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A SUMMARY OF AN ASSESSMENT OF NEW OPTIONS IN ENERGY RESEARCH AND DEVELOPMENT

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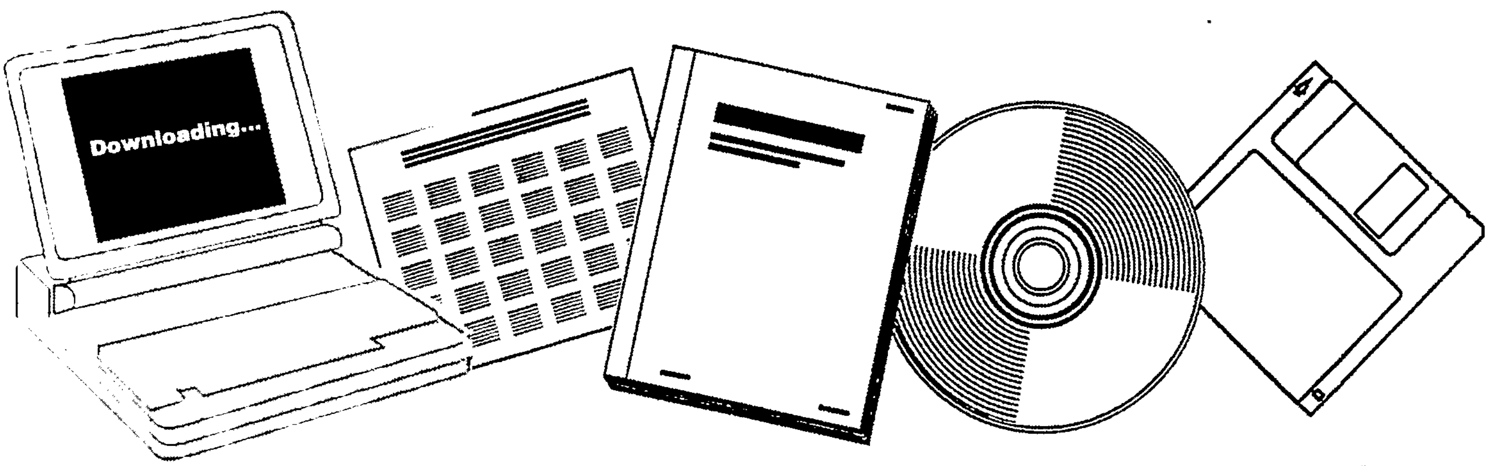

U.S. Department of Commerce
National Technical Information Service

A Summary of

AN ASSESSMENT OF NEW OPTIONS IN ENERGY RESEARCH AND DEVELOPMENT

Prepared by

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for the

National Science Foundation
Energy Task Force

June 7, 1973

Note: At the conclusion of the OST-FCST assessment of energy R&D options, Associated Universities, Inc. prepared a draft final report. That report was reviewed by the OST Energy Advisory Committee and their comments were incorporated in the draft. The kind of revision required to turn a first draft into a publishable final report were never made, however. The present paper is a summary of the report as it currently exists.

BACKGROUND OF THE ASSESSMENT

In his energy message to the Congress of June 4, 1971, the President made priority commitments in three energy R&D activities and asked his "Science Advisor.....to make a detailed assessment of all the technological opportunities in this area and to recommend additional projects which should receive priority attention." The assessment was carried out under the direction of the Office of Science and Technology and the Federal Council on Science and Technology. Technical and analytical support was provided by Associated Universities, Inc.

In the first phase of the study the U.S. energy system was surveyed to identify potentially important technological areas. Areas were sought in which there was the potential for significant improvement through technical R&D. All aspects of the energy system were open for consideration, from exploration and extraction of resources through conversion and transmission technologies to the various means of using energy. The only technologies excluded from the assessment were those already identified in the energy message for priority attention--the liquid metal fast breeder reactor, stack gas treatment to remove sulfur oxides, and coal gasification to pipeline quality gas.

The concern of the study was with the long-term effects of the energy system, effects on the environment, on human health and welfare, and on the nation's natural resources. Thus, environmental and resource considerations, as well as internal costs, provided the basic criteria in selecting and evaluating new technologies.

Following the initial selection process, technical panels were established in eleven technical areas, each panel being organized by one or more Federal Agencies. Specific requirements and ground rules were established for the evaluations to be contained in the reports on the panels. These ground rules were designed to insure that common assumptions would be used in the evaluations and also that all of the information required in a systematic overall assessment would be provided.

A special advisory committee to OST, composed of experts from industry and universities, evaluated the output from the technical panels and the integrative analysis of the support group. The advisory committee then framed a set of specific recommendations for new and revised energy R&D activities. These recommendations were determined in the late summer of 1972 as input to the development of the FY 1974 budget.

A draft of a final report from the assessment has been prepared. The purpose of this paper is to summarize the contents of that draft.

ANALYSIS OF THE PROBLEM

A set of energy system models were developed for the specific needs of this assessment. These models were used to analyze the problems inherent in the current pattern of evolution of the energy system and to evaluate the impact of new technologies.

In the near term (to 1985) the problems facing the energy system are primarily ones of supply stemming from policy and institutional factors. These include problems of urban air pollution, constraints on coal production and use, decreasing production of natural gas due to price regulation and lack of investment in new domestic petroleum refining capacity. Many of these factors have resulted in looking to the importation of foreign oil as a solution to near term problems. But the importation of oil, particularly from the middle east, raises further difficulties, perhaps the most serious ones of all.

In the longer term, in addition to increased environmental problems of energy use, finite resource constraints will start to be felt. Figures 1 and 2 show projected cumulative consumption of gas and oil relative to various estimates of domestic supply. The large variability of those resource estimates should be noted. In addition to the general goal of reducing the environmental impact of the energy system, the specific goals of energy R&D in this period are to provide a flexible set of alternatives to the use of conventional gas and oil resources.

