SEPTEMBER 1973

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TERRASTAR

SCHOOL OF ENGINEERING
AUBURN UNIVERSITY
AUBURN ALABAMA 36830

FINAL REPORT
NASA GRANT NGT-01-003-044

NASA/ASEE SYSTEMS
DESIGN SUMMER
FACULTY PROGRAM

NOTE

TERRASTAR

TERRestrial Application of Solar Technology And Research

by

AUBURN UNIVERSITY ENGINEERING SYSTEMS DESIGN

SUMMER FACULTY FELLOWS

FINAL REPORT

CR- 129012

Prepared Under

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UNIVERSITY AFFAIRS OFFICE HEADQUARTERS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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and

PROGRAM DEVELOPMENT
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

The TERRASTAR report presents the results of a systems approach study on the Application of Solar Energy to the Energy Crisis. The report was completed in 11 weeks by 20 senior faculty from universities throughout the United States. These faculty represented a variety of disciplines in the engineering, life, physical, and social sciences.

The application of solar energy to the energy crisis of the 70's and beyond is discussed in the context of energy consumption in the U.S., energy resources in the U.S., and the state-of-the-art of solar energy applications. Solar energy application concepts, such as solar farms (a term used to describe vast fields of concentrators collecting solar energy for the generation of steam to drive power turbines), an orbiting solar power station, and the conversion of solar energy into solar power for heating and cooling of individual buildings on the earth, are discussed.

The report emphasizes the application of solar energy to the heating and cooling of buildings since this application seems to be more promising in the near term as far as research and development are concerned. The importance of initiating research and development on all solar application concepts is stressed as an important step in pursuing the use of solar energy. Immediate steps leading to the application of solar energy to heating and cooling of buildings are outlined to insure appreciable energy displacement through the use of solar energy by the year 2020.

The report is divided into four parts. The first part presents the energy overview and discusses energy consumption and energy resources. Three scenarios for projected energy consumption through the year 2020 are discussed. One scenario following through on the current exponential projection of energy consumption through the year 2020 discusses the implications of energy consumption increasing from about 70 Quads in 1972 to 377 Quads by the year 2020. Scenario two, which calls for drastic constraints on energy consumption and supply, discusses the implications of these constraints on limiting the total increase in energy consumption and supply to 98 Quads by the year 2020. Scenario three, the recommended goal for the U.S., discusses the rationality of pursuing a consumption and supply curve which reaches a level of 148 Quads by the year 2020. As indicated, the implications of each of these scenarios are discussed and related to energy resources in the U.S. and the World. In particular, the implications of foreign oil imports are discussed in relation to the consumption and supply projections.

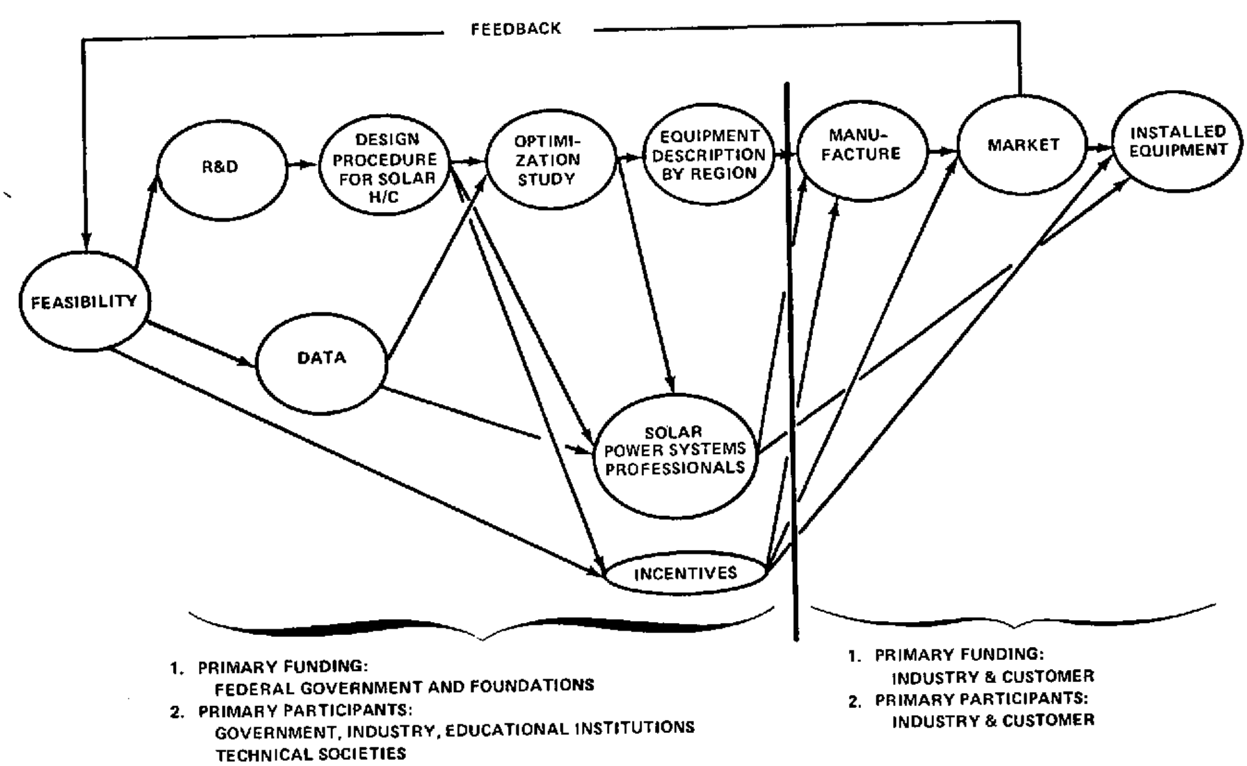
Part II of the report discusses solar energy systems for buildings and power generation. The various components for solar energy systems are examined. Solar heating and cooling in buildings is presented in terms of the components required for space cooling and heating and the problems associated with solar power systems are presented.

Part III discusses strategies for and the impact of solar energy utilization. A National energy policy is examined, the potential for solar energy is presented, the impacts for solar energy utilization are discussed, and the market potential for solar heating and cooling in buildings is examined on a national and regional basis. Finally, Part III presents a suggested strategy for solar heating and cooling in buildings.

Figure A-1 on the following page presents this overall strategy. It consists of a feasibility study, research and development on equipment and components for solar heating and cooling in buildings, the development of a design procedure for solar heating and cooling in buildings, the collection and analysis of data such as solar insolation data and climatic data, an optimization study of building types by region, and development of optimum equipment for particular buildings and particular regions. The description of this optimized equipment by regional areas would then lead to the manufacturing and marketing and, finally, installation of solar power equipment as indicated in Figure A-1.

