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AN OVERVIEW OF ARMY MOBILITY ENERGY RESEARCH AND DEVELOPMENT

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Dependence on foreign oil sources and the attendant strategic problems of securing the long lines of supplies from possible interruption raise a question of the ability of the Armed Forces to carry out its mission in the event of a national emergency. cont.

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Energy is essential for the Army in maintaining readiness to assure national security in peacetime, crisis, or war. The Army Energy Plan, which is in concert with and support of national energy goals, establishes the basis for reducing energy consumption, reducing dependency on conventional hydrocarbon fuels, and tasks the Army to obtain a position of energy leadership. In this report, the Department of Army Energy goals/objectives are identified and the framework for planning Army Mobility/ Energy/ Research and Development is outlined. Key elements of the Army Mobility Energy R&D plan of action include an organization plan, technical assessment, technical performance plan, and a management plan. The Army Mobility Energy R&D Program has been categorized into four program areas--fuels, other fluids, engines, and other equipment. Examples of individual projects, as well as an overview of the Army's Mobility Energy Research and Development are provided with respect to meeting Army Energy goals.

FOREWORD

This work was conducted at the U. S. Army Fuels and Lubricants Research Laboratory (USAFLRL) located at Southwest Research Institute, San Antonio, Texas under Contracts DAAK70-78-C-0001 and DAAK70-80-C-0001 during the period June 1979 through October 1981. The work was funded by the U. S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, Virginia, with Mr. F. W. Schaekel (DRDME-GL) serving as contract monitor. Project technical monitor was Mr. M. E. LePera, MERADCOM-DRDME-GL.

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I. INTRODUCTION

Dependence on foreign oil sources and the attendant strategic problems of securing the long lines of supplies from possible interruption raise a question of the ability of the Armed Forces to carry out its mission in event of a national emergency.(1)* The ability of the U. S. to deter armed conflict, to respond to military aggression, to field modern and effective weaponry systems, to meet U. S. worldwide commitments and to exist as a nation depends upon an adequate supply of energy of the type and quality required to meet the Armed Forces' needs. However, at the same time, the military must be aware of and account for the economics of these requirements.

A Congressional conference report was published on the "Energy Security Act"(2) which was signed into law by the President on 30 June 1980. The purpose of the Energy Security Act is to utilize to the fullest extent the constitutional powers of Congress to improve the nation's balance of payments, reduce the threat of economic disruption from oil supply interruptions, and increase the nation's security by reducing its dependence upon imported oil.

In support of national energy goals, the Army Energy Plan (3) establishes the basis for reducing energy consumption and dependency on conventional hydrocarbon fuels and tasks the Army to attain a position of energy leadership. The Army Energy Plan identifies the Army Energy goals and objectives to be:(3, 4)

1. Reduce energy consumption by 35 percent by the year 2000.
   - 1a. Reduce energy consumption in mobility operations by 10 percent by FY85 with zero growth to the year 2000 with no degradation to readiness.
   - 1b. Reduce energy consumption in facilities operations by 20 percent by FY85 and 40 percent by the year 2000.
   - 1c. Expand energy conservation education/information and incentive programs for all Army military and civilian personnel and their dependents.

*Numbers underlined in parentheses refer to list of references at end of this document.

2. Reduce dependence on nonrenewable and scarce fuels by the year 2000.

   2a(1). Develop capability to use synthetic/alternate fuels for mobility.

   2a(2). Increase efficiency of mobility systems by 15 percent.

   2b(1). Develop capability for facilities to use synthetic gas in place of natural gas.

   2b(2). Reduce consumption of heating oil by 75 percent.

3. Attain a position of leadership in the pursuit of national energy goals.

The energy research, development. test, and evaluation efforts to meet the goals fall into two categories: (1) mobility and (2) facilities. The Army Energy R&D responsibilities include that U. S. Army Development and Readiness Command (DARCOM) develop the Army Energy R&D Plan. The Mobility Equipment R&D Command (MERADCOM), a major subordinate command of DARCOM, has been designated as the lead organization for preparing/maintaining the plan, accomplishing general coordination, addressing voids and gaps in the plan, and conducting an assessment of projects proposed for inclusion in the plan. Additionally, MERADCOM is responsible for preparing the mobility portion of the plan. The Office of Chief of Engineers (COE) develops the facilities element of the Army Energy R&D Plan.

The Army Energy RDT&E plan complies with the broader DOD energy plan and national energy goals. In this regard, DOD has established a set of general energy objectives combined with specific energy goals. The general objectives ensure that DOD energy policies and programs are directed toward meeting the overall energy-related needs of DOD, while the specific energy goals provide a means of measuring the progress towards the attainment of the objectives. The prime objectives of the Army Energy RDT&E program are to provide the technological inputs required to meet the DOD and DA objectives and goals. Accordingly, the major thrust of the Energy R&D plan is directed toward the application and, when necessary, the development of the specific technologies to:

a. Utilize domestically produced synthetic fuels and alternate conventional fuels in military mobile systems.

b. Develop a family of military engines capable of burning a broad range of both synthetic and conventional fuels.

c. Reduce overall energy use through efficiency improvements without compromising flexibility, readiness, or performance.

d. Achieve an adequate degree of energy self-sufficiency for military installations through reduced dependence on petroleum fuels.

e. Encourage the commercialization of domestic synthetic fuels industry capable of producing mobility fuels for military use.

This report provides an overview of the Army's Mobility Energy Research and Development with respect to meeting Army energy goals.

II. BACKGROUND

A. History and Perspective

World industrial growth during the past century has been characterized and hastened by the widespread availability of inexpensive energy, primarily petroleum. The Arab oil embargo of 1973 and subsequent energy supply interruptions served to emphasize a number of points, key among them being that the world's principal oil-consuming countries are not the major oil-producing countries. The Middle East and Africa have an estimated 67 percent of the world's petroleum reserves, while Western Europe and the Western Hemisphere have only 16 percent. By most estimates, these reserves are expected to be essentially exhausted within the next 70 years. In 1973-74, prices for petroleum rose threefold, signaling the end of inexpensive oil. Although the distribution of alternative sources of recoverable fossil energy (such as tar sands and oil shale) favors the Western Hemisphere, economical recovery techniques to exploit these resources have not yet been developed. While coal constitutes 81 percent of the United States' energy reserves, it supplies only 18 percent of the energy consumed.(5)

The United States, with 6 percent of the world's population, consumes more than 30 percent of the world's energy. It uses more energy per dollar of Gross National Product (GNP) than any other industrialized nation. Petroleum is used primarily for transportation, coal is used principally for electric utilities and industry, and natural gas is preferred for residential heating and some industrial uses.(3)

Petroleum production in the United States peaked in 1970 and has decreased since then. As a result, in 1977 the United States imported approximately 50 percent of its crude oil requirements. Many analysts predict that the U. S. petroleum reserves will be substantially depleted before the year 2000, thereby creating a significant problem for the nation and the Department of Defense (DOD).

The national energy strategy is reflected in the following objectives established by the President on 29 April 1977 in the National Energy Plan (5) and reinforced in the National Energy Plan II, May 1979.(6)

a. In the near-term, to reduce dependence on foreign oil and to limit vulnerability to supply disruptions.

b. In the mid-term, to keep U.S. oil imports sufficiently low to weather the eventual decline in the availability of world oil supplies caused by capacity limitations.

c. In the long-term, to develop renewable and essentially inexhaustible sources of energy for sustained economic growth.

Some of the key specific national goals cited by the President to be accomplished by 1985 are as follows: Reduce energy usage growth to 2 percent per year, reduce gasoline consumption by 10 percent, increase coal production by 67 percent, use solar energy in 2.5 million homes, and reduce energy consumption in federal buildings by 20 percent in existing buildings and 45 percent in new buildings.(5)

DOD consumes 1.8 percent of the nation's energy, but consumes over 3 percent of the total petroleum used by the United States. DOD established the following energy conservation goals:

FY74 - 7 percent savings over FY73
FY75 - 15 percent savings over FY73
FY76 - 0 percent growth over FY75
FY77 - 0 percent growth over FY75
FY78 - 0 percent growth over FY75
FY79 - 0 percent growth over FY75

All of these goals were achieved.(3)

Based on 1980 data, the Army's share of DOD energy consumption was 17 percent. Of that amount, 83 percent was consumed in installation or facilities operations and 17 percent in mobility operations.

B. Significant Guidance for Defining Goals for Research and Development

1. General DOD Energy Goals and Objectives

The Department of Defense, in response to the consideration of an assured supply of energy, particularly mobility fuels; and in support of DOD's primary aim of maintaining the operational readiness of the U. S. strategic and tactical forces sufficient to ensure national security regardless of energy supply conditions, has established the following general DOD energy objectives:(7)

a. Broaden the range of mobility fuels which can be used in military systems with primary emphasis on domestically produced synthetic fuels.

b. Promote energy conservation with primary emphasis being to develop more efficient propulsion and power generation equipment and to reduce the dependence of military installations, particularly remote bases, on petroleum-derived fuels by promoting the use of more abundant or renewable energy sources.

In support of these general energy objectives, DOD has established the following specific energy goals:(7)

a. Devise with DOE a national strategy to minimize the disruption of hydrocarbon fuels to DOD.

b. Develop propulsion systems and adequate specification and testing procedures to accommodate a broader range of fuels.

c. Prepare now for the transition from use of petroleum- to synthetic-based fuels in the post-1985 time frame.

d. Comply with the energy-reduction goals for 1985 as set forth in Executive Order 12003 to reduce energy usage in existing and new buildings by 20 and 45 percent, respectively, and to exceed the statutory requirement for fuel economy in the DOD passenger auto fleet.

e. Limit the level of energy usage in 1985 to that used in 1975 through improvements in propulsion systems, increased efficiency of mobile equipment used in operation and training, and increased use of simulators in training.

f. Obtain a 10-percent use of more abundant and renewable solid fuels by 1985.

g. Obtain a 1-percent use of solar and geothermal energy by 1985.

h. Equip all natural-gas-only-heating plants over 5 MBtu/hr with alternative fuel capability by 1982.

i. Maintain a 30-day fuel oil supply for all heating units greater than 5 MBtu/hr.

2. DOD/DOE Cooperative Program Guidance

A Memorandum of Understanding (MOU) between the Department of Defense (DOD) and the Department of Energy (DOE) provides for a broad range of cooperative energy activities, to enhance national security and achieve the United States energy goals.(8)

The MOU scope of cooperative programs includes:

a. DOD will identify to DOE its requirements for fuel necessary to support the peacetime readiness and wartime operations of the strategic and tactical forces;

b. DOD will use its expertise and facilities, as mutually agreed, in research, development, and demonstration programs in support of DOE, within its authority and in accordance with DOD policies and procedures;

c. DOE will collaborate with DOD in ensuring that DOE's programs, including the strategic petroleum reserve program, help to assure the peacetime readiness and wartime operational needs of the strategic and tactical forces;

d. DOE will assist DOD in identifying significant potential areas of energy saving within DOD and will advise DOD of advances in energy-related technologies that have potential application to DOD;

e. DOE will review DOD's annual list of energy-related research, development, test, and evaluation projects to ensure that duplicate projects are not initiated and will advise DOD of the results of that review; and

f. DOE will use its expertise and facilities as mutually agreed to participate in research, development, and demonstration programs, in accordance with established DOE policies and procedures.

A "DOD-DOE Workshop on Joint Energy Activities" was held March 10-12, 1980. The principal purpose of the workshop was to identify specific programs and projects for inclusion in a plan to implement the Memorandum of Understanding between the Department of Energy and Department of Defense. Candidate programs and projects are to include research, development, demonstration, and other activities in areas where the two departments have mutual interests and where the realization of those interests requires joint action.

3. Mobility Energy R&D Plan and the Army Energy Plan

A briefing outlining a Mobility Energy R&D Plan was requested in a letter(9) of 8 May 1978 from the Deputy Director, Material Plans and Programs (DAMA-PPM), for the Office of the Deputy Chief of Staff for Research, Development, and Acquisition (ODCSRDA). The letter stated that:

a. "As one part of the effort to accomplish the DOD and Army energy goals, there should be a coordinated Mobility Operations Energy R&D technology base program encompassing total projects and efforts relating to achievement of specific goals.

b. To initiate this activity, you are requested to provide a review to the Agency and other HQDA members, and a detailed plan which clearly identifies objectives and management structure for the POM 80-84 years. Insofar as possible, your plan should also address the longer range picture to the year 2000 to accomplish the Army energy goals and objectives. Your presentation should include:

(1) 6.1 research programs underway, technical objectives, approach, performing organization, and funding.

(2) Recommendations for new 6.1 work.

(3) 6.2 and 6.3a work being done and what additional 6.2 and 6.3a programs should be pursued.

(4) Identification of major technology gaps, especially those that could impact any of the newly developing weapon systems.

(5) Identification of potential technological opportunities.

c. To aid in planning a complete and comprehensive technology program, the following technical/management areas should be addressed:

(1) Plans for action for coordination between laboratories.

(2) Plans for action for coordination with DOE and other services.

(3) Plans for participation with the DOE Shale Oil Task Group.

(4) Technology transfer to system commands and program/project manager.

(5) Current programs which heretofore have been classed as energy-related as opposed to energy-motivated.

d. This review should involve several laboratories and a number of SPF/SPEFs. Our objective is to ensure a cohesive, coordinated program leading toward a stronger Mobility Operations Energy R&D technology base that will be capable of responding to future ROCs and the overall needs of the Army to cope with the future energy environment. The plan will serve to initiate effective, well-coordinated energy programs, and provide documentation for resource allocation."

As a result of this briefing and a subsequent letter (10), a finalized first edition of the "Army Mobility Energy R&D Plan 1980" was distributed by the Deputy Chief of Staff for Research, Development, and Acquisition on 1? July 1980.(4) This plan describes management structure and recommends thrust areas for attainment of the Army energy goals. These thrust areas include: (a) R&D efforts to increase engine efficiency; (b) test and evaluation to allow for usage of alternate/synthetic fuels; and (c) development/evaluation of lubricants, material, and dispensing systems compatible with the emerging fuel/engine systems. This plan recommends implementation of the existing Army Program Structure in response to the challenges of energy conservation and self-sufficiency.

The current "Army Energy R&D Plan 1981" is an updated revised version of the Army Mobility Energy R&D Plan 1980.(11) The updated plan consists of two R&D plans--the Mobility Energy R&D Plan and the Corps of Engineers (COE) R&D Plan. The COE plan pertains to facilities/installations, and is an updated version of the COE Five-Year Research and Development Plan dated 1 October 1978.(13)

Because of the goal set by the Army to procure mobility systems which are 15 percent more fuel efficient by the year 2000, DARCOM was requested by DA(DAMA-ARZ-E) to provide an approach to developing improved fuel-efficient mobility systems.(13)

TACOM has been assigned the lead (13, 14) in defining a fuel-efficiency program plan in these two categories: (1) tactical vehicles, and (2) ground combat vehicles. To assist in carrying out this mission, information was solicited from the major commands to include:(15)

a. Category of mobility systems (tanks, trucks, fixed wing aircraft, rotary wing aircraft, engine generators, etc.). Break-down to category level (e.g., trucks) that all system models (e.g., M809 5-ton truck, M151 1/4-ton truck) for the category which can be tested to the same criteria as developed for "c" below.
b. Listing of all system models for each category (trucks--M809 5-ton, etc; heavy tanks--M60, M1, etc.).
c. Criteria for measuring category efficiency baseline. The requirement is to establish a simplified test condition that will permit determination of baseline fuel usage rate and improved fuel usage rate after application of new technology. The test criteria and

parameters should be identified. For example: Criteria for a truck might be to measure fuel usage range (miles/gal.) for truck operating on level paved road at 25 mph for distance of at least 50 miles loaded at rated load; ambient temperature of 60°-70°F; using standard military grade of fuel; given normal maintenance tuneup before starting run; and any other parameters necessary to ensure identical test conditions.

d. Annual fuel usage per system model (FY79). Basis for establishing annual fuel usage for a single model system should be given. For example, it might be based on an assumption of X miles or hours/year multiplied by the average gallons of fuel per mile/ hour. The number of gallons of fuel for a single system model (e.g., M809) will then be multiplied by the number of items in the Army inventory to determine annual fuel usage for each system model (M809--15,000 gal./yr X 25,000 trucks = 375,000,000 gal./yr for M809).

e. System model density (1980-1990-2000). Estimate number of items in the Army inventory for these years.

f. Potential areas of efficiency improvements for each category. List at least six subsystems that may have potential for improving efficiency of each category of mobility systems.

g. Research and development programs and funding (6.1, 6.2, and 6.3A) for programs which have potential for increasing the efficiency of identified mobility system categories. Listing should include project number, project title, funding, objective of program, and current status.