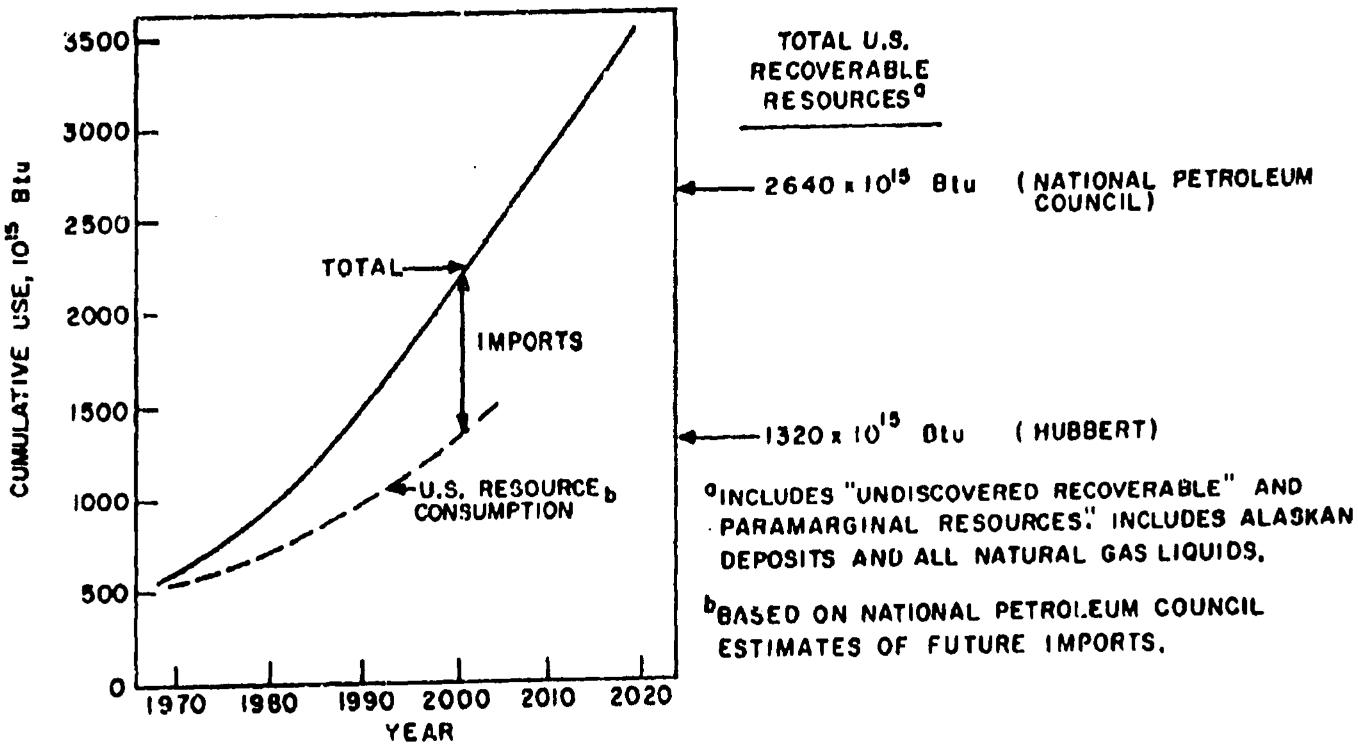
In the section which follows, eleven technological areas are identified in which expanded R&D programs can provide the options that will be required in the future.

NEW RESEARCH AND DEVELOPMENT INITIATIVES

Extraction of Energy Fuels

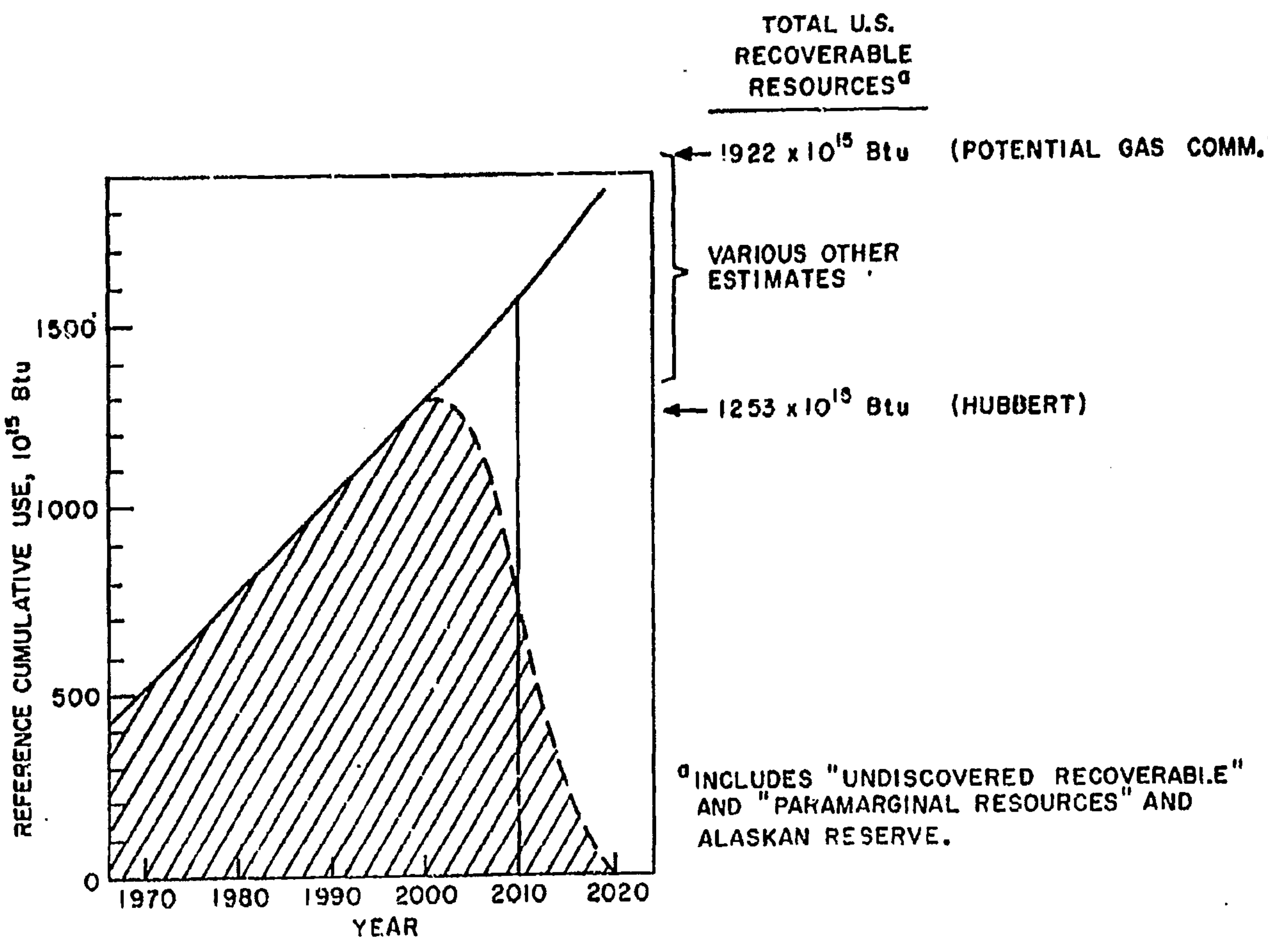
The development of new technologies for the extraction of resources can lead to more effective recovery techniques with reduced environmental impact. The technical areas in resource extraction that are important in the R&D sense are: (1) stimulation techniques to increase the recoverability of petroleum and natural gas production, (2) development of oil shale, (3) underground gasification of coal, (4) utilization of organic wastes, and (5) primary extraction of coal.

