFIC AND TECHNICAL RESULTS

In order to provide a perspective for identifying possible future shortages of critical materials, the early ARPA work focused on identifying national security policy implications and research programs to address, from the DOD perspective, the consequent issues and problems. In this process four basic issues were identified which established a basis for ARPA research addressing potential materials' shortages in advanced technologies:<sup>8</sup>

- Determination of military resource independence. In order to understand the impact on DOD of the changing U.S. raw materials position on the world scene, there is a need to identify and project DOD demand for materials vis-a-vis an overall data base which accurately describes current world and U.S. demand and supply plus development of a basis for making future projections. Although the creation of such a data base is more properly the responsibility of the Department of Commerce or of Interior, DOD should encourage its development and ensure it reflects DOD needs.
- Impact of new technological and economic factors. The DOD interest in its resource dependence should also consider possible effects of technology change to include identification of alternatives to alleviate shortages. To an appropriate degree, studies could also address the effects of the interaction between raw material supply, energy, and economic variables, all of which affect the supply of materials and the choice of alternatives.
- Weapon system/force structure implications. Resource availability will affect the nature of research towards new systems as substitutes are sought for scarce and expensive materials and the tradeoff between resource availability and system performance may enter weapon system evaluations. These considerations, in turn, could impact on force structure determinations.
- Soviet analogue. An important consideration in determining the effects on national security of the declining U.S. self-sufficiency in raw materials is the Soviet resource position vis-a-vis that of the U.S. A study in this regard could be useful.

Addressing all of these issues fully would, of course, be somewhat beyond the ARPA charter. However, as can be seen by the remaining results these issues had a bearing on the formulation and the conduct of the ARPA programs in the materials' shortages area.

a. Key Dependencies of the DOD for Products Potentially Critical in the Event of Material Shortages<sup>9</sup>

The principal scientific report in this effort embraced a material consumption and flow analysis of 17 critical materials to estimate the amount of each consumed by U.S. industry to supply DOD final demand, and to describe their direct and indirect flow through industry. The results are shown in the following table.<sup>10</sup>

The table indicates, for example, that indirect consumption is a major factor in total aluminum requirements, also in tungsten and energy sources. On the other hand, direct consumption is a major factor in requirements for lead, titanium metal and zinc castings. It is also notable that DOD is a major consumer of titanium metal.

The second part of the study investigated economic impacts of shortages of material and energy resources. The consequent major recommendations and conclusions were:

- (1) Among the resource shortages analyzed, the economic impacts of energy shortages are particularly adverse. The availability of these resources deserves continuing priority attention by DOD.
- (2) Among the material resources studied, chromium, aluminum, and tin are commodities for which a stockpile for economic purposes may be desirable, because of potentially adverse economic impacts of shortages of these materials, high levels of imports, insecurity of import sources, and limited domestic reserves. Platinum is also a candidate for an economic stockpile or alternative measures to assure supply, especially because of its economic impacts at relatively low shortage levels. Additional analysis of measures to protect against adverse impacts of shortages of these materials is recommended.
- (3) A framework has been established to guide DOD advance planning for shortages. One example of the results of applying this framework is that DOD is likely to experience supply problems for ammunition products during an aluminum shortage. Indicators of other potential DOD supply problems can be derived for 17 material and energy resources from information presented in the report and the appendix to the report.

**CONSUMPTION PERCENTAGES FOR 17 MATERIALS  
(1972)**

Material	Percentage of Consumption that is Direct*		DoD Consumption as a Percentage of U.S. Total
	U.S.	DoD	
Aluminum	37%	53%	6%
Chromium	31	42	5
Coal	35	18	3**
Cobalt	12	11	5
Copper	42	46	5
Lead	48	64	8
Natural gas	39	32	3**
Nickel	43	57	8
Petroleum	37	45	4**
Platinum	31	36	4
Silver	42	31	3
Tin	4	4	4
Titanium metal	67	72	41
Titanium pigment	15	8	3
Tungsten	34	34	9
Zinc castings	68	69	4
Zinc galvanizing	22	8	4

\*Direct consumption is that which goes from raw material to final demand products without any intermediate consumption of the product.

\*\*The energy resources have significant sales directly to final demand which are not included in these figures. Thus, while only 4 percent of petroleum is consumed by industry for DOD, approximately 5 percent of total U.S. petroleum is consumed by DOD.

Additional extensions of the resource shortage model are recommended to explicitly treat substitution and price effects that occur during shortages.

b. Potential Criticality of Materials in New Technologies for Advanced Weapon Systems

(1) The results are embraced in three reports. One, concerning future requirements for materials used in military optical devices, concluded:<sup>11</sup>

- Germanium may be in short supply in the near or immediate future. Substitute materials sacrifice something in optical, mechanical, or thermal properties.