Concomitant with the development of equipment and design procedures are incentives for the adoption of solar heating and cooling equipment. These incentives can take many forms such as tax breaks for private homeowners or building contractors to subsidies for R&D and equipment development which would encourage the free enterprise system to assume the responsibility for developing the solar power systems domestic market, as well as the export market. It is important to note that there is a need for professionals and technicians trained in solar power systems to support the solar power heating and cooling equipment market and the availability of these professionals could be a part of the incentive program.

Finally, the report presents conclusions and recommendations germane to the terrestrial application of solar technology and research. The reader should note that the SI system of units is not employed in the text. The choice of the British system of units was made to coincide with present practice in the power industry. The last appendix presents conversion tables to convert values from the British system to the SI system.



STRATEGY FOR THE ACCEPTANCE OF SOLAR HEATING AND COOLING IN BUILDINGS

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PREFACE

1973 MSFC-AUBURN Systems Design Experience

The application of solar energy to the energy crisis constituted the broad problem statement for the training exercise for the 1973 MSFC-Auburn Engineering Systems Design Summer Faculty Fellowship Program. The group, consistent with the program intent, narrowed the project to evaluate the potential, and develop strategies for implementing the heating and cooling of buildings by use of solar energy.

The basic systems approach as employed is illustrated in Figure 1. As is seen, any problem is viewed as consisting of an objective, requirements to satisfy the objective, and constraints and criteria which are controls that must be considered when trading-off approaches to the requirements in order to arrive at a plan or means of satisfying the objective. The four steps of the systems approach, (1) translation, (2) analysis, (3) trade-off, and (4) synthesis, seem obvious until the problem becomes complex and one has difficulty in identifying an objective, requirements, constraints, and criteria. These terms are defined as follows:

Translation - determining a common language (or terminology) for the statement of the problem objective and the criteria and constraints that are acceptable to, and understandable by, all participants.

Analysis - determining as many alternative approaches as possible to solve the problem as a whole or to solve portions of the problem.

Trade-Off Study - applying selection criteria and constraints to choose the combination of alternatives to meet the objective.

Synthesis - a combination of the analysis and trade-off phases to achieve a "best" solution to the problem statement that was structured during the translation phase.

Other terms used in the approach are defined as:

Objective - the function of the system or the strategy that must be achieved, performed, or accomplished.

Requirement - a partial need (stated in the most generic form) to satisfy the objective. A requirement may be itself an objective for a subsystem study.

Alternative - one of many ways to satisfy or implement a requirement.

SYSTEMS APPROACH (DEDUCTIVE/INDUCTIVE)

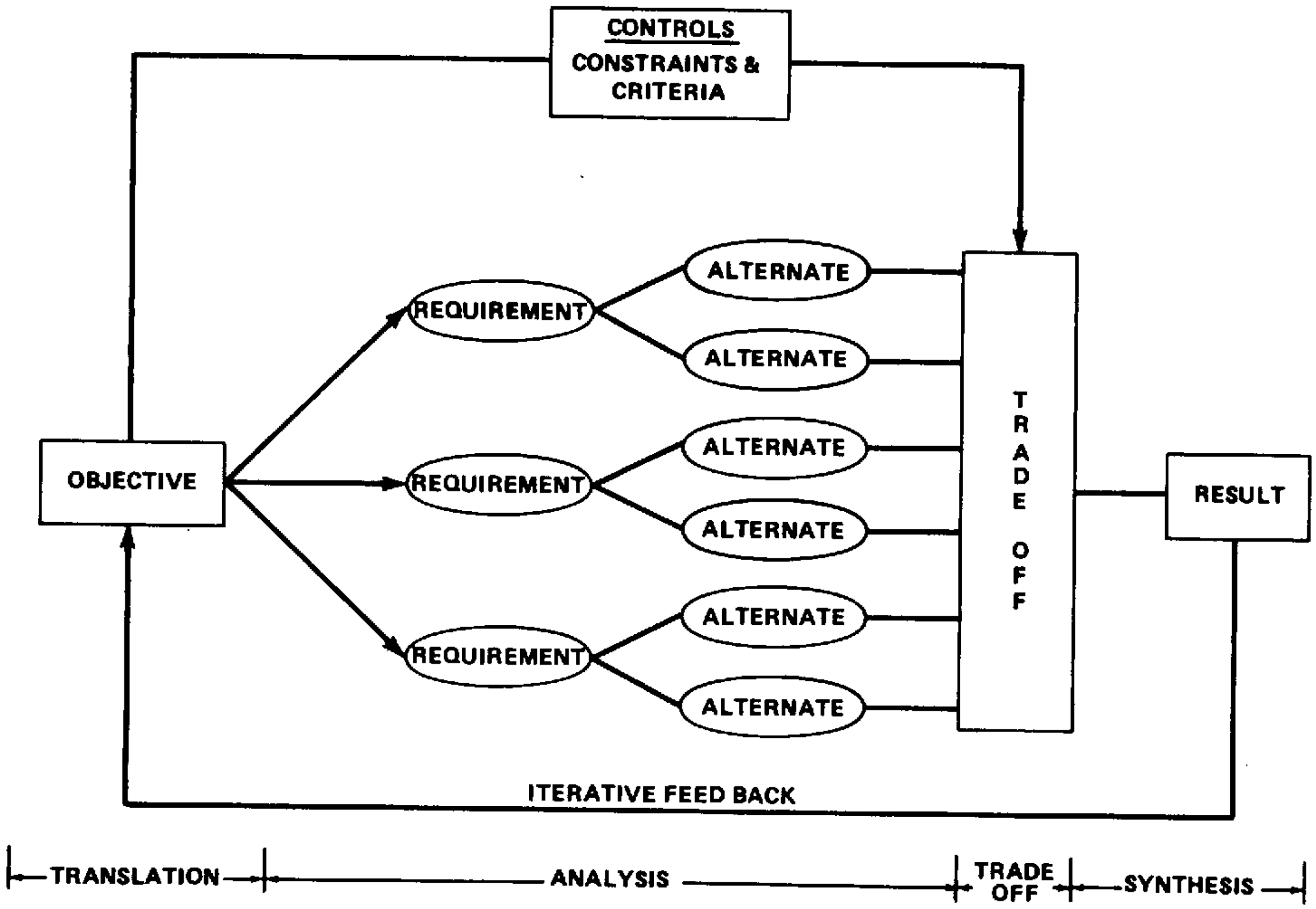

FIGURE 1. STEPS IN THE SYSTEMS APPROACH

Criterion - a measure of the desired performance of the system or strategy to meet the objective.

Constraint - an upper or lower limit on the system or strategy.

The systems approach as described above was used by the faculty fellows as an outline to guide their efforts during the evolution of the TERRASTAR project. The diagrams for the study are displayed herein to provide a background for the reader.

First, the faculty fellows organized themselves into four task teams and elected task group leaders and a project leader. This process of electing leaders was conducted three times during the course of the program to give as many participants as possible the opportunity to serve in a leadership role. The task group organization is seen in Figure 2.