The development of techniques to stimulate production from known oil and gas fields can reduce the quantities of these fuels that must be imported in the near future. Although oil recovery efficiency has been improving for several decades by an estimated



REFERENCE DEMAND FOR PETROLEUM AND DOMESTIC SUPPLY

Fig. 1



REFERENCE DEMAND FOR NATURAL GAS AND DOMESTIC SUPPLY

Fig. 2

0.5% per year, still only about 30% of the original oil in place is recovered. The known fields contain nearly 60 billion barrels of oil and 300 trillion cubic feet of gas that cannot be economically recovered at current prices with existing technology. In the intermediate term, additional quantities of liquid and gaseous general-purpose fuels can be obtained from oil shale and organic wastes, both of which are abundant resources in the U.S.

Technologies for the conversion of coal into gaseous and liquid fuels and for the combustion of coal with minimal air pollution are required to enable this abundant fuel to play a greater role in the U.S. energy system and such technologies are discussed below. Improved techniques for the primary extraction of coal are equally important. Only a very small percentage of the coal reserves are economically recoverable with present technology. Underground mining is one of the most hazardous occupations and surface mining can be damaging to the environment. Specific factors to be addressed in the development of coal recovery technology are increased productivity, safety, and environmental control. Underground (in situ) gasification provides an alternative technique for the extraction of energy from coal reserves.

A summary of recommended R&D funding in this area is given in Table I.

Solar Energy

Radiation from the sun represents the largest renewable energy resource on the earth. The amount of solar energy striking the land area of the United States is thousands of times larger than the energy that is consumed in this country.

TABLE I

Summary of Resource Extraction Program

Program element	Current R&D Objective	First year cost $ million	Long-term cost $ million/year	Notes
Stimulation of oil and gas				
Earth fracture studies		1	22/11	
Nuclear stimulation		15	89/10	
Oil shale				
In situ processing		5	40/8	
Waste management		2	6/6	
General system development		4	40/10	
In situ gasification of coal		1	2/2	
Conversion of biological waste	Development and demonstration of concepts	10	40/7	
Underground coal mining		10	100/10	
	Total	$48 million		

Despite a number of inherent problems in its use, particularly its intermittent and diffuse nature, there are a number of approaches to the application of solar energy. The fact that these have been relatively unexplored gives to solar energy a distinct appeal with regard to R&D activities.

The major areas of prospective R&D are:

Thermal Energy for Buildings: Solar water heaters are commercially available in many countries, space heating systems have been demonstrated while air conditioning systems are in the experimental stage. All three areas require further development and demonstration emphasizing low cost components.

Electric Power Generation: A number of approaches have been suggested for solar electric power generation. In thermal conversion systems, solar collector and storage devices deliver thermal energy to a steam turbine power plant. Component development should lead to feasibility demonstrations. Schemes using photovoltaic energy conversion depend on the development of low cost solar arrays. Although satellite based systems have been proposed, their potential does not warrant R&D attention beyond systems studies at this point. Modest programs would be appropriate in the areas of wind power extraction and the use of ocean thermal gradients. The feasibility of producing fuels through photosynthesis should be evaluated.

A summary of the solar energy program is given in Table II.

Geothermal Energy

The significance of geothermal energy is that it represents an entirely independent energy source from those which will be pressed so severely in the near future. Furthermore, it is a form of energy which, through assertive R&D, can begin to contribute in the relatively short term. Some exploitation of

Table II

Summary of Solar Energy Program

Program Element	Current R&D Objective	First Year Cost $ Million	Long Term Cost[a] $ Million/Years	Notes
Thermal Energy for Buildings			100/10	All systems should be commercially available at end of 10yrs.
Water Heating	Develop low cost demonstration units	0.6		
Space Heating	Component development and demonstration	2.3		
Space Cooling	Component development	0.6		
Electric Power Generation				
Thermal Conversion	Component development and analysis	2.5	125/10	Funding includes pilot plant. Demonstration plant (investment beginning in the 8th year) could cost about $1 billion and should be cost-shared with industry.
Photovoltaic Conversion	Lower cost of production of arrays	5.0	140/10	Primarily component development & evaluation. Additional expenditure for central station pilot plant could begin in yr 6.
Wind and Ocean Gradients	System studies	0.7	2/3	
Fuel Production	Feasibility analysis	1.0	3/3	Pilot plant development could start after 3 years.
TOTAL		12.7		

[a] More detailed recommendations for the break-down of these costs are given in the Panel report.

geothermal energy is already under way. To that extent of exploitation, at least, the technology has proved to be economic. Economics will dictate what fraction of the vast total geothermal resource base is exploitable in any practical sense. Geothermal energy is not without its environmental problems, however, but those problems appear no more severe than those associated with the near-term technologies with which it competes.

The evaluation of the potential use of geothermal energy is made difficult by the lack of information on the geothermal resource base. Optimistic estimates indicate that a generating capacity of 400.000 Mw could be developed in the western U.S. by 1995. In any event a priority R&D topic is an augmented program of regional geologic, geophysical and geochemical studies of resources. These should include the geopressured resources of the Gulf Coast and impermeable dry rock regions. In addition, development work needs to be carried out on exploration and drilling methods, and technologies related to reservoir development and energy extraction from low grade heat sources. Environmental effects must be studied both in terms of effects studies (particularly seismic and subsidence) and emission control.

Table III summarizes the recommended R&D program.

<u>Clean Fuels from Coal</u>

As the nation's most abundant fossil energy resource, coal can play a major role in meeting future energy needs. Methods must be developed for utilizing coal in its classical role to produce electric power in a more environmentally acceptable manner as well as for the conversion of coal into liquid and gaseous fuels to serve both electric and non-electric energy demands. The successful development of effective economical

Table III

SUMMARY OF GEOTHERMAL ENERGY PROGRAM

Program Element	Current R&D Objective	First Year Cost $ Million	Ten Year Cost $ Million
Resource Appraisal	More precise estimates of magnitude, quality and distribution of resources.	6	142
Exploration Methods	New geophysical exploration methods, high temperature drilling & logging technology.	2.5	25
Reservoir Development and Production			
Hot water	Develop desalination and reinjection	2.5	125
Dry hot rock	Develop fracturing techniques	2.3	71
Utilization Technology and Economics	Materials and component evaluation. New devices, cycles for energy extraction.		
Hot water-wet steam		4.0	143
Dry hot rock		0.5	54
Environmental Effects	Gas removal technology, noise control, subsidence and seismicity monitoring.	2.5	35
Institutional & Legal		0.5	5
	Totals	$ 20.8 million	$600 million/10 yr

processes for controlling sulfur dioxide emissions from coal-burning power plants, either during the combustion process, by stack gas scrubbing, or by removal of sulfur from the fuel, could help to reverse the existing trend away from coal as a boiler fuel and provide environmental benefits in the near term. It is important, at the same time, to address technological and environmental problems in the coal extraction area in order to resolve the constraints that they may place on the utilization of this fuel. Technological opportunities in the extraction area were discussed above. Advanced power cycles which can increase the efficiency with which coal is used in the generation of electricity are also discussed in a separate section.