Based on the requested input, a "Plan for Organization and Execution" ("Fuel Conservation Through Energy-Efficient Mobility Systems") was completed and submitted to DARCOM (16). Each of the projects identified in this plan is covered in the "Army Mobility Energy R&D Plan 1981" in a more nonspecific manner and is covered in detail as Army Mobility Energy R&D Project Summaries for Mobility Operations.

3. Army Energy Program

The Army Energy Program (AR 11-27) promulgates the Army's responsibilities and provides other guidance.(17) The overall objectives of the Army Energy Program are stated as follows:

a. Assure the availability and supply of energy to Army forces in accordance with mission and readiness priorities.
b. Participate in the national effort to conserve energy resources.
c. Attain, as a minimum, conservation goals established by DOD.
d. Participate in national research and development efforts toward new and improved energy sources.
e. Implement DOD energy-reporting requirements.
f. Promote Army-wide awareness of the essential need to conserve energy resources, and to foster a willingness to participate in conservation of these resources.
g. Recognize accomplishments of Army personnel in energy conservation.

5. Other Guidance

References 18 through 25 provide additional guidance for the implementation of Army Energy Research and Development.

III. DISCUSSION OF FRAMEWORK FOR PLANNING ARMY MOBILITY ENERGY R&D

The Army Mobility Energy R&D Program provides a framework to reduce use of mobility fuels through improved engine efficiency, to develop multifuel engines, and to provide for introduction of synthetic fuels and alternative energy sources in Army mobile equipment. The program is being implemented, additionally, with sufficient scope to include all nonfixed facility fuel-consuming equipment and to accommodate energy conservation as well as energy supply objectives.

Figure 1 illustrates how many Army Mobility Energy R&D projects originate.

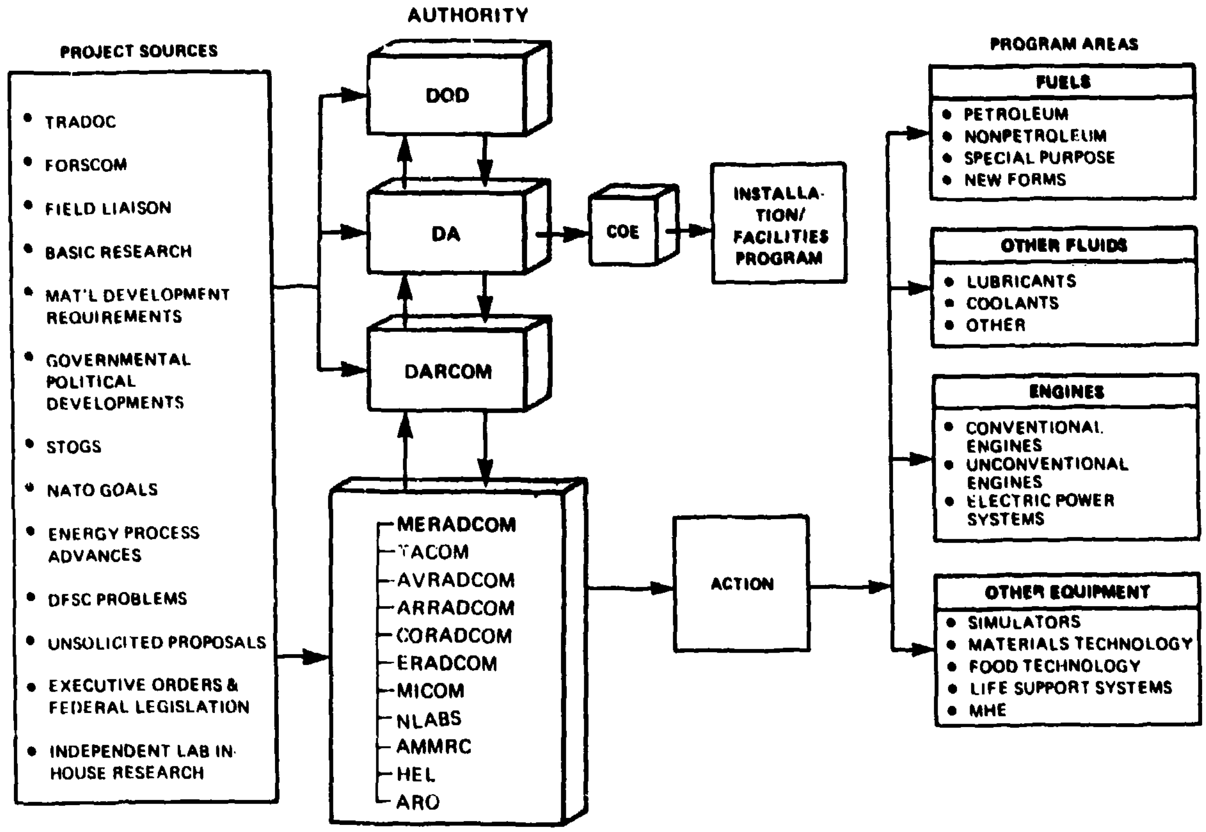


FIGURE 1. ARMY ORGANIZATION FOR MOBILITY ENERGY RESEARCH AND DEVELOPMENT PROGRAM

The project sources shown in the figure have been selected as examples of numerous additional sources that could be cited. Communications between the subcommands (MERADCOM, et.al.) and project sources are unrestricted, but authorization for specific projects must be received via the DA-DARCOM authority process. However, project activities can and should be adjusted by the subcommands as appropriate within the scope of the authorized program elements. Some project areas require special intra-DOD coordination. A good example is that the USAF had lead service responsibility for turbine fuel development while the Army (AVRADCOM) is a major helicopter engine-developer/turbine fuel user. Similarly, the Army (TACOM), in its ground vehicle selection support role for DOD, must interface with the USN and USAF energy plans to ensure that commercial ground vehicle procurements are consistent with energy goals.

Each of the Army subcommands and laboratories which conduct energy-related projects, as well as the Corps of Engineers, submit periodic project summaries to MERADCOM. These summaries are consolidated into the overall program plan. Briefings on the consolidated plan are then held as needed during DARCOM, DA, and DOD reviews to provide visibility and to recommend adjustments, authorization, and funding.

The Army Mobility Energy R&D Program can be categorized into four program areas--fuels, other fluids, engines, and other equipment. Figure 1 identifies the sub-elements under which the individual projects can be assigned. The sub-elements under "Fuels", "Other Fluids", "Engines", and "Other Equipment" are sufficiently broad to accommodate all product-oriented possibilities. Operational, procedural, and other soft-science projects which either conserve fuel or improve its availability are also performed under the program elements.

The Program Performance Plan is illustrated in Figure 2. The progress routes pass through four phases of effort, any one of which may lead to the output examples shown. Two important messages are communicated by Figure 2.

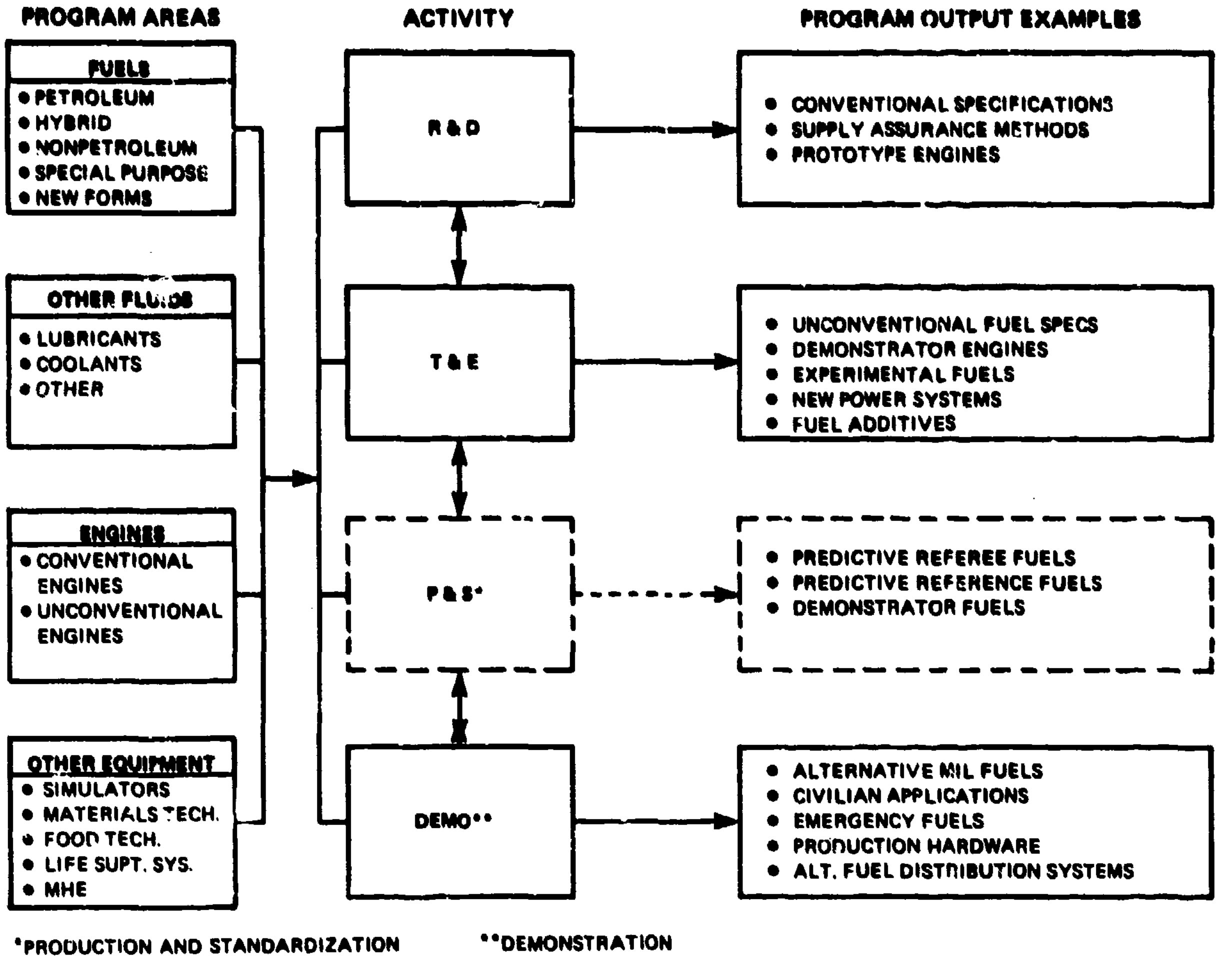


FIGURE 2. ARMY MOBILITY ENERGY PROGRAM PERFORMANCE ELEMENTS

The first message is that the traditional RDT&E phases required for most hardware items are not generally sufficient for the progress of alternative fuels. DOE recognized this in 1976 when preparing the first national energy plan.(5) It has been determined that alternative fuel processes require significant demonstration phases in order to eliminate economic uncertainty of their alternative fuel projects. DOE uses the initials RD&D to define their alternative fuel progress phases. DOE does not eliminate the T&E phases, but chooses instead to consider them to be parts of the development phase.

It has recently become apparent that demonstration phases intended for energy source process methods are insufficient for continuing the progress form process yields into finished fuel forms. Numerous process development projects have been undertaken, for example, by DOE, and many have resulted in the production of pilot batches of synthetic fuel components. Ironically, only a few of these components were ever blended into finished fuel compositions and fewer still were ever demonstrated in the field. Until 1979, the Navy was the only organization that had actually made special arrangements for the production and standardization (P&S) of finished fuels from oil shale. They had, in effect, identified the necessity for P&S phases for all new finished fuel compositions. DOE has recognized that special phases are required to produce and standardize finished fuels containing nonpetroleum components. The DOE national road test(26) of alcohol/gasoline fuel blends has required that special attention be given to the P&S activity. In Figure 2, the P&S phases are enclosed with dashed lines to signify the uncertain responsibility for these functions. Whether considered by DOE, DOD, or another agency, these functions must be addressed to ensure future synthetic fuels availability.

The second message is that progress toward the end application of energy projects does not necessarily pass through all phases of Research and Development, Test and Evaluation, Production and Standardization, and Demonstration (RDTEPS&D) in an orderly manner. For example, conventional fuel specifications are usually developed as modifications of preceding specifications. The finished product is a document which is not usually identifiable with other physical RDT&E work. Figure 2 thus lists "conventional" fuel specifications as a completed output from the R&D phase. "Unconventional" fuel specifications, however, usually involve T&E activities as well as prior R&D work. The predictive referee fuels shown under the P&S phase represent fuel examples that must proceed through R&D and T&E phases. As the name implies, "predictive" referee fuels are compositions that can be blended today as "best estimates" of fuels expected in the future. Such fuels are urgently needed to aid the development of future engines. Obviously, the P&S phase is also essential for the preparation and supply of special fuels such as the fuels (600,000 barrels) from oil shale that are required for a forthcoming

DOD program.(27) Obviously, too, the P&S phase is a necessary, but separate, activity from the Demonstration phase.

Figure 3 is an expansion of Figures 1 and 2 to provide an overall representation of the Army Mobility Energy R&D program performance. It should be noted that Figure 3 was prepared to illustrate the flow routes of project efforts within the mobility energy program/plan. Figure 3 additionally illustrates the flow routes of communications that are required to keep the program in perspective with Army goals and objectives. The DARCOM program is controlled and optimized via DARCOM/DA and DOD authority, technical and techno-economic feedback including information exchanges, and an assessment activity.