(2) A second study, summarizing initial findings for a DOD workshop in January 1974, stated that consideration should be given to expanding the domestic supply of germanium.<sup>12</sup>

(3) A third study summarizes that:<sup>13</sup>

- A case study of high temperature gas turbine engines circa 1990 indicates that chromium is potentially an increasingly significant risk.
- Action should be taken to maintain current chromium stockpile objectives and revise these objectives according to new system production requirements as necessary.
- Ceramic technology as a substitute for chromium in high temperature gas turbines has the lowest risk of present candidates.
- Three other materials are potentially critical--cobalt, columbium, and tungsten in applications such as superconducting systems and lightweight structures.

c. Critical Materials Needs in U.S. Emerging Technologies in the Civil Sector

The results are covered in a single report.<sup>14</sup> The initial phase of the research was a screening study which identified some 57 emerging technologies in 15 U.S. industries as possible candidates for further study. Emerging technologies were defined as those

which are expected to become increasingly accepted by industry in the next 15 years, to the extent that their market penetration is expected to be significant by the year 1990. Six of these technologies were selected for in-depth analysis to identify possible future criticalities in material availabilities or production capacities. The conclusions and recommendations of the study were:

(1) Of the six technologies studied in depth, two face potential problems in available raw materials--

- Platinum for fuel cells.
- Helium, niobium, copper, nickel and chromium for superconductors.

(2) Five face potential production capacity shortages--

- Electroslag remelted (ESR) steels.
- Graphite and boron fibers for fiber-reinforced composites.
- Fiber optics for lasers.
- Silicon nitride for high temperature gas turbine engines.
- Superconducting alloy wire.

(3) With related recommendations that DOD and/or ERDA:

- Study the use of ESR to prepare complex castings.
- Consider strong support of helium conservation.
- Sponsor a program to improve the quality and reliability of NbTi wire for superconducting technology.
- Fund additional research of silicon nitride and SiALON as alternative materials in gas turbines.
- Increase efforts to develop fuel-cell catalysts with no or little platinum-group metals.

- Coordinate the quantitative military demand for low-attenuation fiber-optic cable.

(4) And, also, that this report provides a methodology for periodic review of key emerging U.S. technologies.

d. Materials Requirements for Advanced Energy Systems--  
New Fuels

This study sought to identify materials-critical aspects of the use, production, transportation, and storage of new fuels derived from nonfossil sources. Hydrogen was the principal new fuel studied; hydrogen-derived fuels considered were ammonia, hydrazine, boranes, silanes, carbon monoxide, and methyl alcohol. The materials implications of the use, transportation, and storage of oxygen (produced as a by-product in hydrogen generation) and of the use of active metals in batteries were also examined during the study. The principal study results were:<sup>15</sup>

- (1) Of the four program areas--use, production, transportation, and storage--the materials requirements related to hydrogen production were considered the most important. It was considered that the electrolysis of water was the most likely route by which hydrogen could be produced in the quantities required. However, the efficiency of electrolyzer systems is highly dependent on advances in electrocatalyst materials, materials for electrode structures and electrolyte matrices, and electrolyte materials.
- (2) The use of hydrogen as a fuel in a wide variety of equipment did not appear to pose any insurmountable obstacles, although extensive materials research, development, and testing programs would be required to ensure maximum safety, reliability, and efficiency in hydrogen-using equipment. It is in the area of use that materials projects of highest relevance to DOD were found. Problem areas of particular importance to DOD requiring materials support included the use of hydrogen as an aircraft fuel, the further development of fuel cells for the direct conversion of hydrogen fuel to electrical energy, and the use of active metals in high energy density batteries.

e. DOD's Dependence on Catalytic Processes

In the course of the workshop deliberations, held over a two-day period in Santa Monica, California, it was determined that DOD was already supporting catalyst research on a small scale but that such research was limited because the material science of catalysis was not sufficiently developed to facilitate the production of alternate fuels, nor supplementary fuels, nor easy interconversion of fuels. It was determined, however, that industry could probably invent the catalytic technology necessary to produce new fuels for military use, if given sufficient incentive. The principal conclusions and recommendations were:<sup>16</sup>

- (1) The security-of-supply problem for energy and for catalysis is a national more than a DOD problem. The R&D capabilities of the DOD may be effective in contributing to long-term solutions of the national problem.
- (2) Present industrial trends in fuel and petrochemical production imply increased reliance on catalyzed processes. The DOD should be aware that these trends may result in a dangerous dependence on foreign suppliers of catalysts and may require increasing national stockpiles of catalytic materials such as platinum.
- (3) Most of the fuels and petrochemicals used by the DOD are produced through processes that involve heterogeneous catalysis. Sponsoring basic catalysis research in areas not covered by industry is a desirable task for the DOD. Research in heterogeneous catalysis is likely to produce knowledge that can also be applied to fuel cells, photography, corrosion, lubrication, adhesion, and membranes--all of which have important military applications.