There is no lack of prospective processes for the conversion of coal to liquid and gaseous fuels and for the clean combustion of coal. These processes are in various stages of evolution, some in the development stage, some ready for larger scale demonstration, others in actual use. The first requirement for the definition of a balanced program in this area is an engineering-economic evaluation of all these processes on a common basis. It was not possible to perform such an evaluation as part of this assessment. Thus the program in clean fuels from coal outlined in Table IV is only a rough outline of what should be included in the context of the overall energy R&D enterprise. The total effort, amounting to $140 million in FY '74 is based on pursuing all promising options and includes a program for producing pipeline gas. There should be strong industry participation in all of these programs; with such participation the increase in federal funding represented here is approximately $50 million.

TABLE IV

Summary of Clean Fuels from Coal Program

Program element	Current R&D objective	First year cost $ million	Long-term cost $ million/year	Notes
Advanced combustion	Development of fluidized bed boilers	10		30 MW pilot plant included in program
Low-Btu gasification	Process for use with combined cycle	30		Includes work on Lurgi, dispersed phase and fluid bed gasifiers
High-Btu gasification	Pilot plant work	60		Includes work on six processes for the production of pipeline quality gas
Coal liquefaction	Pilot plant work on four processes	40		Includes work on four different processes
	Total	$140 million		

Advanced Cycles for Power Generation

Current power cycles that are used to convert the chemical energy of fuels into electricity operate at efficiencies between 30 and 40%. Since an increasing fraction of energy in this country is going through the electric conversion process, it is increasingly important to develop higher efficiency generating systems.

There are two basic approaches to achieving better utilization of the energy content of the fuels used in power plants. One approach involves utilization of what otherwise would be waste heat for heating and other applications. Such "total energy" systems are discussed elsewhere in this report. The alternate approach involves new power cycles and devices that can convert thermal energy to electricity at higher efficiencies.

The conventional steam cycle is limited by materials considerationsin the upper temperatures at which it can operate and thus its thermal efficiency. Topping cycles achieve higher efficiencies by employing a high temperature working fluid such as air or liquid metal so that thermal energy may be added to the cycle at a higher temperature with the reject heat from the topping cycle supplied to a steam cycle. Gas turbines, liquid-metal turbines, and MHD generators may be employed as topping cycles. Of these, open cycle MHD systems require increased Federal support at the component and technology development level.

A centralized program on fuel cell systems for solar, synthetic fuel and fossil fuel power generating applications is also recommended. This program would include some development work in addition to a management and coordination activity.

A coordinated study effort is required to evaluate four or five alternative cycles in depth on a comparable basis. High temperature topping cycles for conventional plants and low-temperature bottoming cycles for power plant or geothermal power systems should be considered in this analytical study.

This program is summarized in Table V.

Alternative Breeders

The development of an economical breeder reactor is justifiably a cornerstone of the nation's energy R&D program.

The importance of the development of a viable fast breeder system dictates that due consideration be given to the finite possibility that the Liquid Metal Cooled Fast Breeder Reactor (LMFBR) will run into difficulties which might prevent or seriously delay its widespread adoption. Thus, the evaluation in this assessment concentrated its attention on the three most promising alternatives to the LMFBR, the Molten Salt Breeder (MSBR), the Gas Cooled Fast Reactor (GCFR) and the Light Water Breeder Reactor (LWBR). If the realization of the MSBR concept and the GCFR confirm present indications either one could prove to be a credible alternate. The funding of these concepts should be increased in order to pursue adequately their development and in order to provide information essential to evaluate their future potential.

By the end of FY 1975 two LMFBR demonstration plants should be in operation abroad. Development of the LMFBR in the United States will be further advanced, and knowledge of the problems, prospects and potential advantages of the GCFR and MSBR will be clearer. At that time the relative prospects for the three concepts should be reevaluated and a decision made whether to continue or extend government support of development of the MSBR, the GCFR, or both.

Because of its very limited breeding ability, the light water breeder reactor is not considered to be a true alternative to the LMFBR. It has the potential, however, of making far better use of original resources than do conventional light water

TABLE V

Summary of Advanced Cycles Program

Program Element	Current R&D objective	First year cost $ million	Long-term cost $ million/year	Notes
Open-cycle MHD	Development of components	5	32/6	
Fuel cells	Development of improved system	2	19/7	This program should provide coordination of current projects
Study of alternative	Design of several power cycles	5	22/6	
	Total	$12 million		

reactors and has a number of other attractive features. The current program for this concept appears adequate as it now stands.

Table VI summarizes the recommended program.

<u>Fusion</u>

Fusion provides one of the very few potential long term solutions to the problem of supply of clean energy. As that problem has large dimensions, so does the program in controlled thermonuclear research required to provide a solution. Viewed in the context of all potential energy R&D, a high priority is given to continued development of magnetically confined fusion. Increased funding in FY '74 is recommended with a primary target the demonstration of scientific feasibility in the next 8-10 years.

Laser pellet fusion was also considered but it was judged that R&D in that area should continue to be justified under the program of military applications. Such funding currently appears to be adequate in terms of possible non-military application.

The following are the major areas in which fusion R&D should be pursued:

Magnetic Confinement Research: The program must plan for experiments demonstrating scientific feasibility for each of the three major concepts: tokamak, mirror and theta pinch. The recently authorized PLT tokamak experiment should be the penultimate step toward that goal. In the case of magnetic mirror and theta pinch systems, considerably more work is required before a feasibility experiment can be designed.

Development Programs for Near Term Experiments: Work should be expanded considerably on the development of superconducting magnets and magnetic energy systems and neutral beam sources. These activities will have a major impact on the speed with

Table VI

SUMMARY OF ALTERNATIVE BREEDER PROGRAM

Program Element	Current R&D Objectives	First Yr Cost $ Millions	Notes
Molten Salt Breeder	Materials development and reprocessing technology	8	Reassess after 2 years
Gas Cooled Breeder	Technology of emergency cooling, pressure vessel integrity and fuel performance	4	In addition to substantial industrial program
	Total	$12 million	

Note: The light water breeder reactor is considered an important development program, but not a true alternative to the LMFBR.

which scientific feasibility experiments can proceed. In addition, a number of other technologies will require attention including high current switches, r.f. energy sources, direct energy converters, plasma diagnostics and feedback control systems.

Basic Plasma Research: This category includes both theoretical and experimental studies aimed at a broad range of relatively basic problems.

Fusion Reactor Technology: Over the next few years the programs aimed at solving the technological problems of practical fusion devices must be stepped up considerably. Some of the most important current areas for work are: superconducting materials for power plant magnet systems, radiation damage of reactor components, control of tritium leakage and corrosion problems related to blanket coolants.

A summary of the recommended Fusion R&D program is given in Table VII.