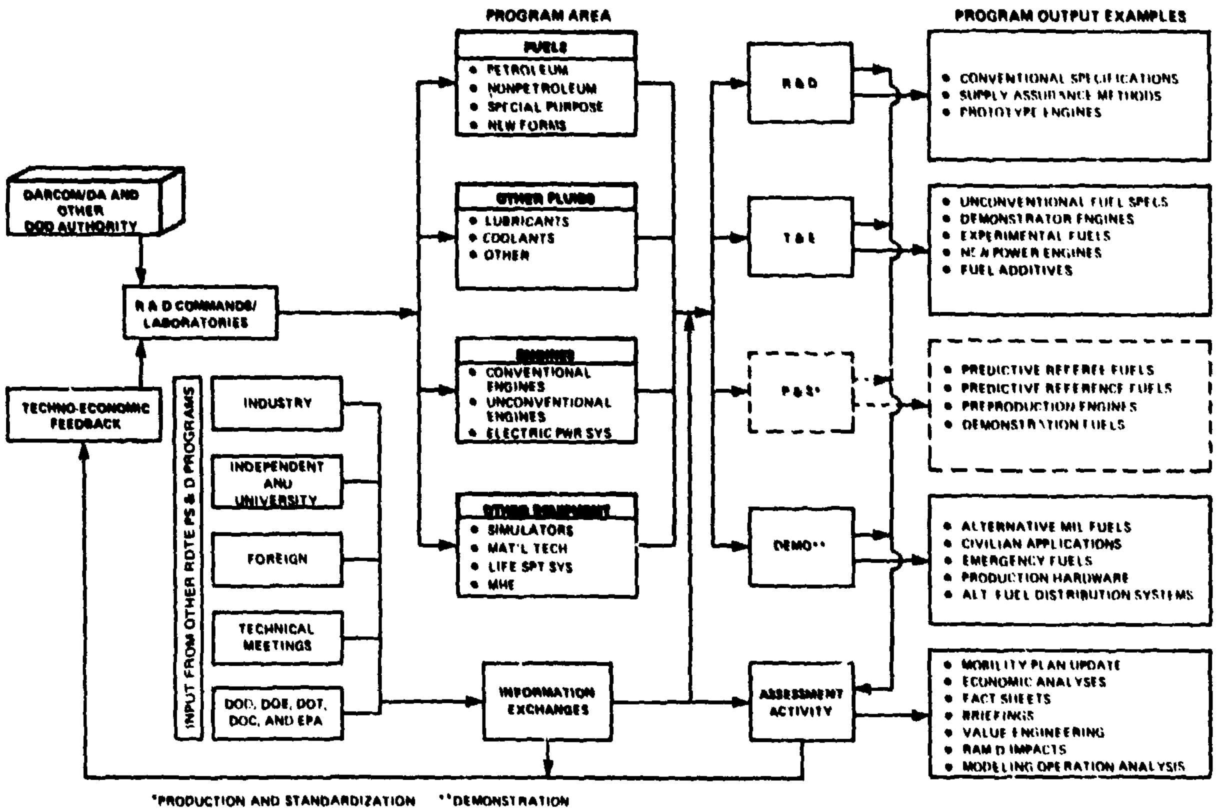


FIGURE 3. OVERALL REPRESENTATION OF ARMY MOBILITY ENERGY PROGRAM PERFORMANCE

The influence of DARCOM/DA and other DOD authorization on the program is obvious and needs no additional explanation. Likewise, the necessity for information exchanges and surveillance of other RDTEPS&D activities is also well recognized. The assessment activity functions as a vital part of overall coordination by MERADCOM. Its purpose is to bring the results of the fuels, other fluids, engines, and other equipment projects into perspective with Army logistical, tactical, combat, and other national objectives. Its function is to minimize the conduct of marginal, nonrelevant, and uneconomic projects as well as to advocate emphasis on projects that are more economical and defense oriented. Additionally, the assessment activity provides continuing (vis-a-vis periodic) adjustments of the physical project activities, thus assuring maximum performance efficiency of the program and providing a yardstick measurement of successful goal achievement.

As input for development of the 1981 R&D plan, 145 energy-related/supporting projects were submitted by all of the DARCOM R&D commands. Quantitative assessment methodologies have been developed to evaluate the energy relevance of projects proposed or being carried out under the monitorship of the Army Energy R&D Plan. The numerical value system established for the energy relevance assessment process is shown in Table 1. Point values from 1 through

TABLE 1. NUMERICAL VALUE SYSTEM FOR ENERGY RELEVANCE ASSESSMENT
(Note: Makes no judgment on project to meet Army requirement, only its contribution to Army Energy R&D)

Energy Relevance Number*	Definition
5	Must program, should be funded, excellent energy support.
4	High potential, should be funded, high energy support.
3	Good, funded if monies exist, good energy support.
2	Marginal, limited support to Army energy goals.
1	Undecided, need to examine further to determine if it should remain in Energy Plan
0	Not energy-related
MARK (For 6.1 projects not directly supportive of developmental projects)	
+	Relevant
-	Not relevant

*For Mobility Energy R&D

5 are assessed, depending on the relevancy of the proposed project to the Army Energy R&D Program. Using this "energy relevance rating" system, the energy relevance assessment illustration in Table 2 was prepared.

TABLE 2. ENERGY RELEVANCE ASSESSMENT ILLUSTRATION
(PREPARED: JUL 30, 1981)
****

Project Title	Command	Energy Relevance	Funding Type
Adiabatic Diesel Engine	TACOM	4	6.2
Advanced 1000 HP Diesel Engine	TACOM	3	6.3a
MACI Engine Program	TACOM	1	MACI
Fuel Cell Powerplant	MERADCOM	5	6.1
Hybrid Fuel Cell	MERADCOM	3	MACI
Energy Conservation	ERADCOM	0	6.1
Engine Combustion Research	ARO	+	6.1
Multisource Fuel Engines	AVRADCOM	5	6.4
Seals/Wear	AVRADCOM	3	6.2

A Quantitative Assessment Methodology has been developed which considers three characteristics of the projects pertinent to meeting the Army energy goals.(28) In the first consideration, an estimate is made of all the individual items of the Army inventory and their total contribution to Army energy usage. Products designed to meet the Army energy goals are assigned Modes of Effectiveness (MOE) based on their possible energy savings. The MOE considers energy savings in three areas: (1) total possible energy savings based on projects and projections submitted; (2) total possible savings when a weighted project success factor is included; and (3) total possible energy savings in terms of dollar investment for accomplishment. In the second consideration, the possible energy savings and the effects on high fuel consumption items, high density items, and critical items are being investigated with orientation toward present TOE structure and mission accomplishment. In a third consideration, a fuel saving cost analysis has been developed to encompass the total fuel costs and savings features that may be applicable to any mobile system and accommodates evaluation of candidate energy consumption programs.

The elements of the potential fuel savings MOE Number 1 are combined as indicated in Figure 4 for each project to produce the average annual potential current-source fuel savings of each project over the time horizon. The product $C_{ik} \cdot E_{ijk}$ gives the potential LHFCS (Liquid Hydrocarbon Fuels from Current Sources) saved in year k for project j by consumer i based on the successful development of the project. This product is reduced by the net petroleum balance (I_{ijk}) for that combination to result in the net potential LHFCS savings for that project, consumer, and year. Summed over all applicable consumers for the project, the net total potential savings for project j and year k is produced. This value is then averaged over the time horizon Y_1 to Y_2 to result in the desired MOE 1 value for project j. Each project is independently evaluated in this manner and assigned an MOE 1 value. Projects with higher MOE 1 values possess greater potential for LHFCS savings than those with lower values.

$$S_{j(y_1, y_2)} = \frac{\sum_{K=y_1}^{y_2} \sum_i a_{ij}(C_{ik} \times E_{ijk} - I_{ijk})}{(y_2 - y_1 + 1)}$$

WHERE

$S_{j(y_1, y_2)}$ = AVERAGE ANNUAL POTENTIAL LHFCS SAVINGS OF PROJECT j OVER THE YEARS y_1 TO y_2

a_{ij} = APPLICABILITY (YES = 1, NO = 0) OF PROJECT j TO CONSUMER i

C_{ik} = ACTUAL (OR PROJECTED) LHFCS CONSUMPTION OF CONSUMER i IN YEAR k

E_{ijk} = FRACTION AVERAGE LHFCS SAVED BY CONSUMER i DUE TO PROJECT j IN YEAR k ASSUMING SUCCESSFUL PROJECT

I_{ijk} = NET ADDITIONAL LHFCS CONSUMED IN YEAR k IN THE COURSE OF IMPLEMENTING PROJECT j TO CONSUMER i (OVER THAT CONSUMED IN YEAR k IF PROJECT j NOT IMPLEMENTED TO CONSUMER i)

(y_1, y_2) = SPECIFIED HORIZON TIME

NOTE: LHFCS—(LIQUID HYDROCARBON FUELS FROM CURRENT SOURCES)

FIGURE 4. POTENTIAL FUEL SAVINGS (MOE 1)

The elements of the expected fuel savings MOE Number 2 are combined for each project in Figure 5 to produce the average annual expected current-source fuel savings of that project over the time horizon. The technical risk factor (R_{ijk}) for project j being applied to consumer i in year k is multiplied by the previously determined net potential LHFCS savings for that project, consumer, and year. This new result, the expected LHFCS savings, is summed over all applicable consumers to produce the net total expected savings for project j in year k. This value is then averaged over the time horizon Y_1 to Y_2 to result in the desired MOE 2 value for project j. Each project is independently evaluated in this manner and assigned an MOE 2 value. Projects with higher MOE 2 values possess greater expectation of LHFCS savings than those with lower values.

$$E\left[S_{j(y_1, y_2)}\right] = \frac{\sum_{K=y_1}^{y_2} \sum_{i} a_{ij} \times R_{ijk}(C_{ik} \times E_{ijk} - I_{ijk})}{(y_2 - y_1 + 1)}$$

WHERE $E\left[S_{j(y_1, y_2)}\right]$ = AVERAGE ANNUAL EXPECTED LHFCS SAVINGS OF PROJECT j OVER THE YEARS y_1 TO y_2

R_{ijk} = TECHNICAL RISK FACTOR. THE LIKELIHOOD OF ACHIEVING E_{ijk} AND INCURRING I_{ijk} IN YEAR k FOR PROJECT j AND CONSUMER i

FIGURE 5. EXPECTED FUEL SAVINGS (MOE 2)

The elements of the expected fuel savings/dollar cost MOE Number 3 are combined as indicated in Figure 6 for each project to produce the expected current-source fuel savings per dollar (present value) cost of each project over the time horizon. The previously determined net total expected LHFCS savings for project j in year k is summed over the time horizon Y_1 to Y_2. This total expected savings is then to be divided by the total expected costs (present value) of the project over the same time horizon. These total costs are determined from the two cost elements. The scheduled production and implementation net costs (P_{ijk}) for project j and consumer i in year k is multiplied by the appropriate technical risk factor (R_{ijk}) and summed over all applicable consumers for project j to produce the expected production and implementation net cost for project j in year k. This is added to the scheduled R&D costs (D_{jk}) to result in the total expected costs for project j in year k. This result is summed over the years Y_1 to Y_2 to produce the total expected costs (present value) of the project over the time horizon. The ratio between total expected LHFCS savings and total expected costs is the value of MOE 3 for project j. Each project is independently evaluated in this manner and assigned an MOE 3 value. Projects with higher MOE 3 values possess greater expectation of LHFCS saving per dollar cost than those with lower values.

$$E\left[S_{j(Y_1,Y_2)}/\$\right] = \frac{\sum_{K=Y_1}^{Y_2} \sum_{i} a_{ij} \times R_{ijk}(C_{ik} \times E_{ijk} - I_{ijk})}{\sum_{K=Y_1}^{Y_2} \left(D_{jk} + \sum_{i} a_{ij} \times R_{ijk} \times P_{ijk}\right)}$$

WHERE $E\left[S_{j(Y_1,Y_2)}/\$\right]$ = EXPECTED LHFCS SAVINGS PER DOLLAR COST OF PROJECT j OVER THE YEARS Y_1 TO Y_2

D_{jk} = RESEARCH AND DEVELOPMENT COSTS SCHEDULED FOR PROJECT j IN YEAR k

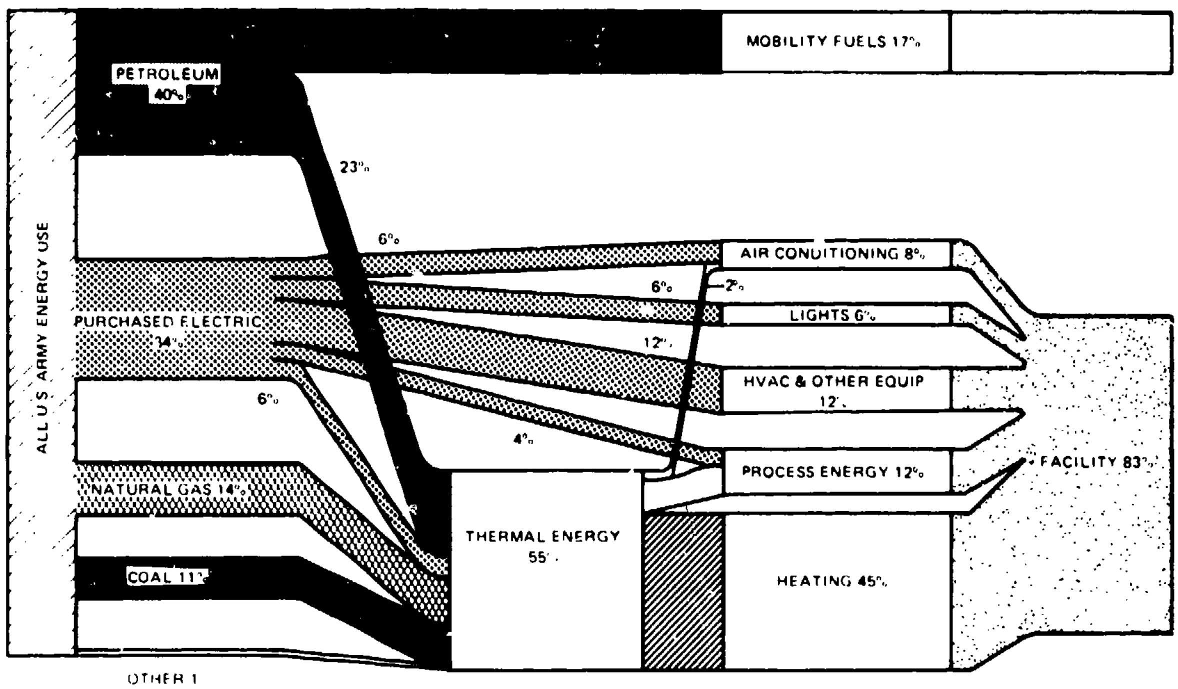
P_{ijk} = PRODUCTION COSTS SCHEDULED FOR THE APPLICATION OF PROJECT j TO CONSUMER i IN YEAR k.

FIGURE 6. EXPECTED FUEL SAVINGS/DOLLAR COST (MOE 3)

IV. DISCUSSION OF TECHNICAL PROGRAMS

Figure 7 provides an illustration of the Army's use of energy resources. While mobility fuels account for only 17 percent of all energy used, it represents 43 percent of the petroleum used by the Army.

The Army Mobility Energy R&D Program has subdivided technology for mobility operations into four general program areas, including fuels, other fluids, engines, and other equipment. The background, current projects, and a technical assessment of each of these general technical program areas are covered in the following discussion.



SOURCE ARMY ENERGY OFFICE 1980

FIGURE 7. ARMY USE OF ENERGY RESOURCES

A. Fuels

The fuels portion of the Army R&D plan emphasizes finished fuels technology. This is an activity that is readily distinguished from processing and refining activities. The technical scope leading to most finished fuel possibilities is illustrated in Figure 8. This figure identifies only some of the large number of fuel components that may be combined, along with desirable additives, in the blending of finished fuel compositions.