In a later report,<sup>17</sup>

- (4) Experimental research programs directed toward reaching a basic understanding of catalysis of importance to DOD are required since industry is principally motivated to commercialize new catalytic processes rather than to explore theory, with the result that basic understandings are not enhanced.
- (5) Theoretical research programs are important to DOD's capitalization on the energy benefits which catalysis can provide.

(6) In the field of applied research it is important to DOD to develop improved catalytic technology in connection with the use of catalysis in the production of solid and liquid propellants.

(7) Certain applied research recommendations:

- Improve catalytic methods for hydrogen production--a fuel to be used in fuel cells for quiet power generation, for deep-sea recovery vessels, and as a heat source to drive turbines.
- Study non-noble metal catalysts for inexpensive, reliable fuel cells that operate on fuels other than hydrogen and oxygen.
- Explore the novel catalytic requirements that would be involved in building small, mobile, ship-board refineries, to produce hydrocarbon fuels on nuclear powered ships, from coal and oil.
- Explore the interfacial and catalytic factors involved in decomposition of solid phase propellants and explosives.
- Investigate any possible catalytic effects involved in the ablation of heat shield materials from missiles or re-entry vehicles.

**TECHNOLOGY UTILIZATION AND  
TECHNICAL INFORMATION TRANSFER**

A review of technical results versus the research objectives indicates the objectives were essentially met. The tangible results, as far as the effectiveness of technical information transfer, that are readily determinable have been noted below. However, there are also less tangible outcomes which benefit the scientific and government community, and should be understood and appreciated whenever studies of broad scope and policy-related such as these are undertaken. The studies have been distributed and are available through the Defense Documentation Center. Additionally, these ARPA-sponsored studies have improved the state of the art in identifying and anticipating critical materials' shortages and identifying potential avenues to meet the resulting technical challenges for the benefit of the DOD and the scientific community.

- a. The principal ARPA research in the materials' shortages area contributed directly to the reviews held for the DOD Materials Shortages Workshop among government and industrial representatives during January 1975 in Washington, D.C.<sup>10,12,14</sup> It is also currently reflected in the continued representations by the Department of Defense in Government interagency coordination for actions to be taken which, as it concerns critical materials, urge that actions be taken to:<sup>18</sup>
  - (1) Review and update U.S. stockpiling measures.
  - (2) Provide early warning of shortages of materials necessary to meet production needs for DOD hardware (beryllium, asbestos, chromium, etc.).
  - (3) Identify substitute materials and processes.
- b. This research effort has also developed methodologies which are available to be used by DOD to:
  - (1) Illuminate, based on current consumption data, key dependencies of the DOD on industrial sectors of the economy for final demand products which would become critical in the event of material shortages,<sup>10</sup> and
  - (2) Analyze U.S. technologies for possible future criticalities to the U.S. and the DOD in material availabilities and production capacities.<sup>14</sup>

- c. The ARPA work on ceramics for high temperature gas turbines is being increased, pointing towards an engine demonstration in FY77. Fifty percent of the FY77 funding and 100 percent of the FY78 funding for continued research of the automotive propulsion aspects of the ARPA program is being transferred to ERDA.<sup>19</sup>
- d. The Department of the Army is continuing the research to considerably reduce the amount of platinum catalyst needed in fuel cell electrodes.<sup>20</sup>
- e. As it concerns electroslag remelted steels, it is noted that ERDA has a FY77 program to buy and test large ESR elbows for nuclear power plants.<sup>21</sup>
- f. With reference to superconducting technology, Battelle and others have achieved considerable recent success in improving the quality and reliability of NbTi wire.<sup>22</sup>
- g. The methodology used and the results of the studies<sup>9,10</sup> to illuminate key dependencies of the DOD for materials which are potentially critical have been briefed to the Federal Preparedness Agency, the Department of Commerce, and the Bureau of Mines (Department of Interior). It was also the basis for a presentation to the American Institute of Mining, Metallurgical and Petroleum Engineers in a symposium in Arlington, Virginia on November 11, 1975, which was later published by the National Science Foundation.<sup>23,24</sup>