The diagramatic display of the systems approach used is seen in Figures 3 through 11. Figure 3 shows the overall systems approach diagram for the group. A number of sub-systems studies are nested within the system study of Figure 3. In fact, increasing definition of a problem system study and the requirements of a sub-system are in turn objectives for sub-sub-system studies and so on. This nesting concept is illustrated in Figure 4 through 12. Each requirement in Figure 3 is the objective of a sub-system approach study as diagramed in Figures 4 through 7. The requirements of the objective shown in Figure 7 are objectives for sub-subsystem studies shown in Figures 8 and 9. This nesting of systems studies within systems studies is further seen as the requirements of Figure 9 are seen as sub-sub-subsystems studies in Figures 10, 11, and 12.

The constraints and criteria, constituting the controls for trade-off of the study, as depicted in Figure 3, are an important, yet often misunderstood, aspect of the systems approach methodology. In general, the constraints are the bounds on a system or strategy and the criteria are the measures of system performance. The TERRASTAR project controls were separated into two generic areas: operational and functional controls. Operational controls are invariant and are composed of those physical limitations inherent in every finite project effort. Examples of such items are the limitation of time, personnel capabilities, library resources, budget, etc. Each task group of the project was controlled by these same limitations over the project duration.

The functional controls indicated in Table I are the constraints and criteria imposed upon the efforts of the TERRASTAR design group. Some of these controls are invariant and others are established by the system planners.

The approach as discussed herein is presented to set the

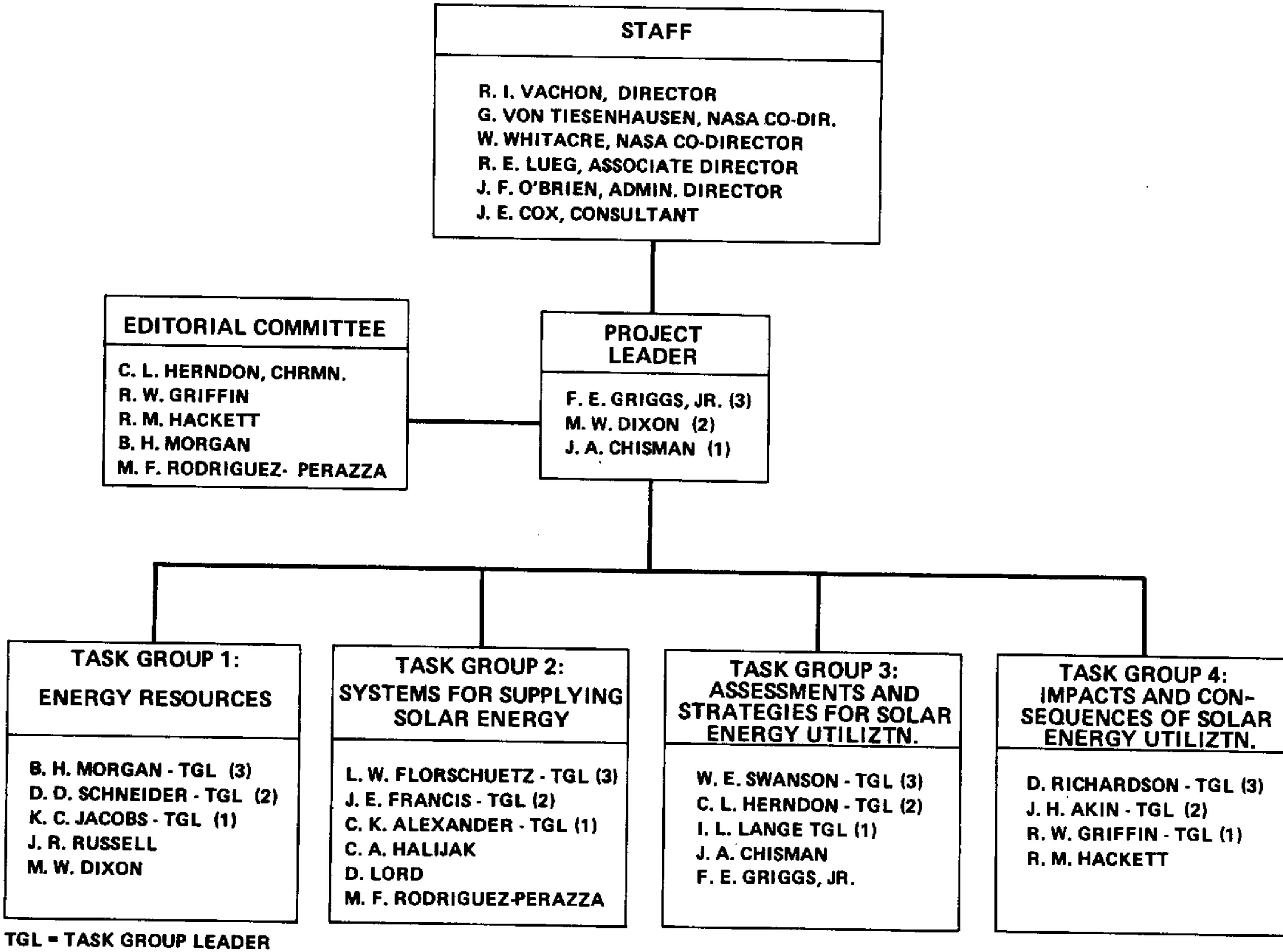

FIGURE 2.