<u>Hydrogen and Other Synthetic Fuels</u>

The term synthetic fuels, as used here applies to such materials as hydrogen, methanol, and ammonia but does not apply to gas or liquids produced from coal. The latter were discussed above. Synthetic fuels may be employed as general purpose fuels for residential, commercial, and transportation applications; as chemicals in industrial processes; and as energy storage media for central station electric applications. They are of interest primarily because they may be derived from the more abundant solar, nuclear, or thermonuclear resources and provide a convenient fuel form for transport, storage, and ultimate utilization. Thus, they provide promising alternates for supplying the long-term needs for gaseous and liquid general-purpose fuels.

Table VII

SUMMARY OF FUSION PROGRAM

Program Element	Current R&D Objective	Program Cost $ Million FY'74	FY'74-'82
Confinement Research	Demonstrate scientific feasibility		
Operations		25.8	427
Major Device Fabrication		4.3	81
Supporting R&D			
Plasma Research	Understanding of plasma behavior	9.5	116
Development	Develop superconducting magnets, energy systems, beam technology	10.4	168
Reactor Technology	Develop superconducting materials, energy storage, radiation damage studies, etc.	5.0	211
	Total	$55.0	$1003/9 years

The production of hydrogen may be carried out by electrolysis or, perhaps, by the thermal decomposition of water. In the near term, however, hydrogen and fuels derived from hydrogen can, and most likely will, be made more economically by the direct conversion of fossil resources or possibly from urban and agricultural waste products.

Because of low transport costs for gaseous and liquid fuels as compared with electricity, synthetic fuels may be produced at remote, well-regulated plants, and such production would not contribute to the primary pollution problems that exist in urban centers. The synthetic fuels, especially hydrogen, may be consumed with very little or no air pollution in a variety of energy conversion and utilizing devices for both stationary and motive power. This low pollution characteristic of hydrogen energy systems is particularly attractive for urban applications.

Research areas of greatest current importance are hydrogen production, hydrogen storage, particularly using metal hydrides, safety, and systems analysis. Funding recommendations are summarized in Table VIII.

Electric Transmission and Systems

Research and development in electrical transmission can reduce the cost, increase the efficiency and reliability and reduce the environmental impact of transmission equipment. The significance of improvements in this area extends beyond the potential impact on transmission per se to increased freedom in power plant siting relative to load centers. Studies of large transmission systems and interconnections between systems are needed to increase the reliability and operating efficiency of complex transmission networks.

R&D is recommended in the following areas. These programs

TABLE VIII

Summary of Synthetic Fuel Program

Program element	Current R&D objective	First year cost $ million	Long-term cost $ million/year	Notes
Production	Increased efficiency and reduced cost.	1.0	17/6	
Storage	Development of metal hydrides.	0.3	3/5	
Systems Analysis	Study specific hydrogen energy systems and safety aspects.	0.2	3/5	
	Total	$1.5 million		

should have considerable industrial participation with the federal share of individual projects ranging from 20-40%.

Analytical Studies: A coordinated set of planning studies is recommended to better understand the requirements and relative benefits of alternative high power transmission systems. The role of utility coridors should be included in these studies.

DC Systems: Development work is required on ac/dc terminals, miniturized terminal equipment. and dc circuit breakers. Test facilities for dc components should be constructed.

UHV AC Overhead Transmission: To the extent that environmental problems are resolved. development work should aim at producing a 1100 Kv line by 1980 and a 1500 Kv line by 2000.

Sub-surface Transmission: Continued work is recommended on cryoresistive and superconducting transmission concepts and increased support is recommended for the development of extruded dielectric cables and gas-spacer systems. Submarine cable systems need analysis and development.

Fundamental Research: Research is required on basic breakdown phenomena. At the present time the reliability of utility equipment is less than predicted or desired and the failures most often involve phenomena that are inadequately understood.

These programs are summarized in Table IX.

Transportation

The direct fuel requirements for the transportation sector account for about 25% of the total energy consumed in the U.S. and about 55% of the U.S. petroleum consumption. When the energy requirements for automobile manufacture and repair, and for road building and maintenance are included, a much greater fraction of the total energy demand can be attributed to transportation. In view of projected shortages of domestic petroleum,

Table IX

SUMMARY OF PROGRAM IN TRANSMISSION AND CONTROL

Program Element	Current R&D Objective	Program Cost[a] FY '74 $ Million	Program Cost[a] Long Term $ Million/years
Analytical Studies	Study interconnected systems and benefits of alternative technologies.	1.2	4/3
UHV AC Overhead	Develop 1100 Kv line by 1980, 1500 Kv by 2000.	11.2	78/7[b]
DC Transmission			
Conversion Equipment	Develop plasma valve and advanced solid-state converter.	2.0	14/7
Auxiliary Equipment	EHV DC circuit breaker, etc.	2.1	15/7
Miniaturized Terminal	Develop 250-500 Mw miniaturized terminal.	5.7	40/7
Undergound Cable	Develop extruded dielectric cable.	2.3	16/7
Test Facilities	Prepare facilities for testing cables and components.	4.3	30/7
Demonstration	Demonstrate DC elements in an AC system.	4.3	30/7
Subsurface Transmission	Develop extruded dielectric and gas spacer cables; develop submarine systems	2.5	17/7
Control Systems			
Development & Analysis	Develop modeling techniques, digital controls, etc. Analyze security needs.	6.3	44/7
Nat'l Simulation Lab.	Provide facilities for simulation studies of power system behavior.	14.3	100/7
Fundamental Studies	Research on physical-chemical bases of failure modes.	10	70/7
	TOTALS	$66.2 million	- $458 million in 7 yrs.

(a) A significant portion of these costs are expected to be borne by industry.

(b) This program may be decreased in future if competing technologies are successful.

new transportation technologies that can improve the efficiency with which people and goods are moved and reduce the attendant environmental impact are of major importance. It is recognized that certain policy decisions and institutional factors can influence transportation efficiency, perhaps even more effectively than new technologies by shifting demand to more efficient modes.

An R&D area of major importance is the development of advanced automotive power systems including light-weight diesels, advanced gas-trubines, Rankine cycle engines, electric battery systems and hydbrids. Fuel economy as well as reduced emissions should be amphasized in the program. Work on the advanced gas turbine should be directed towards increasing the operating temperature.

Opportunities also exist for increased fuel economy in automobiles through aerodynamic drag reduction, rolling friction reduction, improved load-engine matching, and the use of smaller engines. Most of the technologies required to achieve increased economy are available and now require effective demonstration.

In order to fully assess new technologies in the transportation sector, a comprehensive planning model is required. Such a model would predict the modal split in the transport of goods and people as a function of price, trip time, convenience requirements, etc.

This program is summarized in Table X.

Urban and Residential Energy Utilization

As in the transportation area, urban and residential energy utilization is far less efficient than it could be with the application of existing technology. Nevertheless, development and demonstration programs can stimulate the use of more efficient techniques.