**NATIONAL SECURITY IMPLICATIONS OF POTENTIAL  
MATERIALS' SHORTAGES IN ADVANCED  
TECHNOLOGIES**

**FUNDING SUMMARY**

	<u>FY73</u>	<u>FY74</u>	<u>FY75</u>	<u>FY76</u>
<b>RAND</b>			<b>\$120K</b>	<b>\$100K</b>
<b>SRI</b>	<b>\$ 81K</b>	<b>\$ 45K</b>	<b>119K</b>	
<b>BMI</b>			<b>70K</b>	
<b>RDA</b>	<b>106K</b>	<b>4K</b>		
<b>Totals:</b>	<b>\$187K</b>	<b>\$ 49K</b>	<b>\$309K</b>	<b>\$100K</b>
<b>Overall Total:</b>	<b>\$645K</b>			

(1) ARPA Order No. 133-1, December 19, 1972, and instructions from Deputy Director, Technology Assessment Office (TAGO), ARPA.

(2) E. Szwed et al., National Security and National Materials Policy, Proceedings of the National Academy of Sciences, March 1974.

(3) ARPA Order No. 133-1, October 11, 1972.

(4) ARPA Order No. 133-1, August 11, 1974.

(5) ARPA Order No. 133-1, September 11, 1972.

(6) ARPA Order No. 133-1, October 11, 1974.

(7) ARPA Order No. 133-1, February 11, 1973.

(8) ARPA Order No. 133-1, February 11, 1973.

(9) E. Szwed et al., Strategic Resources and National Security, An Initial Assessment, Strategic Resources Institute, February 1973.

(10) M. Levine, J. Yarboll, Department of Defense Materials Requirements and the Impact of Material and Energy Resource Shortages, Strategic Resources Institute, November 1973.

(11) J. Oakley, Future Requirements for and Availability of Germanium, RAND Report R-800-ARPA, August 1974.

(12) E. Szwed et al., Demand of New Technology on Raw Material Supply: Initial Findings, RAND Report R-800-ARPA, February 1973.

(13) Robert E. G. Deitzel, C. J. Harris, E. D. Moore, W. E. and Wolf, K.A.; Strategic Resource Materials--A Case Study--High Temperature Boron, RAND Report R-800-ARPA, June 8, 1974.

(14) C. Jackson et al., Critical Materials Needs, Battelle Columbus Laboratories, August 11, 1973.

(15) E. Szwed et al., Materials Requirements for Advanced Energy Systems: The Case of Uranium, RAND Report R-800-ARPA, July 1974.

(16) J. Libby et al., ARPA Workshop on Raw Materials for Catalysis, W-111, RAND Associates, December 1973.

(17) G. Fisher, J. Libby, Evaluation of Catalytic Needs of the DOD, RAND Associates, February 1974.

(18) For total communication with Mr. M. Dickson, Naval Ship Research and Development Center, and Mr. James K. ... Installation and Logistics, July 25, 1974.

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- (3) ARPA Order No. 2628, October 23, 1973.
- (4) ARPA Order No. 2865, August 12, 1974.
- (5) ARPA Order No. 2294, Sept. 12, 1972.
- (6) ARPA Order No. 2869, October 3, 1974.
- (7) ARPA Order No. 2484, February 23, 1973.
- (8) ARPA Order No. 2483, February 20, 1973.
- (9) E. Hughes et al., Strategic Resources and National Security: An Initial Assessment, Stanford Research Institute, April 1975.
- (10) M. Levine, I. Yabroff, Department of Defense Materials Consumption and the Impact of Material and Energy Resource Shortages, Stanford Research Institute, November 1975.
- (11) J. Oakley, Future Requirements for and Availability of Germanium, Rand WN-8802-ARPA, August 1974.
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- (13) Salter, R. G.; Dzitser, C.; Harris, E.D.; Mooze, W.E.; and Wolf, K.A.; Strategic Defense Materials--A Case Study--High Temperature Engines, R and R-1970-ARPA, June 8, 1976.
- (14) C. Jackson et al., Critical Materials Needs, Battelle Columbus Laboratories, August 11, 1975.
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- (17) G. Fisher, L. Libby, Evaluation of Catalytic Needs of the DOD, R&D Associates, February 1974.
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- (19) Personal communication with Dr. Ed Van Reuth, ARPA Materials Sciences, July 26, 1976.
- (20) Personal communication with Mr. John O'Sullivan, U.S. Army Mobility R&D Command, July 28, 1976.
- (21) Personal communication with Mr. Joseph Dunleavy, Battelle Columbus Laboratories, August 2, 1976.
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- (24) Proceedings of the Mineral Economic Symposium, National Science Foundation, NSF/RANN-760162, November 11, 1975, pp. 57-61.
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