PROJECT ORGANIZATION CHART FOR THE 1973 AUBURN DESIGN PROGRAM ON SOLAR ENERGY

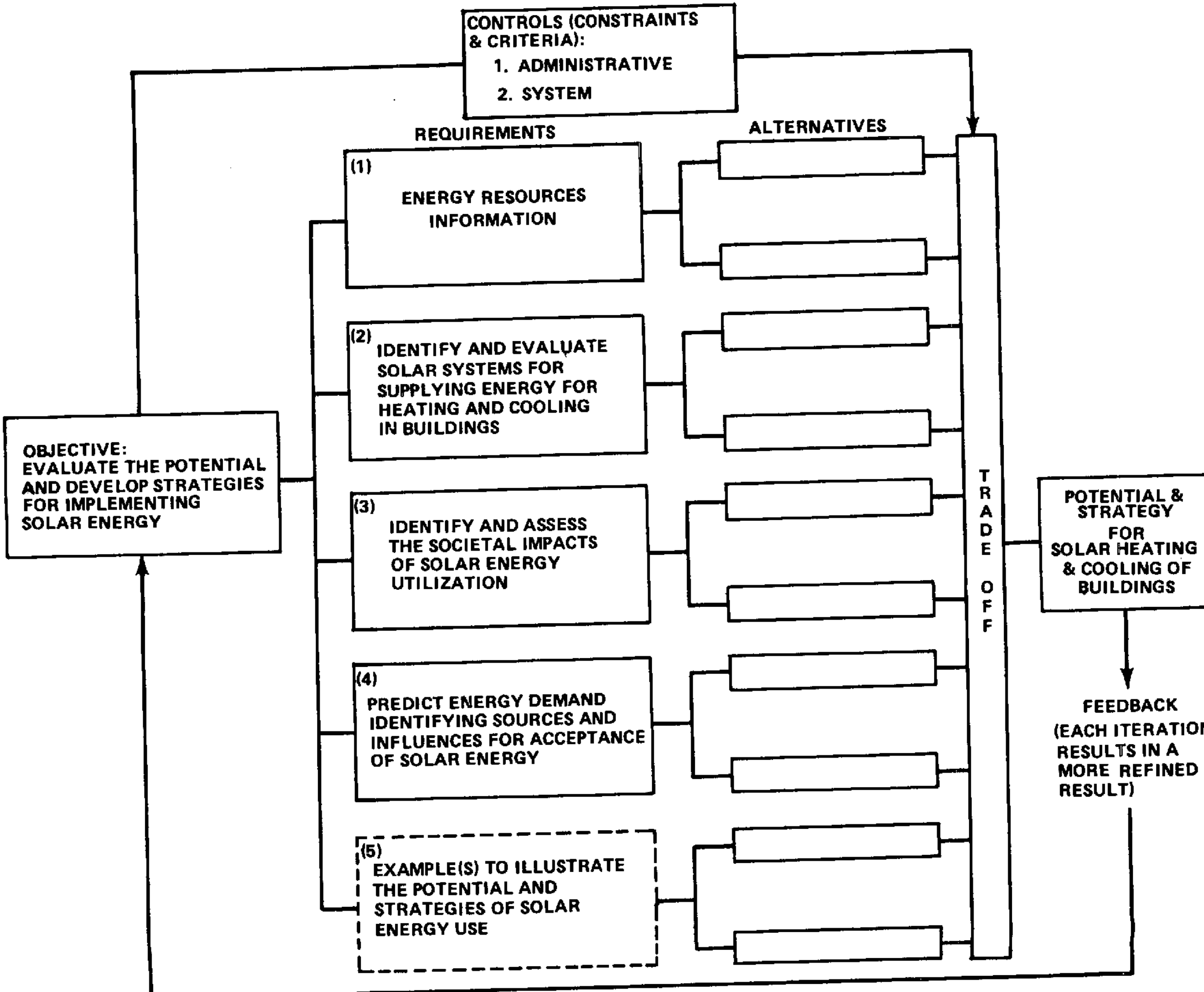

FIGURE 3 SYSTEMS DIAGRAM FOR TERRASTAR STUD

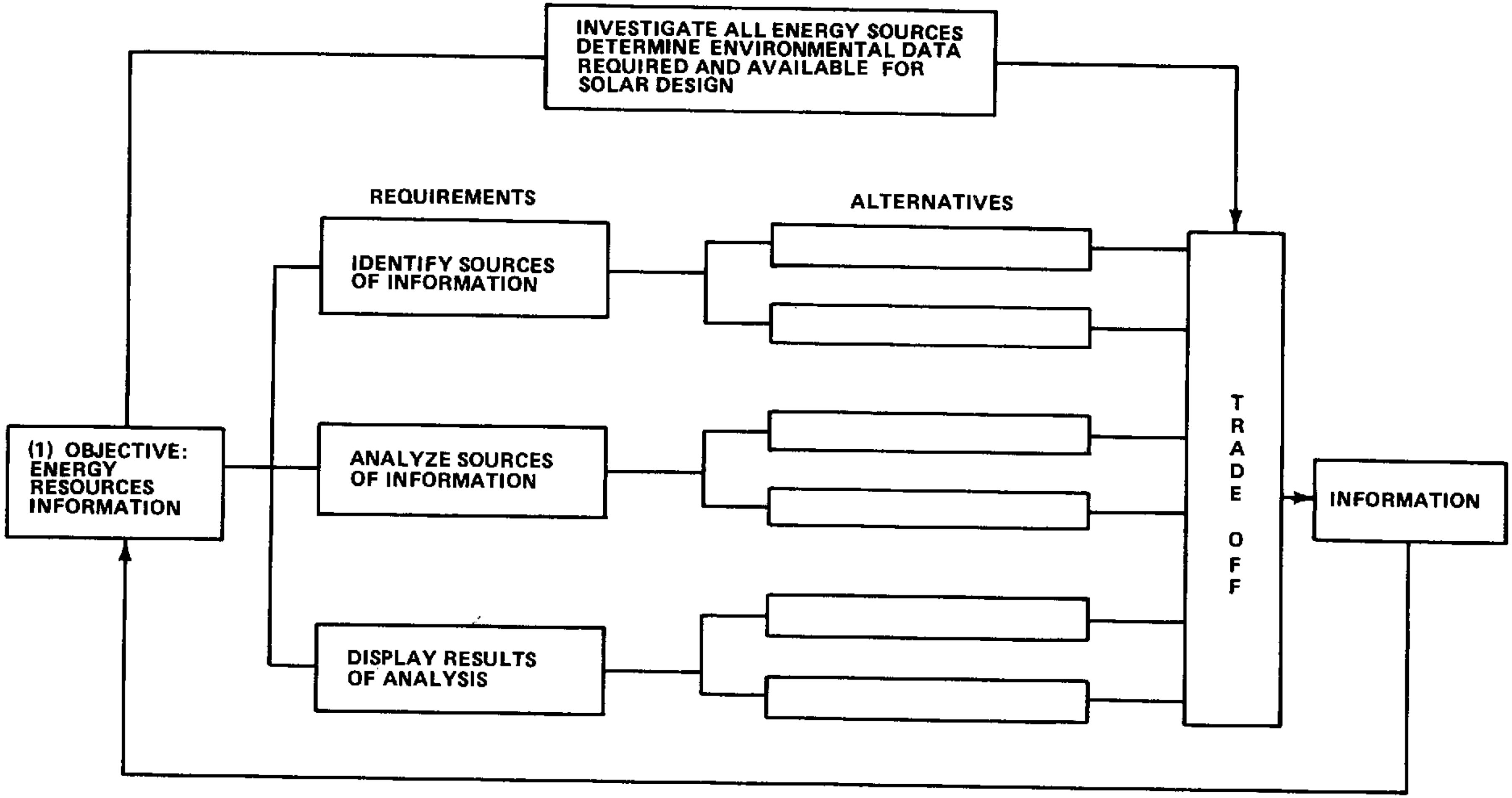