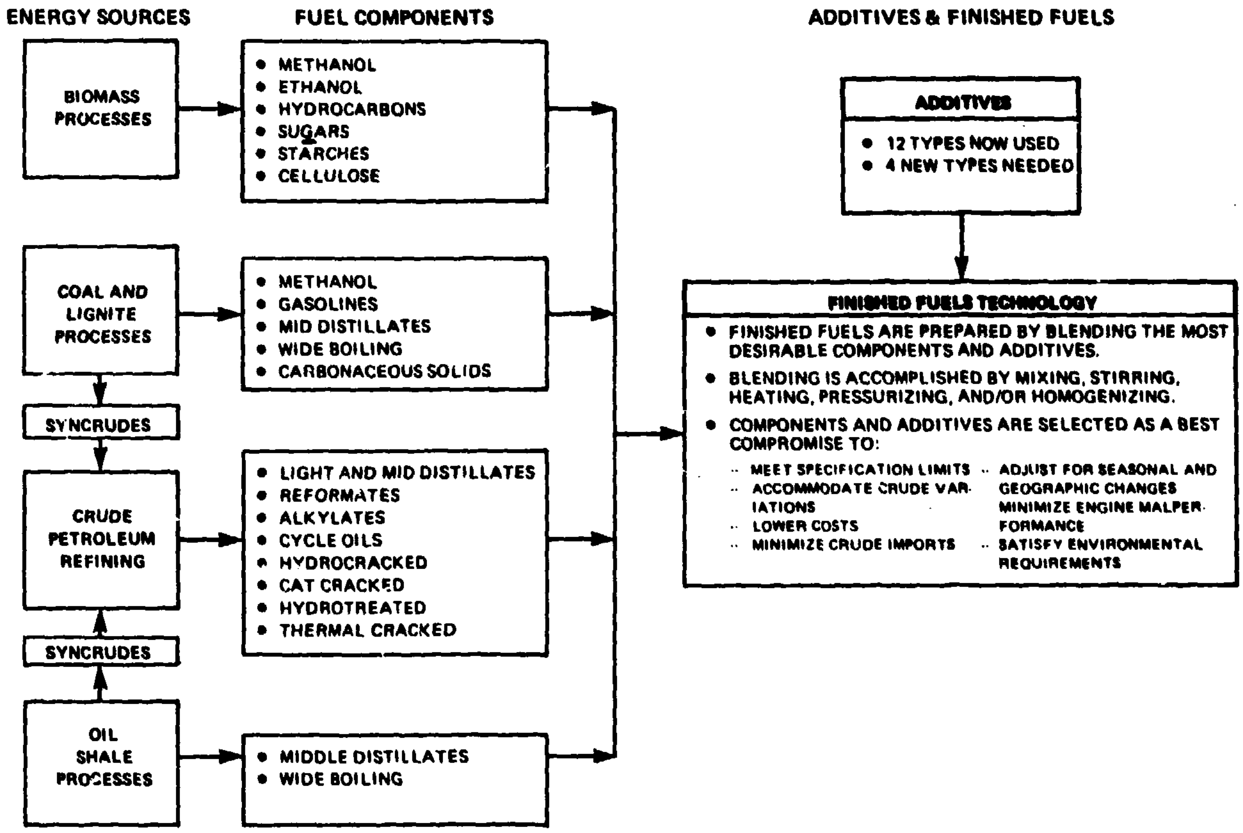


FIGURE 8. FINISHED FUELS TECHNOLOGY

A general misconception persists that finished fuel compositions are established by the refiners and processors. Such compositions, usually described in terms of their physical, chemical, and performance properties, are established by organizations which function independently of refining and processing activities. The organizational structures in the petroleum industry are good examples. Most of the major petroleum organizations have separate product development and technical service divisions which specialize in finished fuel and lubricant components. Some even have essentially autonomous chemical companies that supply additives to the "competitive" refiners.

The formulation and performance properties of additives and finished fuels (including lubricants and related fuels) are the primary technical strength of the product development organizations. From this technology base, the petroleum industry does the following:

(1) Maintains a continuing RDT&E program to adjust their branded and specification products towards more economic compositions--as feedstock change, as refining technologies advance, and as new additives become available.
(2) Develops and introduces new chemical additives and finished products.
(3) Participates in the establishment and revision of fuel specifications to satisfy the major changes in engine, environmental, social, and economic conditions.
(4) Interfaces with government, consumer, and engine manufacturer.
(5) Communicates requirements of consumers and engine manufacturers to refiners and chemical companies.
(6) Tests and evaluates competitive products.
(7) Provides guidance on future fuel compositions to engine manufacturers.

The important aspect of this petroleum industry activity is its correlation with the fuels portion of the Army Energy Mobility R&D Plan. DARCOM, through MERADCOM and the Army Fuels and Lubricants Research Laboratory, has long maintained close liaison with this part of the petroleum industry. Through this liaison, the Army maintains awareness of fuel composition trends on an international as well as national basis. The information gained forms a basis for the preparation of military fuel specifications which correspond with the most widely available commercial fuels. Likewise, areas of fuel quality and performance germane only to the military, i.e., long-term storage stability, broad seasonal usage of a product, etc., must have Army R&D emphasis to assure maximum military readiness.

The current world economic shortage of petroleum supplies, along with national efforts to develop fuels from nonpetroleum sources, adds new importance to the area of finished fuels technology. The technology, as it exists today, is essentially oriented toward finished fuel with petroleum components only. As illustrated in Figure 8, it is obvious that nonpetroleum components are now destined to be used, either separately or in blends with petroleum components. Little information has been developed on the performance properties of the numerous nonpetroleum component possibilities when used in engines. The identification and evaluation of these components with and separate from petroleum components will be a critical prerequisite to appropriate future military fuel specifications.

The Army Mobility Fuels Scenario has been developed based on engineering judgment, current and projected technological development, and projected future fuel policies. The scenario in Figure 9 is on a "time frame" basis through the year 2010, thus providing a base-line that can be easily modified by energy technology advancements, social and economic changes, and adjustment in governmental policies. A fuels scenario is forced to emphasize those events affecting the composition of transportation fuels in general as well as from a military standpoint, yet must recognize the volatile character of the many factors influencing fuels availability. Because of the uncertain nature of projected events, an attempt has been made to identify and briefly present the sources of information which have influenced and will continue to influence a future fuels scenario. Total energy demand/supply is not prime to this scenario, but is considered only when direct influences can be identified and interpreted.

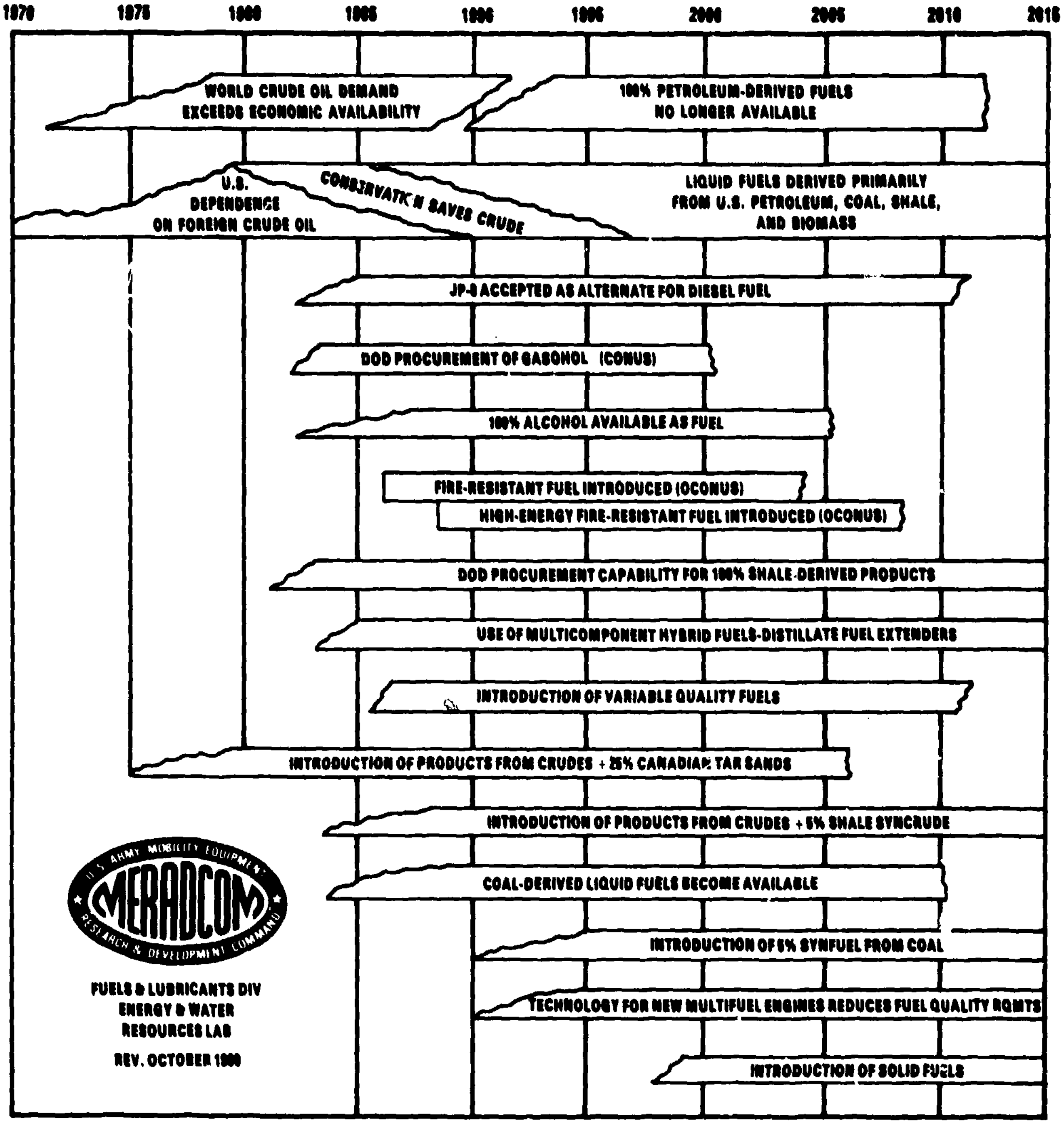


FIGURE 9. ARMY MOBILITY FUELS SCENARIO

No attempt has been made to address such factors as:

- OCONUS combat scenarios,
- energy policies and developments of other countries which could affect the types of future fuels available during wartime outside the United States,
- whether or not CONUS-produced fuels will be transported to an OCONUS theater of operation, or
- whether the military will be required to develop its own fuel supplies independent of the United States civilian sector.

To further expand on its utility, each of the events and items in Figure 6 is briefly discussed chronologically. This will enable a more accurate interpretation of Figure 9 and should provide the reader with supporting information for understanding and re-evaluating time-availability-impact conditions. The brief explanation of entries is as follows:

- The increasing demand for crude oil world-wide has been documented and continues to be emphasized in numerous publications. Because of the recent shortfalls of crude oil and its decreasing economic availability, there has been an increasing number of waivers being requested on certain properties of military specification fuel buys. Entering the 1990's, refineries will no longer be processing 100 percent conventional crude as less desirable crude and synthetic crudes (syncrudes) will be blended into the feedstock streams.
- Concurrent with this decreasing availability of conventional crude sources, new commercial processes for development of fuels from nonconventional fossil fuel sources will begin to evolve, thereby decreasing United States dependence on foreign crude.

- With the gradual phase-in of JP-8 (NATO Code No. F-34) into OCONUS facilities, this fuel will be accepted as an alternate fuel for diesel applications. This acceptability of JP-8 will be based upon establishment of its cetane and lubricity requirements for procurement quantities following engine endurance testing.

- Gasoline containing 10 vol% ethanol, which is gasohol, is currently available in limited quantities for commercial use in spark-ignition engines. In connection with the recently enacted Defense Authorization Act of November 1979 (which mandated use of gasohol in federal vehicles wherever possible), gasohol will become an alternate substitute for gasoline.

- The passage of recent legislation directed toward establishment of a new synthetic fuels industry will serve to initially increase the overall capability for alcohol production. Methanol will become available by production from synthesis gas, coal, or destructive distillation from wood. Ethanol will become available through fermentation of carbohydrates (i.e., sugar cane, corn, potatoes, etc.). The availability of these two alcohols will provide a potential alternate and/or field emergency fuel source for spark-ignition and ground turbine engine applications.

- The fire-resistant fuel for diesel ground equipment will be fielded. However, this fuel will be used only in wartime activities and will be blended in the field. In conjunction with this, the parallel effort in developing a fuel having greater energy content will become integrated with the fire-resistant fuel.

- In support of the recent DOD emphasis on transitioning to shale-derived synthetic fuels, the Army will complete its accelerated program and begin to procure 100 percent shale synthetic fuels on a limited basis. This is part of a DOE-DOD Memorandum of Understanding wherein DOE produces the syncrude, and DOD becomes the prime testing agency.

- With the increasing sources of alcohol and other biomass materials, hybrid fuel blends will become available not only for spark-ignition engines, but also compression-ignition engines. These alcohol/biomass extenders for distillate fuel application will serve not only to extend the existng sources of available product, but also to improve the overall performance as refining operations produce distillates of lowering qualities.

- The increasing shortfalls on conventional crude oil availability will create a need to optimize product yield wherever possible. One approach will be to refine against variable quality fuel specifications. These specifications will allow flexibility in relaxing some requirements with the net result that an increase in the product yield per barrel will be realized.

- Refineries are currently processing Tar Sand Syncrude admixed with conventional crude. The only areas considered to be possible problems are the marginal freezing point of the kerosene fractions and the marginal cetane quality of the distillate fractions. These can be resolved by addition of suitable additives and/or further refinement.

- CONUS petroleum fuels will be refined with approximately 5 percent shale syncrude added to the crude feedstock. This depends on the economics of developing the necessary shale oil crude production capability as well as meeting requirements for upgrading the crude to eliminate problems with nitrogen, arsenic, fines, low hydrogen content, etc., in shale oil.

- Liquid fuels produced from coal liquefaction process will approach 5 percent. This assumes liquefaction of coal will minimally be used for transportation fuels in the years 1980 to 1990 but maximized in producing burner fuels and gaseous fuels. Transportation fuel production will begin in 1990, reaching 5 percent of all fuels available in 1995.

As was stated initially, this mobility fuels scenario is primarily based on projected technological developments. These developments in part reflect the experimental processes which are now being evaluated by DOE and industry for syncrude production. To provide additional information in this area, Table 3 summarizes the current status of the candidate shale retorting and coal liquefaction process.

TABLE 3. PROBABLE SYNFUEL COMMERCIALIZATION PROCESSES

Oil Shale Company	Type	Operation In	Growth To (BBL/D)
Union Oil	Surface Module	'83 - 9000 bbl/D	50,000 - '87
Colony/Tosco	Retort System	'83 - 9000 bbl/D	45,000 - '85
Paraho	Retort System	'83 - 4000 bbl/D	80,000 - '89
Superior	Surface Module	'84 - 13000 bbl/D	---
Equity	Modified In-Situ		
Occidental	In-Situ	'86 - 5000 bbl/D	57,000 - '90
Geokinetics	In-Situ	'83 - 2000 bbl/D	16,000 - '88
Rio-Blanco	In-Situ	---	57,000 - '87
Rio-Blanco	Surface Module	---	19,000 - '88
Coal Conversion			
SRC-II (6000T/D)	Solvent Extraction	'81 - 3000 bbl/D	'84 - 20,000
Exxon Donor (250T/D)	Solvent Extraction	'80 - 350 bbl/D	'85-'87-60,000
H-Coal (250T/D)	Direct Liquefaction	'80 - 430 bbl/D	'85-'87-50,000

MERADCOM is currently conducting RDT&E projects in the following fuels/energy-related areas:

(1) Alternate/Emergency Fuels--This work has involved determining the suitability for using fuels refined from nonconventional sources, hybrid mixtures, and/or direct use of crude oil. Second-generation synthetic fuels from shale crude were provided in late FY79 as part of the Defense Mobility Fuels Action Plan.(29) These fuels will be evaluated in connection with a recent DOD thrust to allow use of shale-derived synthetic fuels in Army equipment by mid FY82.

Concurrent with this, a request by the Secretary of the Army has resulted in initiating a program to evaluate gasohol in military tactical equipment. Areas of concern regarding use of gasohol are system compatibility, marginal lubrication, and storage stability.

(2) High-Energy Fuels--The development of new high-energy fuels and/or energy-augmentation additives has been underway for 2 years. The purpose is to increase the calorific value of a fuel, thereby expanding the range of vehicle operation and improving the operating efficiency of tactical/combat powerplants. Preliminary data have identified carbon suspensions (up to 17 percent) in diesel fuel using emulsifier/stabilizers to ensure a homogeneous solution and high-density liquid hydrocarbon fuels designed for missile engines (i.e., JP-10) as prime contenders. Single-cylinder engine tests have been conducted with these candidates, and increases in engine output were indicated. Further experimentation will involve evaluation of candidate prototypes in multicylinder engine tests.

(3) Diesel Fuel Deterioration--This area has evolved as a result of fuel-degradation problems occurring at various Army depots. A field go/no-go tester is being developed as well as an additive-stabilizer system for depot use. More recently, as a result of interest expressed by U.S. Forces in Europe, a cooperative program was initiated to provide a fully-fueled capability for vehicles in storage in conjunction with the POMCUS program. Additional field testing of the candidate additive stabilizer package at several CONUS Army activities has been planned. One recent example has been to use this stabilizer package for new M60 tanks being stored for up to a year at the Chrysler tank plant facility.