TABLE X

Summary of Transportation Program

Program element	Current R&D objective	First year cost $ million	Long-term cost $ million/year	Notes
Fuel economy	Demonstrate fuel economy vehicle	5	15/4	
Alternate engine	Develop 3 alternative heat engines and battery-driven vehicles	20	250/15	Includes gas turbine, Rankine, and diesel engine as well as electric battery
Alternative transport modes	Develop planning model and perform studies	5		
	Total	$30 million		

A program is recommended for the demonstration of standard utility cores for commercial and residential buildings, the development of more efficient appliances, and the development of construction standards that would operate to conserve energy. In a standard utility core, waste heat from appliances could be recovered for space heating in the winter and could be rejected outside of the building during the summer so that it does not become an additional burden on the air-conditioning system. New architectural concepts and insulation techniques would be considered in developing construction standards.

A program is also recommended to develop total energy system components, thermal storage techniques, and more efficient HVAC components, including heat pumps.

These programs are summarized in Table XI.

CONCLUSIONS

A summary of all the recommended R&D programs is given in Table XII. Two aspects of the programs discussed above and presented in the table should be noted. First, in some cases the recommended programs are entirely new (such as most aspects of the solar program). In others, they are merely accelerations of existing programs (such as in fusion). Second, many of the programs, particularly those close to the demonstration stage, should be performed in collaboration with the utilizing industry. Examples are the programs in clean fuels from coal and electrical transmission.

In assessing the various technologies considered in the study, the impacts--on resources and the environment--of those technologies were analyzed using the Reference Energy System approach. Despite the uncertainties inherent in such analysis, it is of interest to summarize those impacts in the light of the problems identified earlier.

TABLE XI

Summary of Urban and Residential Utilization Program

Program element	Current R&D objective	First year cost $ million	Long-term cost $ million/year
Energy conversion	Demonstrate more efficient total energy system components, thermal storage systems, and HVAC equipment.	4	
Energy conservation	Demonstrate standard utility cores.	7	
	Total	$11 million	

TABLE XII SUMMARY OF R&D PROGRAMS

Program	Major Areas of R&D Activity	First Year Funding $ Millions	Long Term Funding[a] $ Millions/Years
Extraction of Energy Fuels	Oil and gas stimulation, oil shale development, conversion of biological waste and underground coal mining.	42	340/10
Solar Energy	Thermal energy for building, thermal and photovoltaic central station power generation.	12.7	370/10
Geothermal Energy	Resource appraisal, development of exploration and exploitation techniques.	20.8	600/10
Clean Fuels from Coal	Advanced combustion, low-Btu gasification and coal liquefaction.	60	1000/14
Advanced Power Cycles	Open-cycle MHD, fuel cells and comparative studies.	12	73/7
Alternative Breeder Reactors[b]	Molten salt breeder, gas cooled breeder and light water breeder.	35[b]	
Fusion[c]	Confinement research, supporting R&D, technology development.	55	1000/9[d]
Hydrogen Uses	R&D on production and storage of H_2.	1.3	20/6
Electrical Transmission	Advanced AC and DC methods, subsurface transmission, control systems.	66.2[e]	460/7[e]
Transportation	Increased fuel economy, alternate engines and transport modes.	30	270/15
Urban and Residential	Total energy systems and energy conservation technologies.	11	
	Total First Year Funding	$366 million	

[a] Many programs contain elements of different duration. These long term estimates provide only a rough estimate of such funding requirements.

[b] Includes only Molten Salt Breeder Reactor and Gas Cooled Fast Reactor. Light water breeder reactor was not evaluated in detail but the current program was viewed as appropriate.

[c] Refers only to magnetic confinement approach. Laser fusion was judged to be properly justified under the military program.

[d] Rough estimate of total cost to commercial feasibility is $6 billion in 30 years.

[e] Represents total program, federal share of which is 20-40% in specific projects.

Oil Supply

One critical measure of the short term fossil fuel supply problem is the projected rate of oil importation. In Figure 3 the impact of various new technologies on oil consumption is compared with oil importation projections made by the National Petroleum Council. It should be noted that the impacts of the new technologies are plotted separately. Based on the degree of implementation shown in the figure these new technologies can have only a small impact on this problem in the near term. The sum of the impacts in 1985 amounts to about 10% of total consumption. By the year 2000, however, these technologies have the potential of supplying or replacing a total of 45% of total oil demand. At that point in time neither fusion nor solar energy could play a large role in displacing oil, but beyond the year 2000 their utilization could increase rapidly.

Gas Supply

In the case of natural gas, the new technology with the greatest potential impact is coal gasification to high-Btu gas. Figure 4 shows the fraction of future gas consumption expected to be supplied by gasified coal and by importation. These are used to indicate the potential impact of two other technologies namely, stimulation of gas by nuclear explosives and conversion of waste to methane. Although extrapolation beyond 1977 is uncertain, the only new technology with potential short-term impact in this area is nuclear stimulation. Public concern about possible environmental problems of this method, however, may severely limit its applicability.

Electrical Supply

Figure 5 shows the potential contribution that several technologies can make to electricity supply. Note that the reference total electrical demand could be increased significantly