FIGURE 4. SUB-SYSTEM STUDY FOR 1ST REQUIREMENT OF FIGURE 3

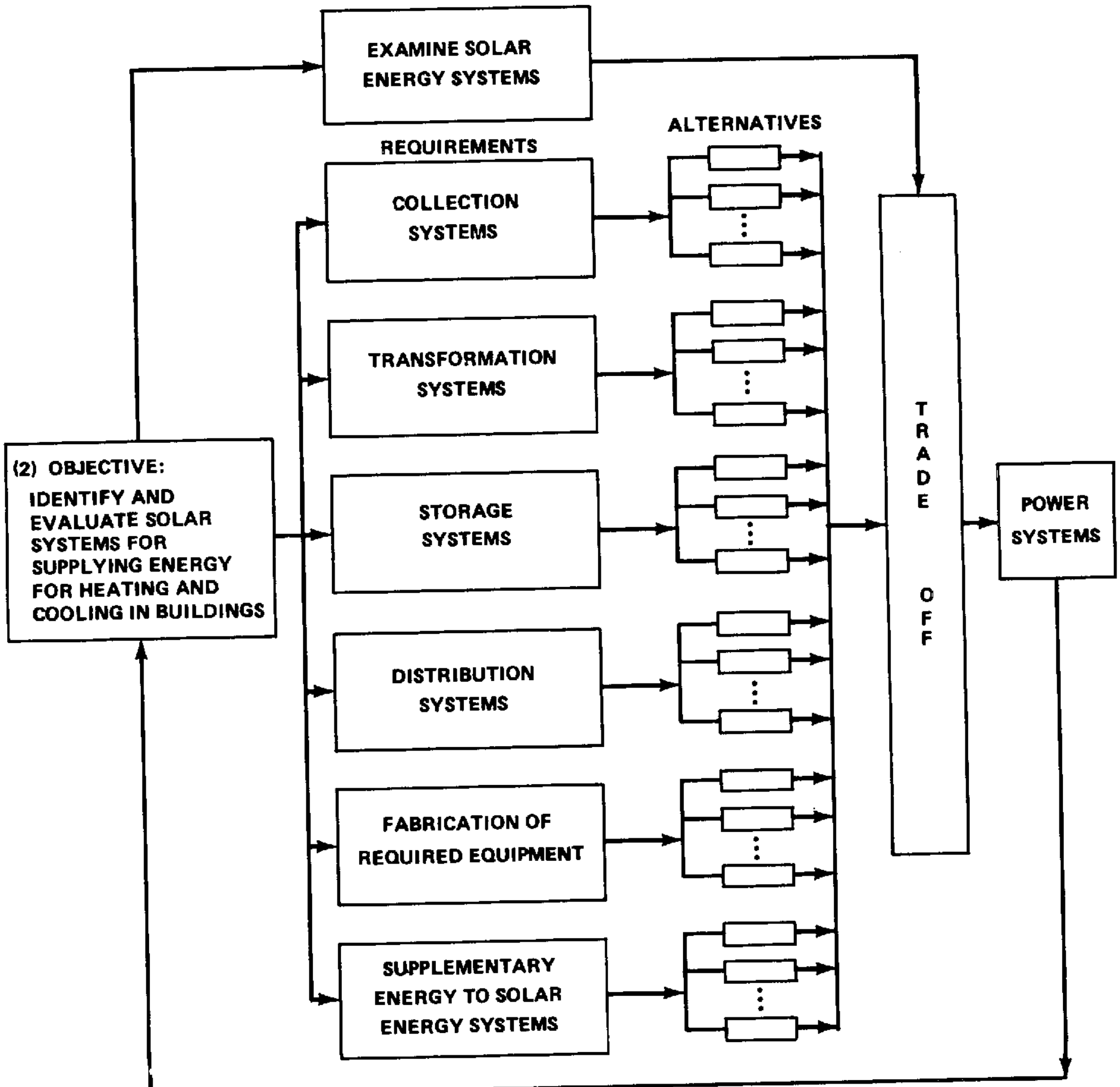

FIGURE 5. SUB-SYSTEM STUDY FOR 2ND REQUIREMENT OF FIGURE 3