(4) High-Sulfur Fuel Utilization--Since a majority of the U.S. combat equipment is powered by two-cycle diesel engines which have a well-defined fuel sulfur limitation (not to exceed 0.7 wt%), this effort has considered a methodology to allow use of high-sulfur fuels in these engines by either (1) a fuel additive or (2) lubri-

cant reformulations. From data developed to date, it appears that the lubricant "fix" may be the more successful approach. A full-scale DD6V-53T diesel engine test will be conducted prior to establishing the proposed field fix policy. Engine wear rates in general, as affected by sulfur content, are a continuous concern with respect to diesel fuel specifications.

(5) 6.1 Energy-Related Initiatives--The initiatives in this area include the development of the capability of using synthetic/alternate fuels as they become available in both Army ground and air vehicles. The effort includes establishment of physical and chemical properties; development of specifications; accelerated aging and storage considerations; preparation of fuel components (alcohol) by enzymatic hydrolysis of cellulose; development of technology for efficient multifuel operable military engines in terms of ignition, flame propagation rates, chemical reactivities, mixing emission, etc.; influence of fuel specifications on gas turbine engine performance; the mechanism of lean limit flammability; wall effects on combustion, ignition, and unsteady flame propagation in turbulent reactive flows and others.

Figure 10 provides a summary of Program Plans for mobility fuels according to identified program tasks. The majority of all existing fuel projects relate to potential synthetic fuel utilization and the R&D data base needed to affect a smooth transition from conventional petroleum-derived fuels. These projects assume production of synthetic fuels by DOE, DOD, or industry within a 1- to 2-year time frame. As of this date, only the processed 100,000 bbl of Paraho shale oil (Navy) can be considered available for such R&D programs. No processed fuel schedule has been found which projects estimated availability time frames for synthetic fuels. Without clearer advanced planning direction, it will be difficult to justify programs, funding levels, and equipment/personnel R&D needs. Likewise, no clear policy has been found which indicates if DOD will be receiving processed fuel products refined from 100-percent syncrudes or from blends of syncrudes and petroleum crudes. If the syncrude/synfuels industry grows incrementally, replacing 10 to 20 per-

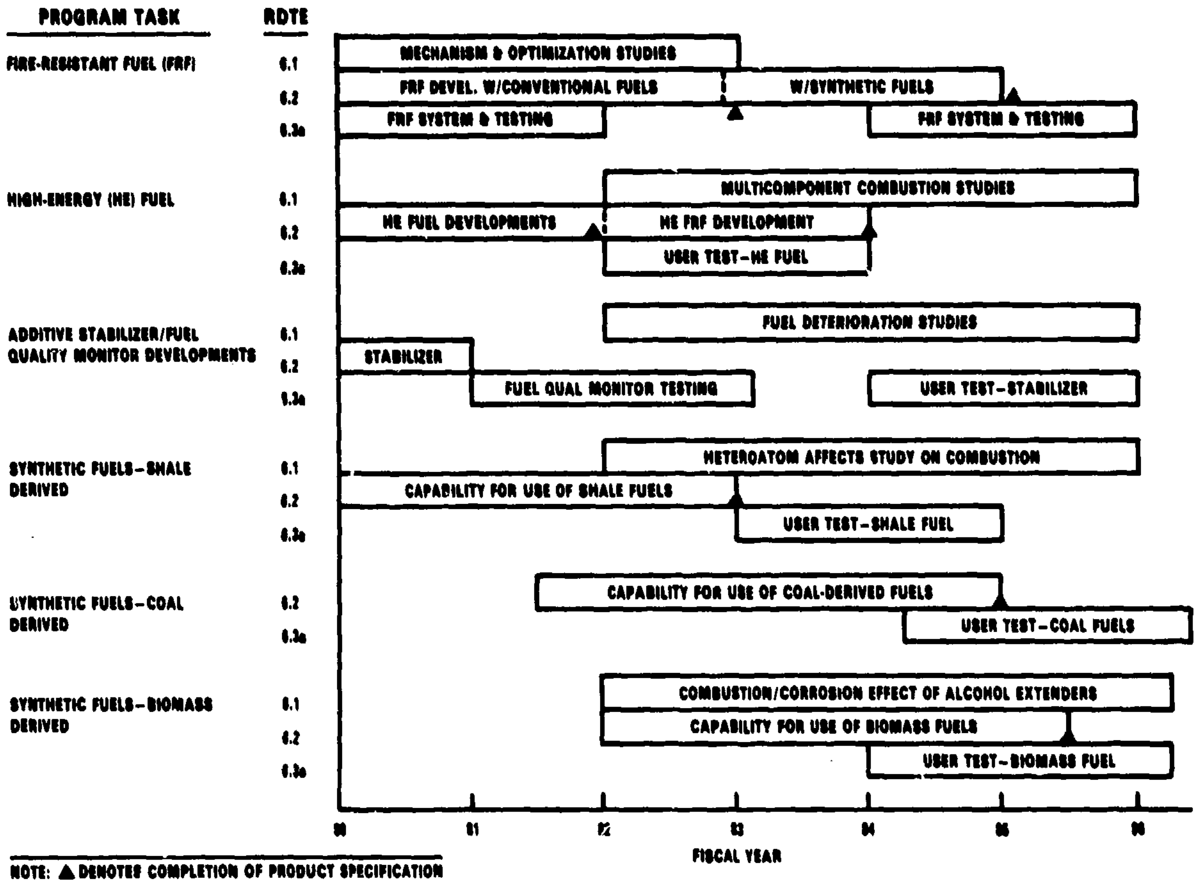


FIGURE 10. PROGRAM PLANS - MOBILITY FUELS

cent of the refinery petroleum crude input over the next 10 years, the transition may not require major end-use R&D like that required for fuels produced from 100-percent syncrudes. Again, major assessment programs coordinated with DOD, DOE, and industry appear to lack the present program outlay.

In reviewing the DA energy goals and the distribution of energy-consuming factions within DA, it is questionable if the mobility sector (43 percent of

DA consumption) can significantly add to the reduction in fuel consumption by 10 percent (1985) and maintain zero growth levels through the year 2000 with no degradation to readiness. Table 4 shows fuel-consumption patterns comparing Army consumption of petroleum for FY77 and FY79. There is an overall decrease in consumption amount by 8.5 percent. Pressures on increased combat force mobility and the resulting equipment density increases; and potential increases in force structure size through FY2000 may offset any potential fuel reduction from RDT&E efforts. Obviously, energy conservation can help. Development of synfuels compatible with today's equipment is also important; guidance indicating which energy goals should be emphasized by which using sector is now being addressed. For example: fixed DA facilities use 57 percent of the petroleum energy and therefore may be the best place for funding projects directed at fuel-reduction goals. Likewise, fixed facilities may be the best place to utilize the first syncrude-refined product since large heating units are less sensitive to fuel composition than aviation turbines.

TABLE 4. ARMY PETROLEUM CONSUMPTION

	Quantity (Million Gallons)			
	FY77	%	FY79	%
Heating	439.5	57.5	378.1	54.1
Jet Fuel	97.1	12.7	96.6	13.8
Diesel	97.1	12.[illegible]	104.7	15.0
AvGas	5.4	0.7	3.4	0.49
MoGas	125.3	16.4	116.5	16.7
Total	764.4	100	699.3	100

In attempting to develop multifuel engines, it appears that a fuels' R&D program, in conjunction with DOE and industry, should evaluate the economic potentials of producing a minimally refined fuel which could become the normal fuel for future mobile ground vehicles. There is no economic justification to assume fuels meeting today's petroleum specifications can be produced from syncrudes without substantial cost penalties. Obviously, multifuel engines need to be insensitive to a broad spectrum of finished fuel classes, but the engine developer needs a better definition of tomorrow's fuel today.

Similarly, it has been DOD policy that the Air Force maintain responsibility for development and specification control of Army aviation fuels. However, as the Air Force develops larger engines with larger thrust and the Army attempts to decrease the size of its turbine engines, fuel requirements, as they relate to composition, for these newly designed engines will inevitably diverge. An aviation fuel developed to satisfy the requirements of an engine suited to Air Force needs will not meet the requirements for the smaller Army turbine engines. An assessment of the needs of small Army engines appear to be warranted in the next 1 to 3 years.

B. Other Fluids

The term "other fluids" includes, but is not limited to, antifreeze, engine lubricants, hardware greases, hydraulic fluids, and special-purpose hardware preservative fluids. Each of these materials generally originates from petroleum crudes and, though procured in small quantities as compared to the overall Army energy needs, is a major factor in military equipment RAM-D. All such fluids are procured by military specification and, in most cases, will have composition or performance requirements different from comparable commercial products. Therefore, Army R&D on these fluids is an expansion of the existing commercial data base. Some examples are:

(1) Antifreezes under MIL-A-46153 became scarce during the 1973 energy embargo due to the production shortfall of ethylene glycol derived from petroleum feedstocks. Commercial antifreezes did not meet the Army specification in the areas of corrosion protection of the military engine cooling system hardware, or the extended use period of 4 years (commercial good for only 1 year). As a result, MERADCOM R&D has developed a promising inhibitor package which may

provide a means of upgrading deteriorated antifreeze and thus extending the useful life of existing stocks. A second program is developing a filter/ conditioner which can filter the coolant to remove insoluble degradation and corrosion products while slowly releasing new inhibitor chemicals into the coolant. Thus, the coolant life is extended, drastically reducing the volume of ethylene glycol procurement in the future years.

(2) Multiple military engine oil R&D activities at MERADCOM include development of re-refined oil quality control to permit use of such fluids. Thus, the life of these hydrocarbon products is extended with a comparable decrease in procurement requirements for original resources. Development of new lubricants which can be made from renewable resources, development of year-around lubricants which reduce oil drains, development of a single lubricant for vehicle engine crankcase and drive trains, and quality analysis techniques to determine used lubricant change periods only when quality degradation is detected, all have direct energy/economic benefits to the military while increasing equipment readiness. These same lubricant programs may improve mechanical friction reduction, thus reducing vehicle energy consumption per unit of work. Programs in greases and preservation fluids have benefits of requiring less equipment maintenance, spare parts procurements, and equipment deadlining, creating a secondary energy benefit by reducing logistics and manufacturing pressures.

(3) Reconditioning of cleaning solvents or the use of waste petroleum products as fixed facility and mobile powerplant fuel extenders provides a secondary use of fluids which in the past have been disposed of by waste pit burning and other elimination methods. Programs to study such secondary uses interface with the COE energy plan and have direct energy conservation benefits.

The "other fluids" area of R&D will probably have minimal impact on the overall Army energy picture. In reviewing existing projects, the goals are unquestionably important for improved combat readiness, maintenance upgrading, environmental impacts, economic gains from reduced supply procurements, and supply availability. Likewise, these projects must address present product reformulation needs if and when new fuel compositions enter the supply system. This need has already been indicated from alcohol/gasoline lubricant research.

Some energy conservation will be noted from projects such as the re-refined lubricant studies and possibly from new lubricant developments in which the base fluids could be produced from renewable resources, as opposed to petroleum crudes. New lubricants which reduce engine friction and thus decrease engine fuel consumption also have potentials. These projects have definite energy conservation potential. However, due to relatively small quantities of usage, funding for these projects could not be justified solely to meet the Army's energy goals.

C. Engines

Engines/powerplants for mobility consume an estimated 16.4 percent of the Army's total fuel requirement. Technical programs related to engines and which encompass all military powerplant systems from aircraft to small electric power generator engines which, based on their end application, are the responsibility of various Army R&D commands. Therefore, this section is subdivided into: (1) ground vehicle engines/TACOM, (2) aviation engines/AVRADCOM, and (3) mobile electric power engines/MERADCOM.

(1) Ground Vehicle Engines/TACOM. The U.S. Army Tank-Automotive Command has the overall mission of development of tactical and combat ground vehicles for the U.S. Army. It is also the Army's engine developer for tank/ automotive equipment. The Army has long held a special interest in multifuel engines with wide fuel tolerance. A ground fleet of vehicles with wide fuel tolerance provides for efficient operation in the field under conditions where fuel supply offers a challenge.

During the period from 1955-1960, the Army Ordnance Corps and Army Tank-Automotive Command initiated design and procurement contracts for a military vehicle multifuel engine designated LDS-427. A follow-on to this engine was an upgraded design version designated LD/LDS-465 multifuel engine which is still in volume use as the powerplant for 2.5-and 5-ton tactical cargo vehicles. In the early 1970s, governmental policies specified that future Army ground vehicle engines below 500 hp be procured from commercial sources and that R&D on this lower horsepower family be curtailed. Therefore, the major engine design thrusts funded by TACOM are directed at combat vehicles requiring 500+ hp powerplants.

One basic exception is the development/selection of a diesel engine to replace the present L-141 gasoline engine used in the M151 1/4-ton tactical vehicle. This replacement effort has been focused on the stratified charge engine and its design evaluation/upgrade to meet military performance requirements. This engine has the potential for multifuel operation. As pointed out in the organization plan, TACOM plays a leading support role in DOD commercial/administrative ground vehicle selection. This role requires close interface with USN and USAF energy plans to ensure DOD energy goals are achieved.

The high mobility multipurpose wheeled vehicle (HMMWV) research is being directed under 6.4 funds to meet objectives including (1) provision of a single vehicle family to satisfy joint-service requirements; (2) provision of a vehicle with outstanding cross-country and onroad performance; (3) replacement of the M274 Mule, M561 Gama Goat, and M792 ambulance; and (4) selective replacement of the M151 jeep and M880 utility truck. This vehicle will produce a 20-percent improvement in fuel economy over the current 1/4- to 1-1/4-ton weight class vehicles and will be diesel powered with an automatic transmission. When this program is approved by Congress, approximately 43,000 units are planned to be procured by 1983.(30)

Military tactical and combat vehicle fuel requirements represent an estimated 0.2 to 5 percent of the total Army fuel requirement. Of this amount, 85 percent is consumed by wheeled tactical vehicles in the 1/4- to 5-ton weight class. The remaining 15 percent is consumed by combat vehicles. Challenges facing the engine R&D community include: (1) seeking ways of desensitizing engines to fuel quality, and (2) increasing overall engine energy utilization efficiency while maintaining equipment combat mobility effectiveness.

There has been an emphasis in the past to develop ground vehicle engines with a wide fuel tolerance, and TACOM has been highly successful in this effort. A review is presented here of some of TACOM's current engines which have been developed for operation on a wide range of petroleum fuels. These include the AGT-1500 turbines for the M1 tank, the 10-kW Auxiliary Power Unit (APU) being developed by TACOM for the M1 tank, the LD-465 series multifuel diesel engines for 2-1/2- and 5-ton trucks, and recent efforts to develop the LIS 162-S stratified charge multifuel engine for the M151 jeep. A review is also presented of current technology development applicable to present tank engines and that will have an impact on fuel tolerance of future engines.

Current engine research efforts are also described which have their primary emphasis on advanced development of the adiabatic diesel and advanced turbine engines. As a new emphasis, engines will be developed which have multifuel capability and which can burn the new synthetic fuels that are beginning to be produced in this country. New technology developments will make significant contributions in continued progress toward high-output engines with widening fuel tolerance for the future. Engine development for alternate fuels for Army ground vehicles past work and future efforts of TACOM is described in the following subparagraph:

(a) Engines for Alternate Fuels--The Need

The very basis of defense depends on a guaranteed energy supply, particularly in the form of liquid hydrocarbon fuels. Energy alternatives are needed that are domestically controllable, and engines must be developed for operation on these fuels. The Department of Defense is required to implement a long-range program to provide for assured fuels to maintain readiness of the military forces. Within the Department of Defense, new thrusts are being made to assist in establishment and support of a commercial synthetic fuels industry within the United States. The DOD Engines/Fuel technology program is being accelerated, and efforts are being made to establish synthetic fuel specifications for the military for the future. New emphasis is being placed on developing engine systems capable of burning a broad range of new synthetic and commercial fuels produced and available in the United States. It is in this engine development for alternate fuels area that TACOM is active. The definition used at TACOM to describe multifuel engines capable of burning alternate fuels is shown below:

> "A multifuel engine is one with the ability to operate on a wide range of hydrocarbon fuels (from gasoline to diesel, including shale oil or coal-derived fuels, with a wide spread of octane and cetane tolerance) in military vehicles without requiring physical adjustment or compromising engine performance or life."