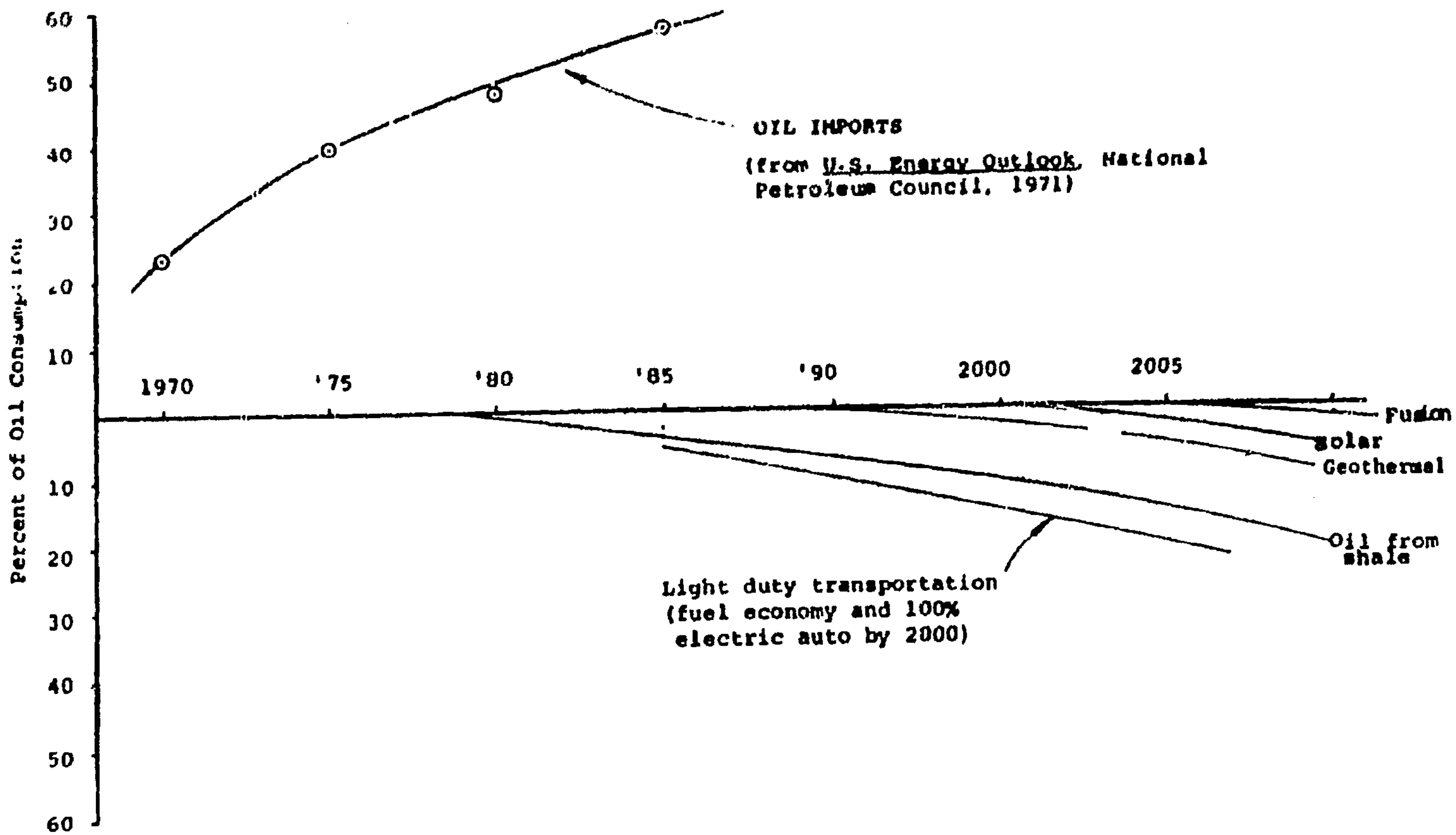


Figure 3 Potential Impacts on Oil Importation

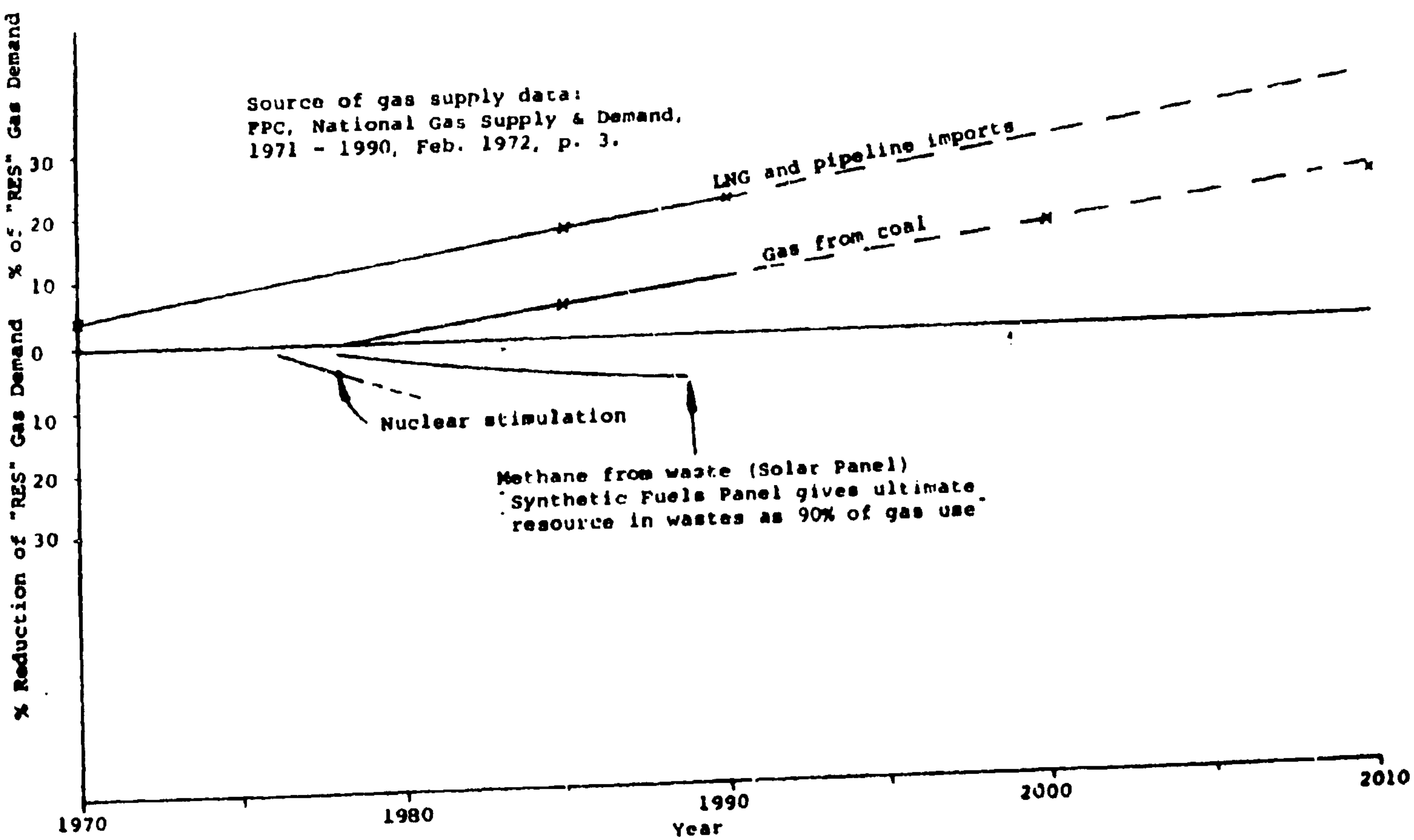


Figure 4 Potential Impacts on Gas Importation

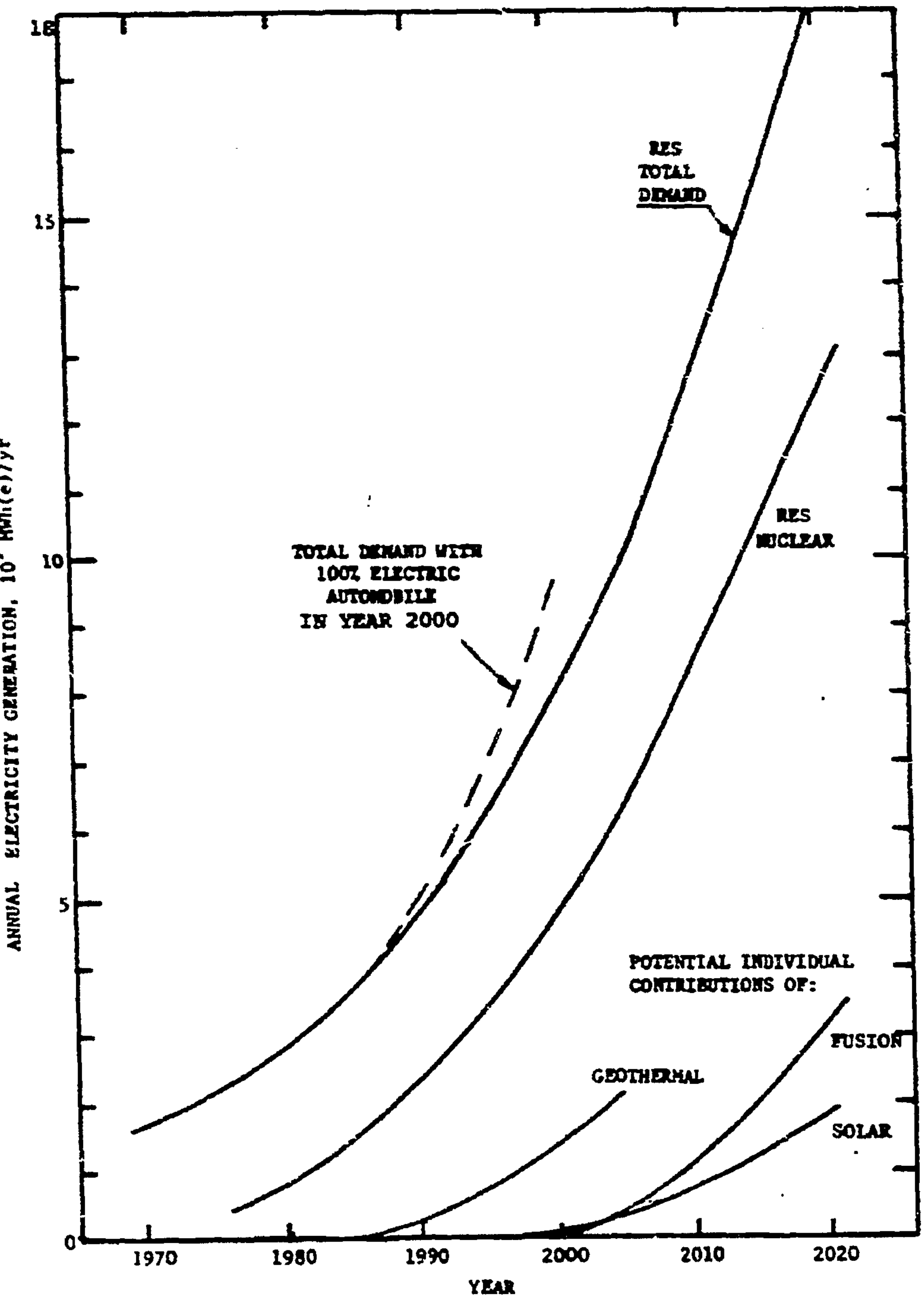


Figure 5 Potential Impacts on Electric Supply

if electrically powered automobiles were to be used appreciably. The figure indicates the perturbation for the introduction of the electric auto starting around 1985 and achieving 100% by 2000. As the figure shows only geothermal energy has potential of contributing to electrical supply in the intermediate term. The use of advanced topping cycles can also have an impact on the amount of fuel used to produce electricity.

Nuclear Energy

Although the main line of fission reactors. light water burners and liquid metal cooled breeders, were not explicitly considered in this study, a few comments should be included.

The fastest growing component of the energy system between now and 1985 will be light water reactors. Although there is no longer a need for Federally-supported R&D for the basic technology of this type of reactor, there is an important need for continued safety research. The problems of long term safe disposal of high level radioactive waste is also of major concern and must continue to receive priority attention until an acceptable solution has been demonstrated. In these areas. the regulatory responsibility of the government requires a continuing authoritative evaluation program beyond the development of technological solutions. These activities. particularly in safety research. are crucial in protecting the near term development of the nuclear component of the energy system.

In both the main line breeder effort and the backup efforts strong safety research programs are necessary if these new technologies are to move expeditiously and with public confidence into their commercial roles.

The Balance of Technical Options

The value of flexibility and variety in available energy technologies is clear from an analysis of current problems of the national energy situation. It should also be clear from the previous discussion of potential impact of new technologies. The variety of needs for energy in this country in the near and distant future cannot be met by only one or two new technologies. Breadth of technical options is also dictated by our lack of knowledge of environmental and health effects of energy-related residuals. Fortunately, as this assessment has shown, there is a large number of places within the system where new technologies, if properly developed, can make significant contributions.

Thus the breadth of technologies discussed above is not incidental; a diversified balance of technical options is vital to the best future development of the system.

Policy Alternatives and Requirements