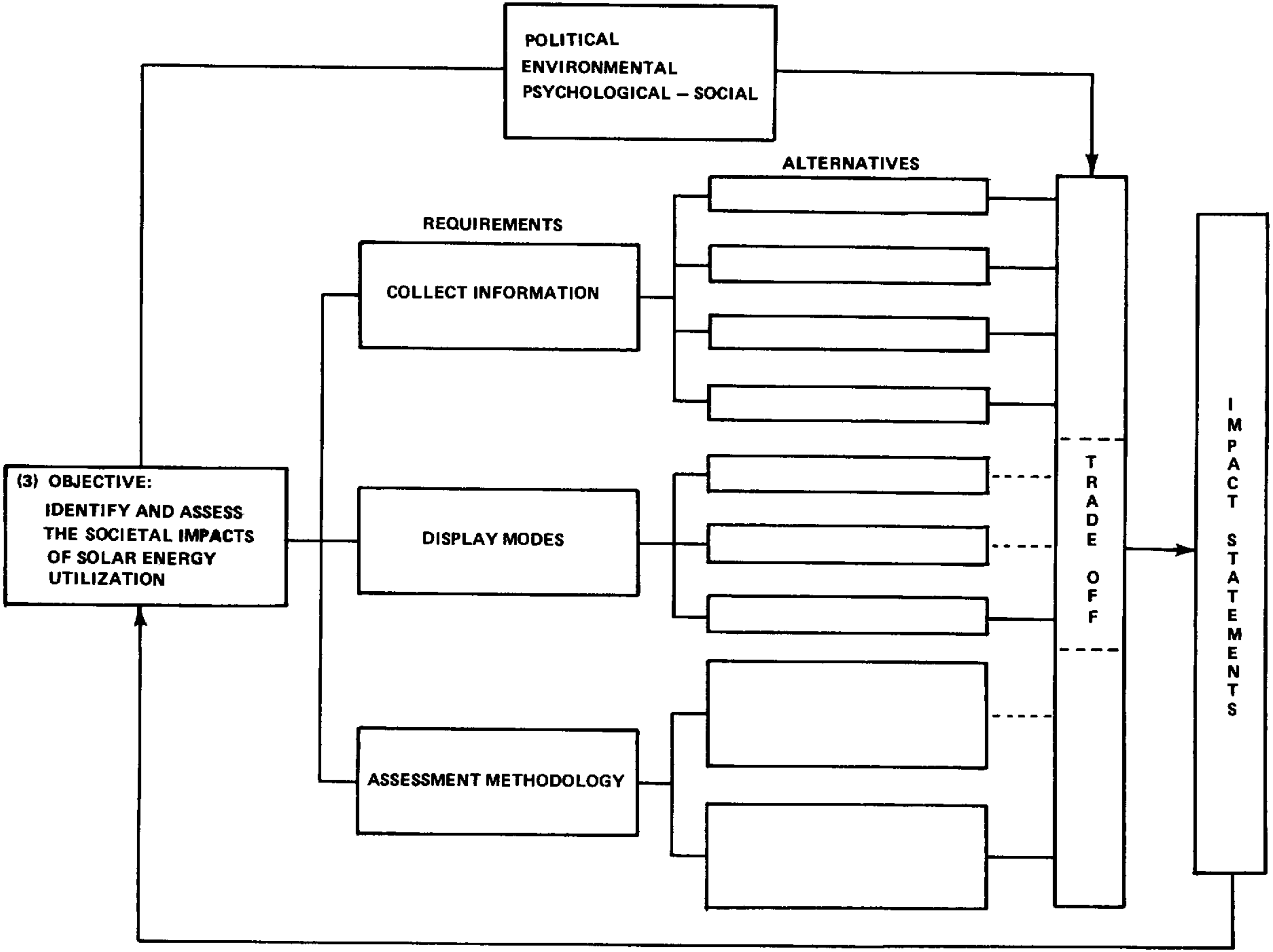

FIGURE 6. SUB-SYSTEM STUDY FOR 3RD REQUIREMENT OF FIGURE 3

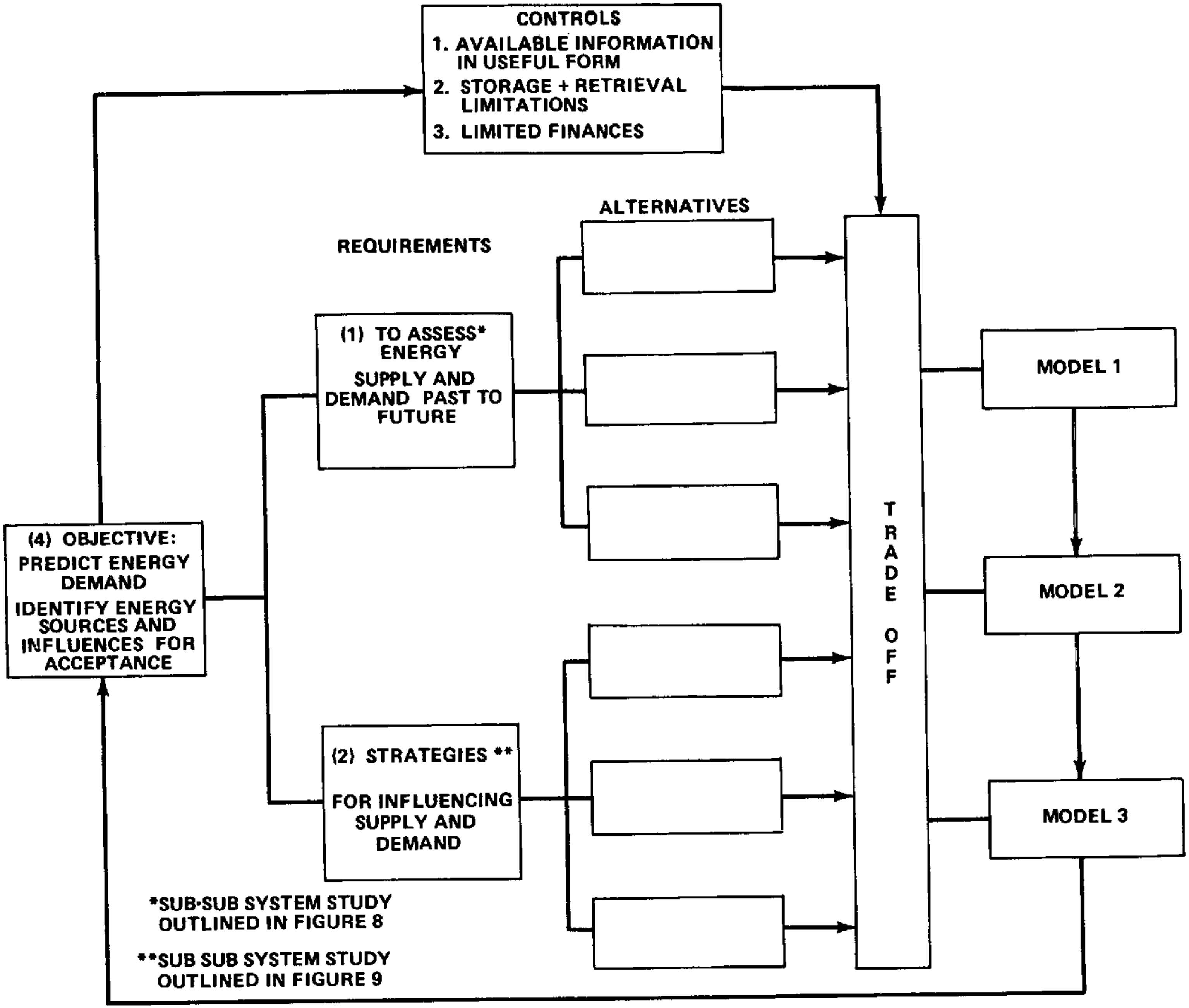

FIGURE 7. SUB-SYSTEM FOR 4TH REQUIREMENT OF FIGURE 3.