(b) Present Wide-Fuel Tolerant Engines

In this discussion, it will be shown how present engines fit this definition and how some will need further development in order that fuels of varying octane-cetane ratings, viscosity and specific gravity can be used. Engines being developed by TACOM with potentially good multifuel characteristics are as follows:

(1) AGT-1500 turbine developed by TACOM (with Avco-Lycoming) for M1 main battle tank (fuels are DF-2, DF-1, DF-A, JP-4, JP-5; gasoline and marine diesel in emergency).

(2) 10-kW APU using the Solar Gemini turbine for M1 main battle tank (fuels same as for AGT-1500).

(3) LD-465 multifuel diesel engines for Army 2-1/2- and 5-ton

trucks (fuels are DFM, DF-2, DF-1, JP-4, JP-5, JP-6, JP-8, Jet-A-1, and Jet-A-2, burner fuel oils No. 1 and No. 2, and combat gasoline).

(4) LIS-163-S stratified charge engine using the Texaco combustion system; developed for TACOM by White Motor Company for use in the M151 1/4-ton jeep (fuels are DF-2, DF-1, and combat gasoline).

(c) The AGT-1500 Turbine

The AGT-1500 turbine operates at a gross output horsepower of 1500. Its physical dimensions provide a tank engine of small size and weight (47.6 cu ft/2500 lb). The AGT-1500 turbine is currently developed with multifuel capability and has been the focus of much of the current research effort on turbine fuel tolerance. This engine operates on a wide range of jet and diesel fuels without reduction in performance because of the fuel control system which controls fuel supply to limit turbine inlet temperature. TACOM's advanced multifuel development resulted in the following accomplishments for the AGT-1500 turbine:

(1) Optimized air blast fuel injector with pilot injection for ignition.

(2) Final combustion design with improved swirler and engine testing.

The M1 Project Manager's Office provided for the full-scale engineering development and complete qualification of the engine for use of DF-2 fuel.

(d) The 10-kW APU for the M1 Main Battle Tank

The 10-kW APU being developed by TACOM for the M1 tank is a small, lightweight multifuel unit. It is designed to provide cold-starting of the main turbine and to provide for standby electric power requirements. This unit incorporates the Solar Corporation Gemini turbine originally developed for

MERADCOM. The APU turbine is being developed to be compatible with all the fuel requirements of the M1 main battle tank. The APU turbine/electrical generator section will weigh 38 kg (78 pounds). Additional modules are used to provide for power conditioning, power regulation, and remote control. A nickel-cadmium battery kit will be used to provide the electrical power requirement for starting to meet the low-temperature starting requirement. The generator set will provide 10-kW of DC electrical power and is rated at 28 volts DC.

(e) The LD 465 Series Multifuel Truck Engines

The LD series multifuel truck engines have a wide range of application in military trucks from 2-1/2 to 5 tons. Approximately 225,000 of these engines have been manufactured since 1962 in naturally aspirated and turbocharged versions with a horsepower range from 125 to 195. These engines have a wide range of fuels which can be employed from diesel to combat gasoline. This engine is limited in use of fuels with a maximum octane rating of 89 RON (corresponding to a cetane rating of 17). It employs a manifold flame heater system for starting and provides for varying fuel injection quantity based on a density compensator which varies fuel delivery with density of the fuel to maintain power delivered.

The MAN combustion system is employed in these engines. This combustion system utilizes an air intake passage shaped to produce high swirl. Near the top of the compression stroke, fuel is injected. Most of the fuel (approximately 95 percent) is deposited as a thin film on the walls of the spherical combustion chamber in the head of the piston. After ignition of fuel in the chamber, the main portion of the charge is progressively vaporized and swept off the combustion chamber walls by high-velocity air swirl. The air swirl continues to remove only the upper surface of the deposited fuel, thus maintaining even combustion. The combustion system thus provides for smooth combustion for a wide variety of fuels.

(f) LIS 163-2 Stratified Charge Engine

Another TACOM engine development program with excellent fuel tolerance is the LIS 163-2 stratified charge engine which was recently developed as a drop-in replacement for the gasoline engines in the M151 1/4-ton jeep. The LIS 163-S stratified charge engine was optimized for operation on diesel fuel but provides excellent fuel economy as well as multifuel capability for operation on gasoline and diesel fuels. It provides for diesel fuel economy which is especially interesting at part-load conditions. This engine development was carried on with the White Motor Company employing the Texaco Controlled Combustion System (TCCS). This engine does not have density compensation.

(g) Tank Engines

(1) AVDS 1790 Diesel Tank Engine--750 Gross HP

The AVDS 1790 diesel tank engine is the current engine used in the M60 main battle tank. This engine is an air-cooled engine developed for TACOM and is produced by Teledyne Continental Motors. The present tank engine has been developed to operate on DF-2, DF-1, or DF-A fuels, and is not designed as a wide fuel tolerant engine. It employs a manifold flame heater system to provide for ease in starting at low temperatures.

(2) AVCR 1360 Advanced Diesel Engine--1500 Gross HP

The AVCR 1360 is TACOM's advanced diesel engine originally developed as a prototype for the M1 main battle tank. Development of this engine is presently being continued as a back-up tank diesel engine. A comparison of engine characteristics of the AVDS 1790 current tank diesel engine and the AVCR 1360 is as follows:

Engine	AVDS 1790	AVCR 1360
Rated HP (gross)	750	1500
Rated Speed, rpm	2400	2600
BMEP @ Rated Output	277	336

Physical Characteristics	AVDS 1790	AVCR 1360
Length, in.	68	73
Width, in.	58	60
Height, in.	47	45-3/4
Volume, cu. ft.	104	107
Engine Wt. Wet, lb	5424	4730

The AVCR 1360 engine has a horsepower rating twice that of the AVDS 1790, the current tank engine, and achieves this power with approximately the same volume and less weight. The primary difference contributing to increased specific power is the use of the Variable Compression Ratio (VCR) piston in the AVCR 1360 engine.

In the VCR engine, a compression ratio of 16.5 is used at light loads while a compression ratio of 9 is used under heavy-load conditions.

The VCR system allows for development of higher BMEP with limited mechanical loading of the engine. Details of the variable compression ratio diesel engine are given in SAE Report 760051, February 1976, "AVCR 1360-2 High Specific Output Variable Compression Ratio Diesel Engine."

(h) Multifuel System Development for Tank Engines

A recent effort has been made by TACOM to develop a system for increasing the multifuel capability applicable to both the existing and advanced military diesel engines and to determine the range of fuels that can be successfully used. The approach used in this study was to provide a manifold heating system to vary manifold temperatures as a function of the fuel cetane number. Manifold temperature regulation was provided to limit maximum rate of pressure rise to acceptable limits. Fuel delivery to the manifold flame heater was regulated by an electronic control system. A fuel-density compensator was employed to provide an indication of fuel density (related to cetane number) to the electronic controller. The fuel nozzle used in the engine testing in this program was a Robert Bosch commercially available, electronically controlled, solenoid-activated fuel injection nozzle. The nozzle was pulsed every 20 milliseconds with total flow varied by controlling length of time of pulse. This program provided a demonstration of automatic operation of the present tank engine with controlled combustion on widely varying fuels. Further refinement of this system is required to provide better manifold air temperature distribution.

Fuels with lower cetane ratings (requiring higher manifold temperatures) resulted in reduced brake horsepower. Brake specific fuel consumption also increased since fuel supply included both engine fuel and manifold heater fuel.

Addition of a fuel density compensator into the fuel injection pump of this engine will also make possible constant fuel flows on a weight basis with lower density fuels and thus reduce the power loss experienced.

(i) TACOM Diesel Advanced Technology Program

In recent years, TACOM has actively pursued several areas of advanced diesel technology primarily aimed at producing higher output engines with improved fuel economy, reduced weight, and greater compactness. Efforts in this area include work on variable area turbocharging, turbocompounding, and electronic fuel injection.

(1) Variable Area Turbocharging (VAT)

The variable area turbocharger is currently being used with the AVCR 1360 engine to provide higher output with an improved torque characteristic. The VAT is being employed at a 4.8 pressure ratio with 16 to 1 peak compression ratio of the VCR piston and 9 to 1 compression ratio at high output.

(2) Turbocompounding

A turbocompound system has also been developed for the AVCR 1360 engine to provide for improving power and fuel economy. This system makes use of a power turbine geared to the engine crankshaft. Turbocompounding results in conversion of exhaust energy to mechanical work which is geared back to the main engine output shaft. Two variable area turbochargers are also employed (one for each bank of the 12-cylinder VEE engine).

(3) Electronic Fuel Injection System

TACOM is currently working with Physics International on an electronic fuel injection system for large diesel engines. Fuel economy benefits can be derived by proper injection control with several combustion-related benefits. These include capability of design for wider fuel tolerance, lower cylinder peak pressures, reduced smoke, reduced noise, and reduced exhaust gas temperature. It is expected that advanced electronic fuel injection will provide increased low end torque, improved transient response, and improved startability. It is believed that electronic fuel injection will assist in achieving diesel engines for the future with wider fuel tolerance. TACOM has been working in the area of advanced high delivery fuel injection systems for several years.

(j) Divided Chamber Multifuel Combustion System

Another combustion system of interest for future multifuel engines is the precombustion chamber type using a flow-plug for cold starting. This combustion system provides for injection and partial burning of the fuel in the precombustion chamber. After ignition, the partially burned fuel and products of combustion are expelled from the hot chamber into the main cylinder where combustion is completed. One advantage of this system is that peak pressures of combustion measured in the precombustion chamber are moderated and reduced in the main combustion chamber. This combustion system is very adaptable for development of multifuel engines since the hot chamber provides for better combustion of more difficult fuels.

TACOM carried through research and advanced development programs with Caterpillar for a family of engines of 4- and 6-cylinder inline engines and 8- and 12-V type engines.

The 12-cylinder superchaged/intercooled engine was developed for 960 horsepower with 1050 cubic inches of displacement. This engine family was referred to as the very high output engine (VHO). It was optimized for use as a diesel engine on DF-2 using a 16.5 to 1 compression ratio. Earlier development showed that 19.5 to 1 compression ratio was needed to make this engine a multifuel engine capable of burning gasoline, jet, and diesel fuels.

One important benefit of developing a family of multifuel engines is that a wide range of power requirements can be accomplished with high interchangeability to parts which simplifies spare parts logistics requirements.

(k) TACOM Combustion Research Program

An important contribution to the development of multifuel engine families will come from single-cylinder combustion research with the variety of fuels of interest for the future. TACOM has been active in the past and will continue an active combustion research program in piston and turbine engines.

The recent turbine engine combustion research of TACOM has been primarily directed toward advanced development of the AGT-1500 turbine engine at Lycoming. Of interest has been improvement for fuel tolerance, reduced smoke, improved starting, and improving stability of combustion. TACOM has also supported a turbine combustion modeling effort at Purdue University.

An important effort to aid in understanding combustion in piston engines was the development of the TACOM Single-Cylinder Research Engine. This engine was developed for TACOM by International Harvester Company to provide an investigation tool for use in research studies in high-output and high-speed ranges typical of the military diesel engine.

The TACOM single-cylinder research engine has been developed and operated near 400 BMEP with a limit up to 600 BMEP at engine speeds up to 3000 RPM. Several of these single-cylinder engines were obtained and they have been widely used at TACOM, at universities, and in industry in support of the advanced combustion engineering program at TACOM.

TACOM is also interested in the future of effects of octane/cetane relationship, viscosity, density, cycle effect of ignition delay, and fuel injection system characteristics.

(1) TACOM Adiabatic Diesel Engine Development

TACOM's primary R&D effort in developing diesel engines for the future is the Adiabatic Diesel Engine Program. This engine is being developed in a cooperative program with the Cummins Engine Company. The adiabatic engine is a turbocharged reciprocating engine with a second stage turbine geared to the crankshaft. The engine is insulated in the piston and cylinder combustion area, and the exhaust passage is insulated to provide for maximum conservation of exhaust energy to the turbocharger and power turbine. The only cooling provided is engine oil cooling of the underside of piston and cylinder area.

At present, a first-stage feasibility engine has been developed to demonstrate high-temperature adiabatic technology using the Cummins NHC 250 engine. The adiabatic demonstrator engine involved using a commercial water-cooled block, draining the water, insulating the combustion chamber, using high-temperature components, and using a turbocompound system to convert waste energy to useful power. The piston used is a composite with a ceramic cap/high-temperature metal fastener/metal base combination. The cylinder liner used is also a composite with ceramic above the top ring reversal position and metal below. The cylinder head, exhaust valves, and exhaust ports are also insulated with ceramic composite materials. It is expected that a considerable amount of design and basic material technology development will be involved in developing the high-output adiabatic engine for the future.

Benefits being achieved in adiabatic operation of engines include improved fuel economy by conversion of waste exhaust energy, increased specific power output, elimination or reduction of external cooling system, and reduced volume and weight of overall power system. The high temperature of combustion with hotter combustion chamber parts also assist in the development of multi-fuel capability for the future.

(2) Aviation Engines--AVRADCOM

The Army aviation aircraft inventory has continued to increase over the past 20 years with the introduction of the helicopter as an essential member of the combined arms concept. Compared to ground piston powerplants, aircraft turbine engines are more fuel demanding from both the standpoint of consumption and reduction of hardware fuel sensitivity. To decrease fuel consumption, programs are being conducted such as (1) higher turbine inlet temperature capabilities; (2) recuperation of exhaust waste heat; and (3) improved internal aerodynamics, stress technology in hardware materials, and combustion processes. Changes of fuel properties, i.e., increased sulfur, higher aromatics, and increased viscosity add further requirements on turbine materials, combustor design, and peripheral fuel systems. As noted earlier, the USAF has lead service responsibility for aviation fuel development. Therefore, AVRADCOM as a major aviation developer must interface very closely with USAF (and USN aviation) to ensure Army/DOD energy goals are achieved in a timely manner.

It is estimated that the Army aviation sector utilizes approximately 28.9 percent of the Army's fuel demand. This represents a significant part of the Army's fuel demand and, in addition, this fuel represents an important narrow fraction of the hydrocarbon crude already stressed by commercial and general aviation energy demands.

(3) Mobile Electric Power--MERADCOM

Electrical power generation equipment in support of military operations range in size from 0.5 to 1500 kW. Over this broad spectrum, the existing equipment inventory includes diesel and spark ignition engines, gas turbines, and fuel cells technology. These technology areas have potential for using nonpetroleum fuels. Specifically, the development of 10- to 60-kW gas turbine engines has included the capability to operate on a broad range of military logistic fuels including gasoline, turbine engine fuel, and diesel fuel. Current R&D programs address the sensitivity of existing reciprocating engine and gas turbines to fuel quality. These programs also address potential multifuel limitations as well as methods to increase power rating and improve fuel economy. Mobile electric power generation equipment consumes an estimated 16.4 percent of the fuel by the Army and provides an essential support element in mobile weapon systems, logistics activities, and communications.

With respect to assessment, a major R&D gap appears in the area of multifuel engine development. As previously stated, TACOM, by DA policy which has been ongoing since the middle 1960s, cannot conduct R&D in this area. Therefore, it is questionable if major multifuel engine design, development, and production can be realized by 1985 unless a massive program effort is initiated. It does not appear reasonable to believe that commercial engine design changes through 1985 will satisfy the Army's broad fuel-tolerance needs and therefore permit the MACI program to satisfy this Army goal. The below 500-hp engine area is where most of the fuel consumption occurs for mobile ground vehicles.