It is important to emphasize again the limited purview of this study. What have been discussed are technological means of influencing the beneficial development of the energy system. Although the study was carried out in full cognizance of other means of institutional and policy natures, such alternatives were not analyzed explicitly. The summary of potential impacts of new technologies given above, however, clearly indicates the limited impact that R&D programs can have in the near term. Detailed analysis is not required to prove that; it follows from the basic time lags involved in R&D and in implementation. Thus, for the most part, we are forced to look to non-technological approaches to solve the near term problems of the energy system. Many of these approaches, including modifications in tax laws, changes in price regulation and import quotas, and encouragement of conservation can be effective in the short term. Although it is necessary to extend these policies into the medium term, they do not solve the medium and long term problems. For example, an increase in the regulated price of natural gas (or deregulation) will increase production of natural gas, but has little impact on the long term problem of gas supply.

This leads to another type of policy action more closely linked to the R&D programs discussed above. As a technology develops from the early research stage to commercial use, increased involvement of private industry operating in a competitive mode is required. However, there are a number of restraints on such involvement. The question of how to best encourage private industrial involvement is one which should be addressed in general but which should also be dealt with in each specific development program.

Future Analysis

In the course of this study it was very clear that the questions being dealt with were of major importance to the nation and, at the same time, it was clear that the conditions under which the study was performed, even if the best under the circumstances, was not entirely satisfactory. The determination of R&D strategies in the energy field is too important and too complex to be carried out under ad hoc conditions. First of all, the sorts of comparative engineering-economic evaluations necessary for intelligent decisions cannot be produced in a short-term effort. Secondly, the analytical tools required to assess the role of new technologies in the future evolution of the energy system require long term development.

Ideally, one would like to base this kind of assessment on fundamental societal goals from which requirements on the energy system and thus on R&D can follow. In this study it was possible to approximate this concept only remotely. The concept implies two requirements. The assessment must be a continuing, multidisciplinary, activity with long time horizons, and it must be situated in an effective location within Government.

This nation's energy system and the research and development which nuture it are too important for these requirements to be ignored.

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