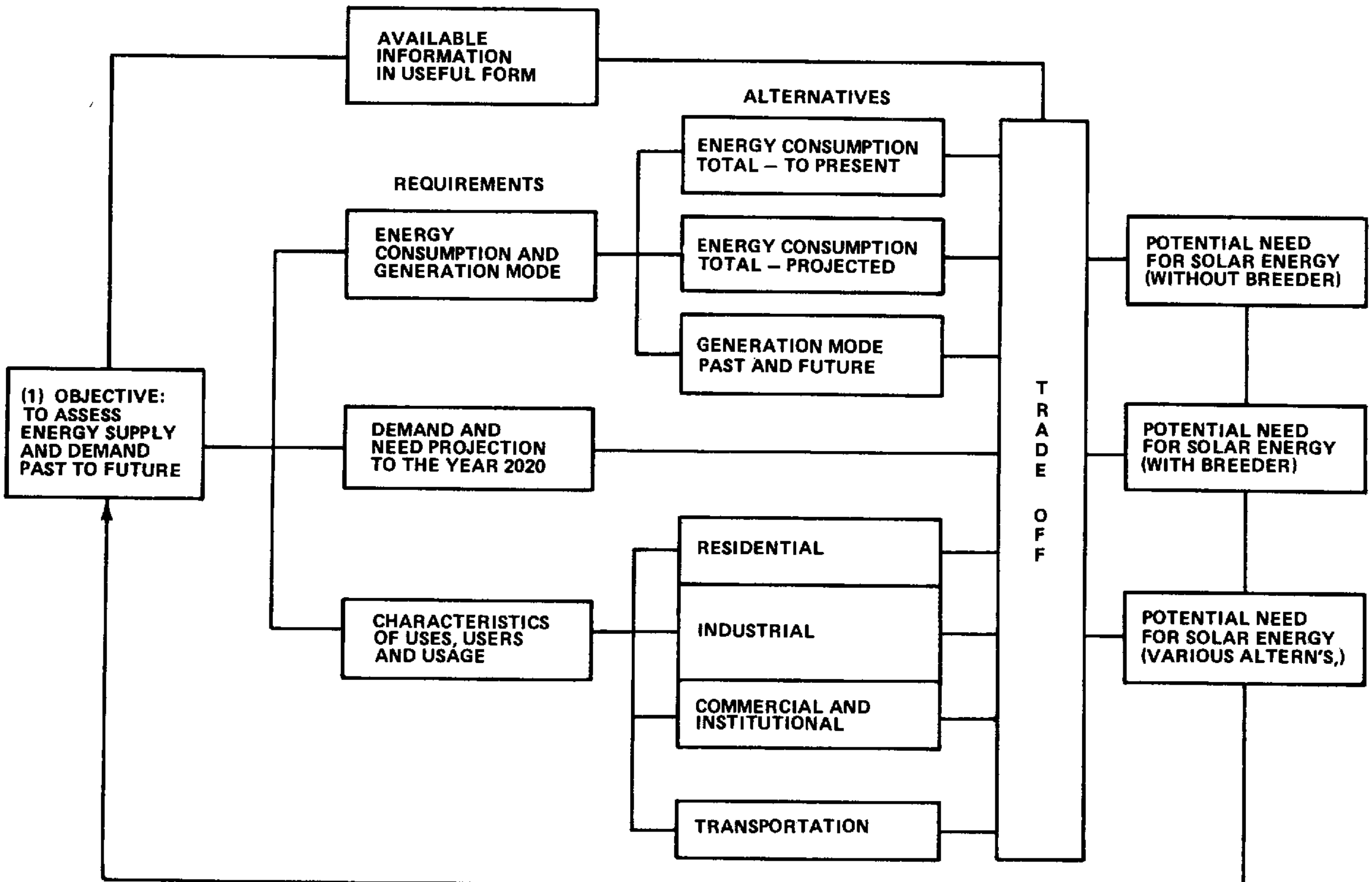

FIGURE 8. SUB-SUB-SYSTEM STUDY FOR 1ST REQUIREMENT IN FIGURE 7

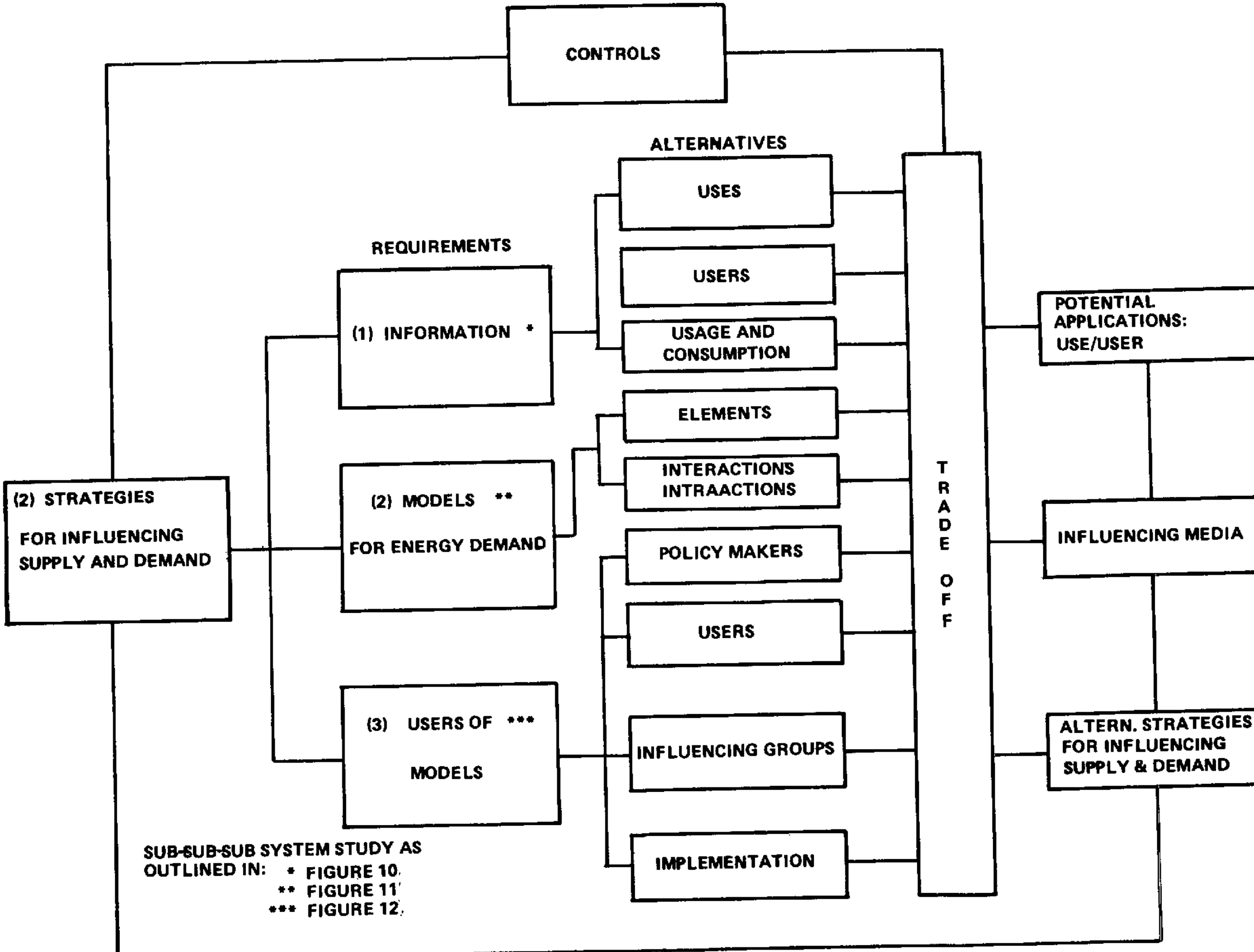

FIGURE 9. SUB-SUB-SYSTEM STUDY FOR 2ND REQUIREMENT IN FIGURE 7