As stated in the Fuels section, aviation turbine engine fuel requirements, based on existing new engine design projects, must be identified to assure fuel-hardware compatibility. These requirements most likely will not be the same for the Air Force and Army aviation. This area appears extremely critical to the transition to syncrude-produced fuels unless all new fuels will meet existing DOD specifications. Turbine combustor R&D programs, if fully implemented, may have a significant effect on the Army's total mobile energy needs and thus warrant increased emphasis.

Another potential for saving petroleum energy exists if fuel cell technology can be advanced rapidly for use as the power system for mobile generator equipment. This technology impacts on hydrocarbon fuel consumption and conversion to renewable energy resources. Such technology may also be applied to other power systems once the full technology potential is evaluated.

D. Other Equipment

It is estimated that 2 to 3 percent of the Army total energy consumption is required to satisfy needs of field heaters, cook stoves, materiel-handling equipment (forklifts, cranes, etc.), railroad locomotives, bridging equipment, and other combat service support items. This energy requirement, though diffused among a broad spectrum of equipment, represents a total fuel demand equal to yearly tactical/combat vehicle consumption. Interaction between future fuel development and these support items is essential. For example, introduction of synthetic diesel fuel and an intensive dieselization of generators, high-mobility multipurpose-wheeled vehicles, etc., will require conversion of existing TO&E food preparation stoves from gasoline to middle distillates and redesign of existing stoves and heaters to handle the lower Btu fuel. Some of this equipment redesign is underway.

Material-handling equipment is procured primarily from commercial companies under the MACI program. Introduction of new fuels or development of multifuel engines may impact on this equipment, especially if the Department of the Army is not permitted by policy to carry out R&D on these end items because of MACI procurement. Likewise, fuel cell development and DOD/DOE electric vehicle R&D may prove valuable in energy/powerplant applications for small tugs and forklifts within major DOD depot operations.

Railroad locomotives owned and operated by the military presently require specification diesel fuel and are energy-intensive equipment due to limited shutdown periods.

Army fuel-handling equipment necessary for fuel distribution is in this category and must be compatible with any new fuel compositions. Material development for fuel hoses, fuel-storage bladders, fuel vapor controls for reducing in-field fuel losses, and different filters could be demanded as new fuels enter the military supply system.

Though these support-type items do not have the high visibility of combat vehicles or aircraft, they do represent the logistics system which provides petroleum and all other supplies to the combat arms. Therefore, each facet of the supply system, from procurement to delivery, will be affected as new energy sources become available to the ground and aviation sectors.

E. Technical Areas for Technology Base Development

To assist in the implementation of the Technology Base development and transfer, the four general program areas have been structured into nine technical areas. They are:

- Fuels
- Fluids
- Engines
- Power Sources
- Simulators
- Materials
- Equipment
- Food Technology
- Innovations

Brief summaries of the above are as follows:

1. Fuels. This is an ongoing program in the Army. The objective is to develop fuels for Army Combat equipment that provide (1) reduced fire vulnerability hazards, (2) increased power and extended range capabilities, (3) availability during critical fuel shortages, and (4) optimal mission performance. Major thrusts are the development

of fire-resistant fuels for combat vehicles, increasing fuel availability through use of alternative/synthetic fuels, development of fuel stability technology and stabilizer additives and the development of high-energy fuels for combat equipment. The effort also involves the evaluation of wide-cut fuels, alcohol-gasoline blends, biomass and other variable-quality fuels (i.e., high-sulfur content diesel fuels), fire-resistant fuels, shale-derived fuels in the short term and coal-derived and biomass fuels in the long term.

2. Fluids. The Army's program in fluids includes development and evaluation of multiseason tactical engine oils, re-refined engine oil applications, adiabatic/VHO engine oil, engine oils for non-optimized combustion, universal diesel/turbine engine oil, fuel-efficient lubricants, and engine oil for sealed, no-drain systems. In the area of hydraulic and power transmission fluids, effort is directed toward development and evaluation of nonflammable hydraulic fluid for combat armored equipment, universal turbine engine/transmission oil for M-1 main battle tank applications, and development of a compressible fluid intended for advanced gun recoil systems. In the area of corrosion and specialty compounds, the effort involves development of an antifreeze extender additive, development of long-life GAA automotive/artillery grease, and investigation of fluid-thickener interactions and solubilities to better understand mechanisms of grease deterioration.

3. Engines. The Army is conducting an effort to confirm the capability and/or define required modifications to existing helicopter engines to allow operations on a wide range of alternate fuels. New engine technology is being developed to effect a 40-percent reduction in fuels consumed in future systems. Evaluations are also underway on the performance of existing and emerging gas turbine engines on synthetic/alternate fuels full-scale engine tests. Diesel engines are being improved by utilizing advanced turbocharging techniques to permit improved fuel efficiency without degradation of electrical power output. The adiabatic diesel engine program will provide the technology required to develop

diesel engines that minimize heat loss and thus effect improvements in fuel economy, reduction in weight and volume, and increase in power output. The Army's development of multifuel engines includes an AGT 1500 turbine for the M-1 tank, a 10-kW APU using the solar general turbine for the M-1 main battle tank, an LD-465 diesel for the Army's 2-½- and 5-ton trucks, and an LIS 162-S stratified charge engine for use in the M151 ¼-ton jeep.

4. Power Sources. In an ongoing program at MERADCOM, the Army is developing more efficient engines for mobile power systems. The DOE generator program, fuel cell development, new engine cycle research, power distribution, and solar energy, both thermal and electric, are being evaluated, particularly for isolated posts, camps, and stations. MERADCOM, acting as lead laboratory in solar photovoltaic development, has conducted demonstration projects in the use and application of photovoltaic energy. Solar energy utilization, in combination with biomass conversion technology, is being considered for evaluation. The development of mobile fuel cell power generators is being directed towards converting 20 percent of mobility operations' petroleum requirements to alternate or synthetic fuels. Advanced fueled fuel cells subsystems with improved efficiency are being developed: a family of methanol-fueled fuel cells powerplants are being developed to fulfill power requirements that cannot be adequately handled by batteries or engine generator sets.

5. Simulators. A range of both simulators and simulator devices is being developed by the Army to enhance training effectiveness, reduce training costs, and reduce energy usage. The simulator impacts on flight training, truck driving training, fire fighter training, etc. In the application of simulator devices to tank system training, the training devices duplicate the interior of a vehicle driver's compartment. The trainee is permitted to initially learn the controls and operator techniques without actually driving the vehicle and without expending the fuel associated with actual operation. The Army, in its simulator programs, seeks

improvement in its current inventory and the development of new areas where training simulators can abe utilized.

6. Materials. The Army, in its material technology, seeks new lightweight mate·ials which are corrosion resistant and compatible with variable quality fuels (i.e., high-sulfur fuels). New and emerging engines and aircraft will require new and improved coatings which remain fouling-free while maintaining structural integrity on the surfaces of turbine blades. Other efforts in material development include identifying the properties of ceramic alloys; establishing the properties of complex metallic, composite, and organic material surfaces; investigating the erosion properties of small turbomachinery; and developing and fabricating high-temperature ceramic materials.

7. Equipment. The Army's program in equipment development includes efforts in hydromechanical tracked transmissions, commercial engine development, analysis of radial versus bias ply tires, evaluation of commercial transmissions, development and evaluation of efficient mobile laundry equipment, and the redesign of roadwheel and track components of tracked vehicle suspension systems. These efforts are mainly in the Army's MACL and PIP energy programs.

8. Food Technology. To reduce energy consumption in the preparation and preservation of food, the Army has programs in radiation preservation of foods, improvements in the efficiency of field ovens and griddles, reduction in food weight/bulk through freeze-drying/compression techniques, improvements in food packaging, and the development of thermo-processed field meals. Energy utilization is minimized in these processes.

9. Innovations. The Army's program as it relates to innovations encompasses all disciplines and is directed towards meeting the Army energy goals through approaches which may be productive but not yet envisioned. Current activities include investigation of the following--mechanisms of combustion, wall effects on combustion, accelerated engine-fuel qualification procedure methodology, quantitativeness assessment methodology for proposed projects,

time-dependent failure of polycrystalline ceramics, thermal barrier coatings for turbine and diesel engines, CH-47 efficiency improvement, and bipolar lead acid batteries. Conservation is an important area for the Army with the potential for significant energy savings. For the immediate future, conservation offers the only means for energy savings. The area needs considerable expansion beyond the obvious and/or required actions.

V. DISCUSSION OF MANAGEMENT PLAN FOR ARMY MOBILITY ENERGY R&D

Management for any Army Mobility Energy R&D project or program remains with the appropriate development command, and they are expected to present these programs/projects at the DA/DARCOM reviews for funding and approval. Programs/projects should be clearly identified as an energy effort contained in the Army Energy R&D plan. Additionally, MERADCOM provides the following:

a. Annual update of the Army Mobility Energy sections of the plan.
b. Staffing for DARCOM/DA inquiries, and coordination with other services, DOE, and other government agencies to ensure compatibility and nonduplication of effort.
c. Refinement of assessment methodology, development of necessary data base, and technology transfer and user assistance.

A review of the existing energy R&D and related projects indicates that established projects can be used as the means of implementing this proposed R&D mobility energy program. Memoranda of Understanding with DOE in the solar photovoltaic demonstrations and research on synthetic fuels provide the basis for maintaining and expanding the United States Army participation in the National Research and Development effort toward new and improved energy sources. It is necessary that proper program priority and resources be provided to assure the adequate and timely completion of specific R&D tasks.

Coordination of the efforts of this program is required at all levels of DA, DOD, and DOE. This includes technical and funding requirements, and the establishment of priorities for development testing, production, and employment. The principal thrust of the formal coordination is through the chain of command with appropriate inputs at each command level.

A. Army Mobility Energy Assessment Function

The overall assessment function is responsible for conducting the following major tasks:

a. Needs Analysis - Examine Army Mobility Energy uses and needs for both peacetime and wartime.

b. Data Base - With technology element, develop a data base on energy technology including operational experience.

c. Methodology - Acquire, modify, or develop methodology, including computer codes/simulation to conduct:

   (1) Trade-off analyses,

   (2) Life cycle costing,

   (3) RAM analysis, and

   (4) Effectiveness analysis.

d. Categorization - Categorize Army Mobility Energy use and needs into logical groupings.

e. System Engineering/Integration - Develop System Engineering/Integration plans and documentation including handling or storage systems for any new liquid or gaseous fuels.

f. Recommendations - Provide results and recommendations for:

   (1) Technology base effort,

   (2) Test and evaluation planning,

   (3) Conservation,

   (4) System design, and

   (5) Evaluation/application of existing or commercially developed energy technology.

B. Technology Base and Transfer

In pursuit of the Army energy goal to "Attain a position of Leadership in the Pursuit of National Energy Goals," the technology base and transfer effort performs four basic functions:

(a) The development of a coordinated energy technology application program that utilizes the total professional and technical resources of the Department of the Army.

(b) The defining of energy efforts and applications uniquely suited for the Army and Army/DOD-sponsored research and development.

(c) The monitoring of energy efforts being accomplished by other Government agencies or by industry, etc., to adapt the technology as appropriate to Army requirements and needs.

(d) The development of an information exchange mechanism among Army personnel and other activities directed toward maximizing user assistance and technology transfer.

VI. SUMMARY

In summary, an organizational framework has been presented for planning the Army Mobility Energy Research and Development Program. Within this framework, an overview of Army Mobility Energy Research and Development programs has been presented. Figures 11-13 summarize the relationship of Army Energy goals to selected projects.

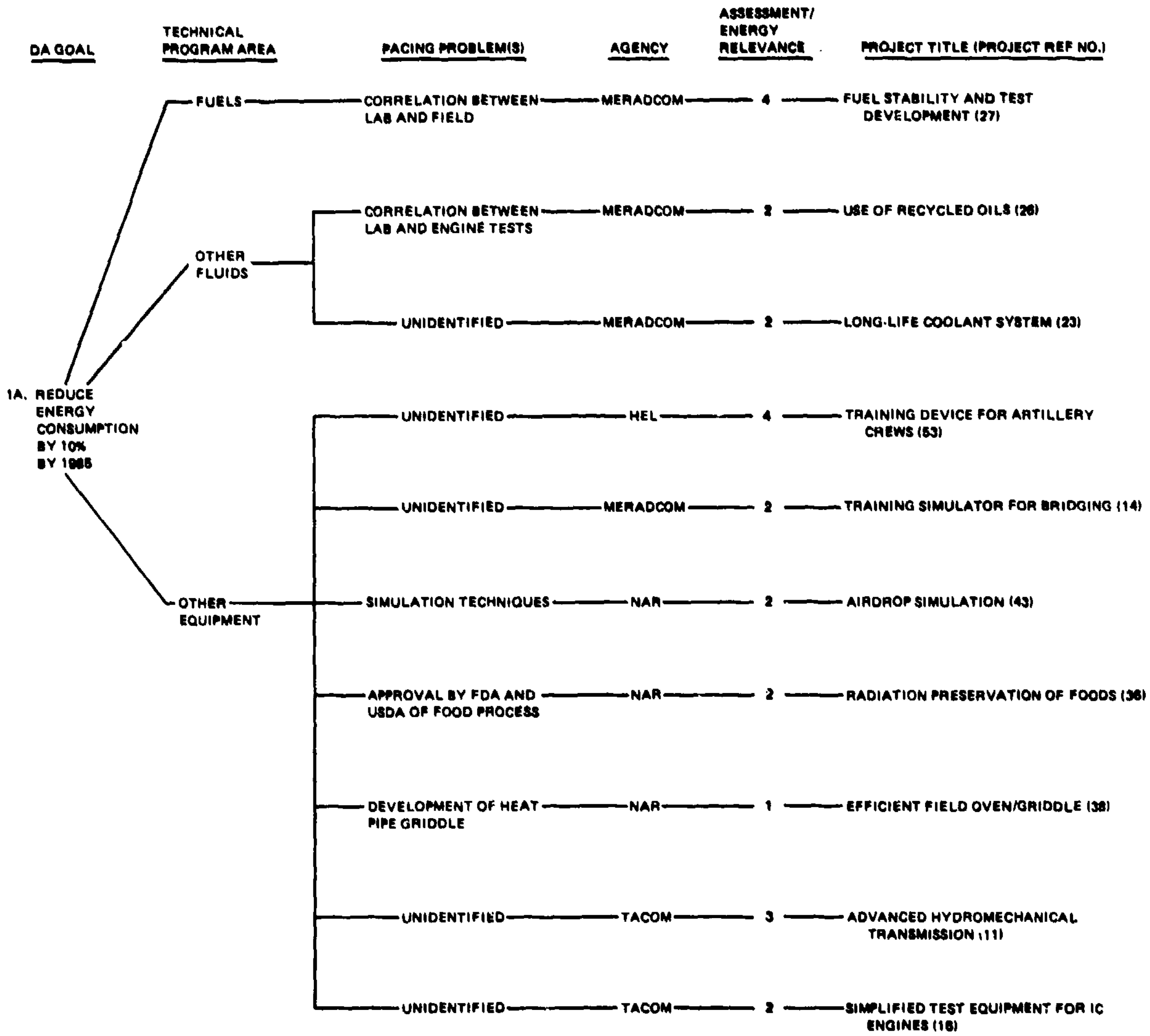


FIGURE 11. RELATIONSHIP OF ARMY ENERGY GOAL 1A TO SELECTED PROJECTS

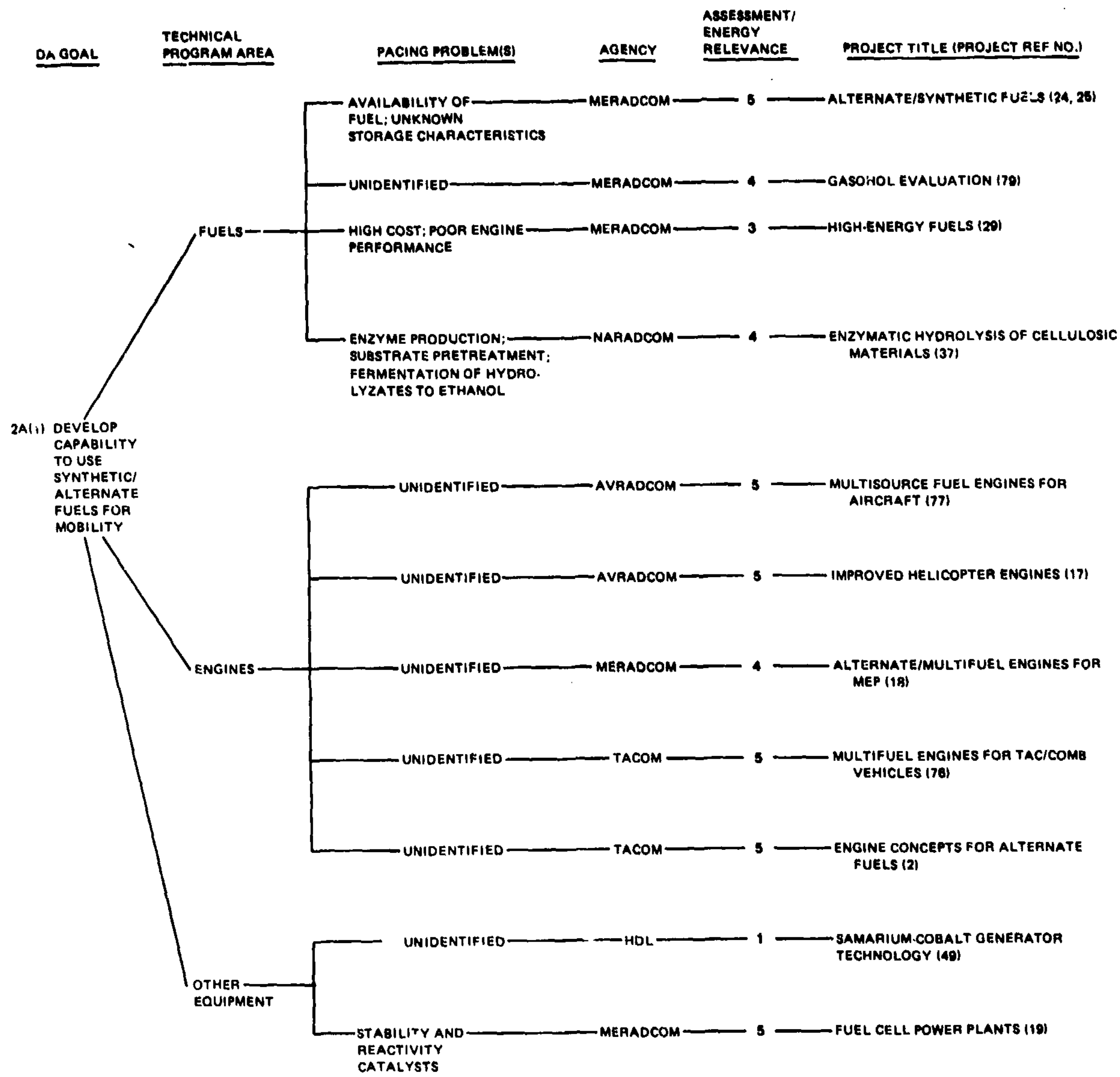


FIGURE 12. RELATIONSHIP OF ARMY ENERGY GOAL 2A(1) TO SELECTED PROJECTS

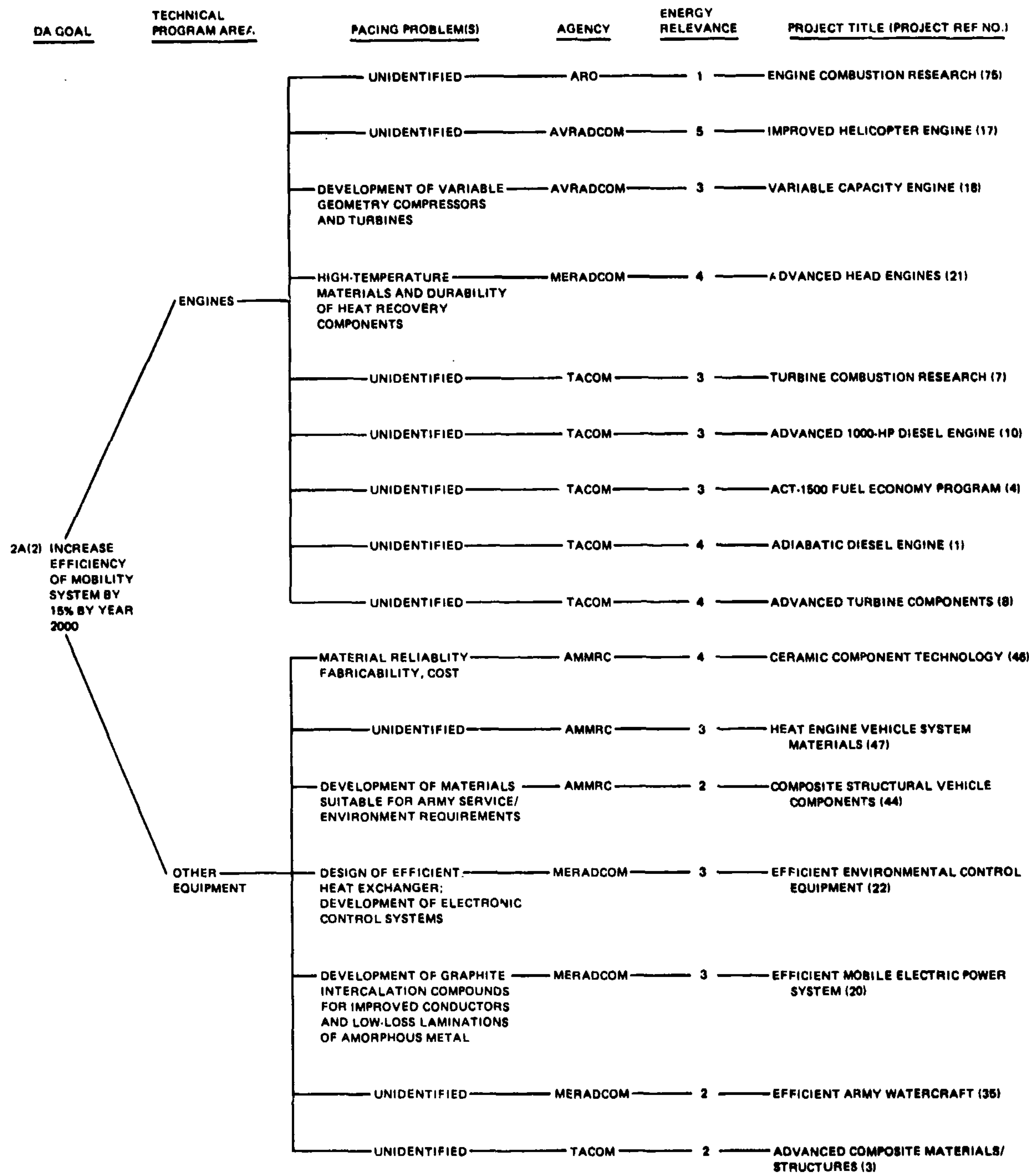


FIGURE 13. RELATIONSHIP OF ARMY ENERGY GOAL 2A(2) TO SELECTED PROJECTS

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Hearings before the Investigation Subcommittee of the Committee on Armed Services to determine the effects of declining petroleum resources on United States military armed forces.

2. "Energy Security Act," Conference Report No. 96-1104, House of Representatives, 96th Congress, 2nd Session, 19 June 1980.

Discussions include production of synthetic fuels (500,000 bbl/day by 1987--2,000,000 bbl/day by 1992), EPA involvement in procuring synthetic fuels, creation and operation of the U.S. Synthetic Fuels Corporation, financial assistance to private sectors for research and production, gasohol, and solar energy utilization.

3. "Army Energy Plan", 8 August 1980, Office of the Deputy Chief of Staff for Logistics, Army Energy Office, Headquarters, Department of the Army, Washington, DC 20310.

The Plan identifies the Army's organization, goals, objectives, and policies with respect to energy. It projects energy consumption and costs to the year 2000 and summarizes the programs required to support the long-range goals. A summary of current and needed energy-related legislation is included.

4. "U.S. Army Mobility Energy Plan, 1980", Office of the Deputy Chief of Staff for Research, Development, and Acquisition, U.S. Army, 15 July 1980.

The plan describes a management structure and recommends thrust areas for attainment of the Army energy goals. The major thrusts of the plan are: (a) R&D effort to increase engine efficiency for rotary-winged aircraft, ground vehicles, and mobile generators; (b) test and evaluation to allow use of alternate/synthetic fuels; and, (c) the development and evaluation of lubricants, material, and dispensing systems compatible with the emerging fuel/engine systems. The management plan recommends using existing Army Program structure to respond to the new challenges of energy conservation and self-sufficiency.

5. "The National Energy Plan", Executive Office of the President, Energy Policy and Planning, Washington, DC, April 1977.

The plan examines the national energy problem; describes the national strategies on energy including conservation, improved energy efficiency, development of alternate and renewable resources; and discusses the national goals, the role of government and public in achieving energy independence.

6. "National Energy Plan, II," Executive Office of the President, Energy Policy and Planning, Washington DC, May 1979.

Updated version of National Energy Plan dated April 1977.

7. "Department of Defense Technology Area Description on Energy Research, Development, Test and Evaluation," prepared by Dr. George Gamota, Office of Deputy Under Secretary of Defense for Research and Engineering (R&AT), 6 September 1979.

RDT&E program description, objectives, analysis, coordination of technology exchange, management strategy, and future thrusts.

8. "Memorandum of Understanding Between Department of Energy and Department of Defense Regarding Crude Shale Oil", dated 23 May 1980.

This MOU provides for coordination, consultation, and cooperation between DOE and DOD in research, development, and demonstration to enhance national security and to achieve the United States' energy goals.

9. "Mobility Operations Energy Research and Development," letter from DAMA-PPM to DARCOM, dated 8 May 1978.

This letter requested DARCOM to develop a Coordinated Mobility Operations Energy R&D Plan to meet the DOD and Army Energy goals.

10. "Army Energy Research and Development Program," letter from Director of Army Research, DAMA-ARZ-D, Department of the Army to MERADCOM, dated 7 November 1979.

This letter outlines the goals and objectives of the Army Energy R&D program and establishes specific issues to be addressed and incorporated into the Army Energy Plan 1981 for mobility as well as facilities.

11. "Army Energy R&D Plan Update for 1981", letter from J. A. Christians, dated 31 March 1981.

Letter serves as transmittal for distribution of 1981 Plan.

12. "Army Facilities Energy Plan" submitted by Lt. General E. H. Johansen, Deputy Chief of Staff for Logistics, Department of the Army, 1 October 1978.

The Corps of Engineers' five-year research and development plan. This plan supplements the Army Energy Plan by providing policy and planning guidance to major Army commands (MACOM) for the development of detailed facility energy plans.

13. "Fuel Conservation Through Energy-Efficient Mobility Systems," letter from DAMA-ARZ-E, Department of the Army to TACOM, dated 26 March 1980.

Requests new R&D initiatives be undertaken to improve the fuel efficiency of Army Mobility Systems. Description of how these programs should be developed and what the development should address. Letter tasks TACOM to take lead in developing a fuel efficiency program plan to cover five given categories.

14. "Clarification of Energy R&D Planning Responsibilities," letter from Assistant Deputy for Science and Technology, Department of the Army to TACOM/MERADCOM, dated 21 October 1980.

Letter reiterates responsibilities of TACOM and MERADCOM with regard to development of Army Energy Mobility Plan 1981. Addresses fuel efficiency portion and other plans to be integrated into future editions.

15. "Fuel Conservation Through Efficient Mobility Systems", letter from DAMA-ARZ-E, DSCRDA, to DARCOM, dated 26 March 1980.

Letter requests new R&D iniatives to be undertaken to improve the fuel efficiency of Army Mobility Systems. Five program categories are to be addressed and justified on the basis of expected return on investment due to fuel savings through systems efficiency improvement.

16. "Fuel Conservation Through Energy-Efficient Mobility Systems, Plan for Organization and Execution", prepared by U. S. Army Tank Automotive Research and Development Command, dated 9 June 1980.

Plan provides justification for programs based on fuel efficiency and improvement. Profiles of individual mobility systems are provided. Emphasis is placed on cost benefit models for energy conservation.

17. AR 11-27; Army Energy Program, 20 July 1976.

Establishes policies, objectivies, priorities, and procedures, and assigns responsibilities for the conduct of an Army Energy Program designed to efficiently manage energy resources.

18. Department of Defense Energy Management Plan, dated 30 June 1979.

The purpose of this plan is to provide an overview of the Department of Defense (DOD) energy management program. The Defense energy management program is designed to achieve national energy goals and objectives which the Congress and the President have mandated, as well as to achieve greater energy self-sufficiency, reduce energy costs, and to ensure the operational readiness of the strategic and tactical forces.

19. Defense Energy Policy Memorandum No. 78-2; Subject: Defense Energy Goals and Objectives, 1 March 1978.

Memorandum establishes energy goals and objectives for DOD.

20. DOD Memorandum for Secretaries of the Military Departments; Subject: Department of Defense Assignments in Support of Military Fuels for Mobility Action Plan, 28 March 1978.

Memorandum assigned specifications in DOD energy program in support of military fuel requirements to the military departments, i.e., develop fuels requirements, develop multifuel engines, develop synthetic specification and testing methods.

21. Memorandum by DUSDRE (RAT) dated 24 July 1979; Subject: Defense Mobility Fuels Programs.

Provides guidance to the military departments for developing accelerated programs for utilization of synthetic fuels and development of multifuel engines.

22. "Assignment of Lead Service Responsibilities for Energy Technologies," Defense Energy Program Policy Memorandum (DEPPM) No. 78-6, 2 October 1978.

Assigns lead service responsibilities for key energy technologies of interest to DOD.

23. Army Policy Statement on Mobility Energy Research and Development, dated 22 December 1978.

This document states that the mission of the Army will be to increase use of synthetic fuels to help satisfy mobility fuel requirements. Defines synthetic fuels and mobility fuels. Army policy is stated and expanded.

24. "Army Environment, 1985-95," Strategic Studies Institute, Army War College.

Document unavailable for annotation.

25. STOG 80, Headquarters, Department of the Army, circa 21 April 1979.

Principal document for formation and prioritization of user-oriented requirements for the mid- to long-range planning periods. Basis for structuring research and development (R&D) programs at the science and technology development level.

26. "Project Plan for Reliability Fleet Testing of Alcohol/Gasoline Blends," U.S. Department of Energy HCP/M2184-01 (Rev), part of the Alternate Fuels Utilization Program, 30 March 1979.

Outlines the best methods of utilizing domestic resources for transportation fuels. Deals primarily with alternative fuels, alcohol fuels in particular.

27. "Accelerated DOD/DOE Shale Oil Products Program," Memorandum from Deputy Secretary of Defense, 25 July 1979.

Document unavailable for annotation.

28. Romstedt, G.N., "Development and Demonstration of the Energy Technology Assessment Model," The BDM Corporation Technical Report No. BDM/W-81-531-TR, prepared under Contract No. DAAK70-79-D-0035 for USAMERADCOM, Fort Belvoir, VA, September 4, 1981. Distribution limited to U.S. Government agencies only.

29. LePera, M. E., "The U. S. Army's Alternative and Synthetic Fuels Program", Army Research, Development and Acquisition Magazine, September-October 1980.

Discussion summarizes activities related to Army Mobility R&D as they comply to Congressional Legislation. Consumption rates and processes of evaluation of fuels are highlighted.

30. Presentation regarding High Mobility Multipurpose Wheeled Vehicle, (HMMWV) by Mr. George J. Bugarin, Systems Manager, TACOM, at the American Defense Preparedness Association (ADPA) "Military Transport for the 1980's" Symposium, Monterey, CA, 27-28 March 1980.

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