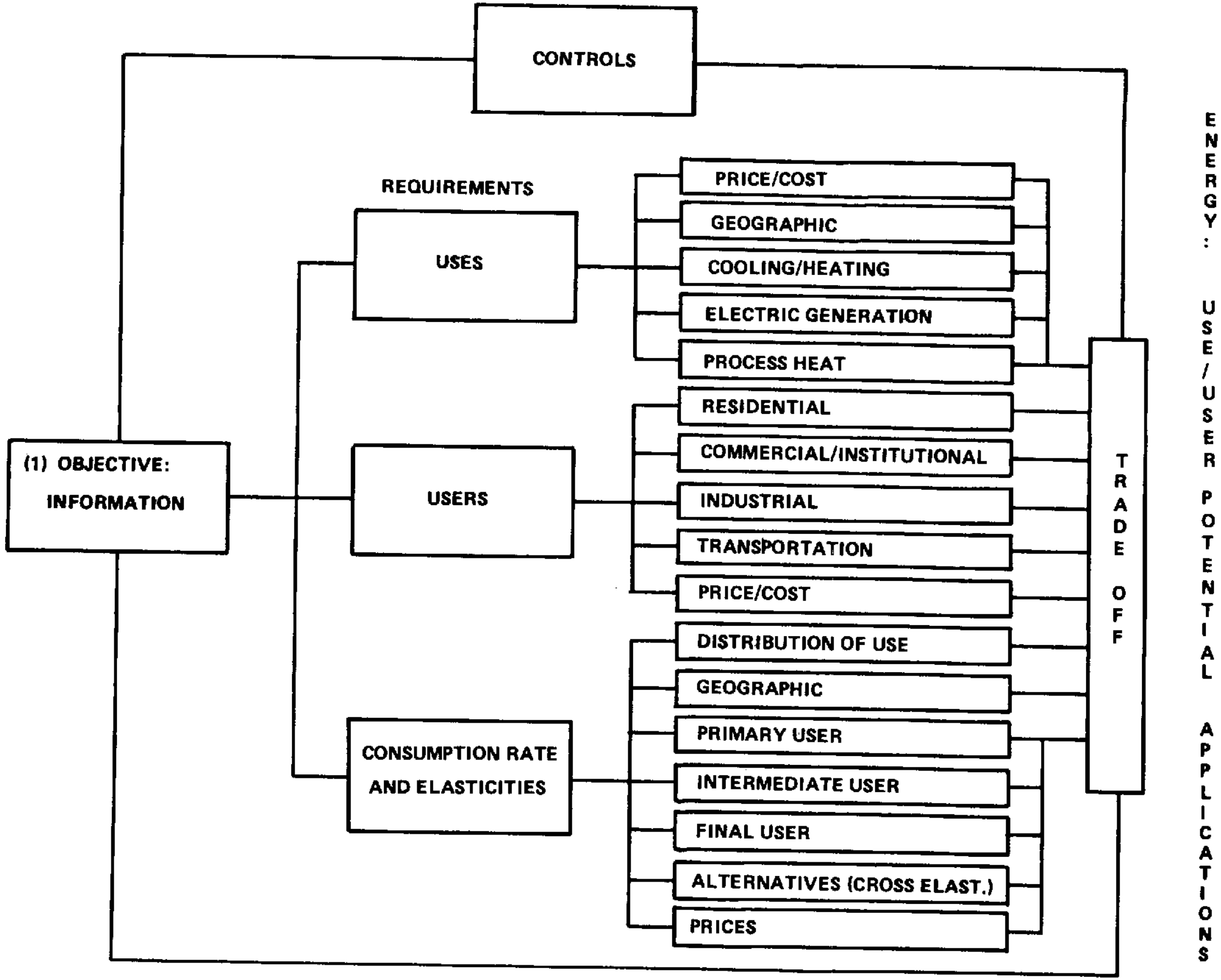

FIGURE 10. SUB-SUB-SUB-SYSTEM STUDY OF 1ST REQUIREMENT IN FIGURE 9

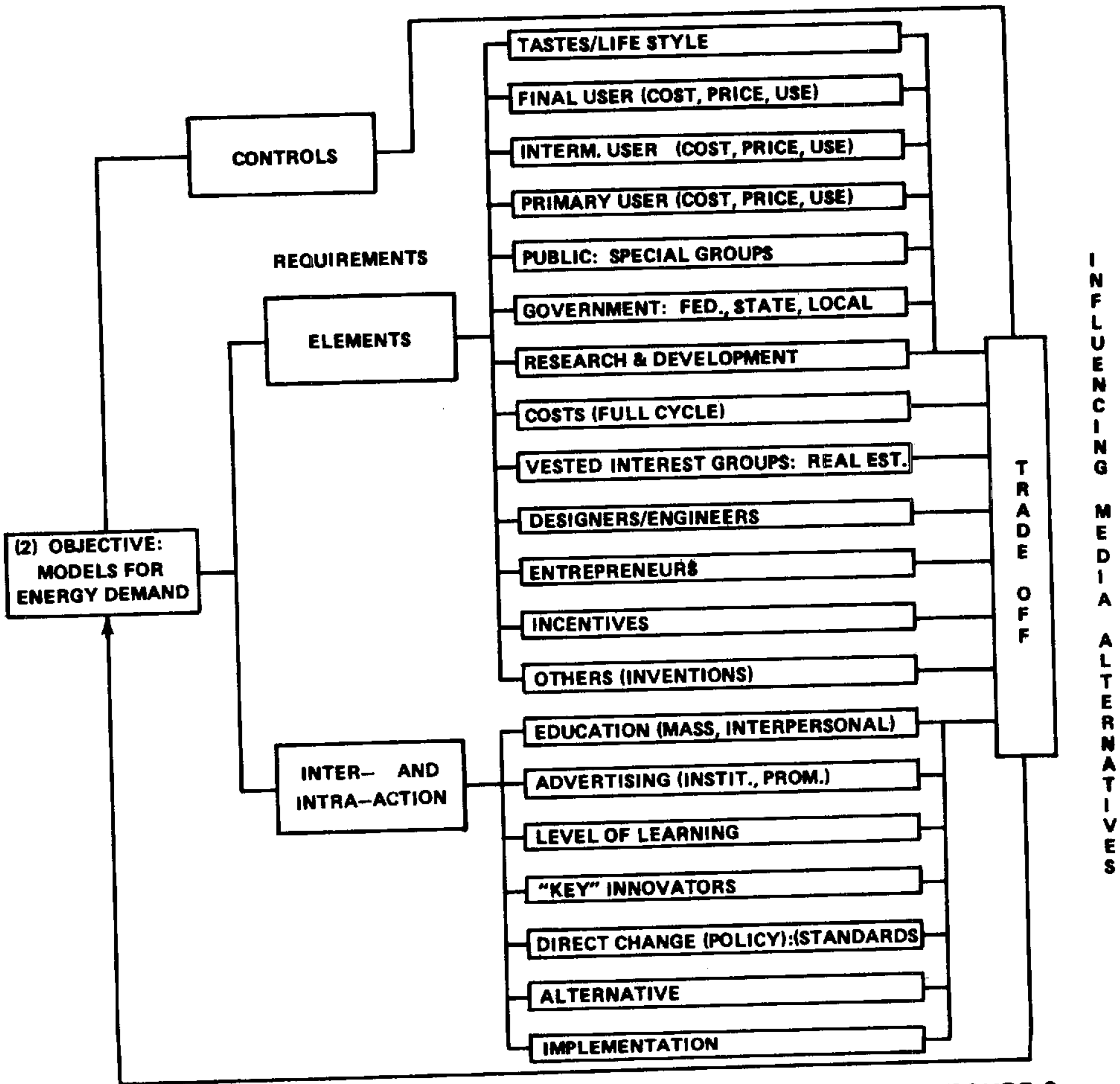

FIGURE 11 SUB-SUB-SUB-SYSTEM STUDY OF 2ND REQUIREMENT IN FIGURE 9

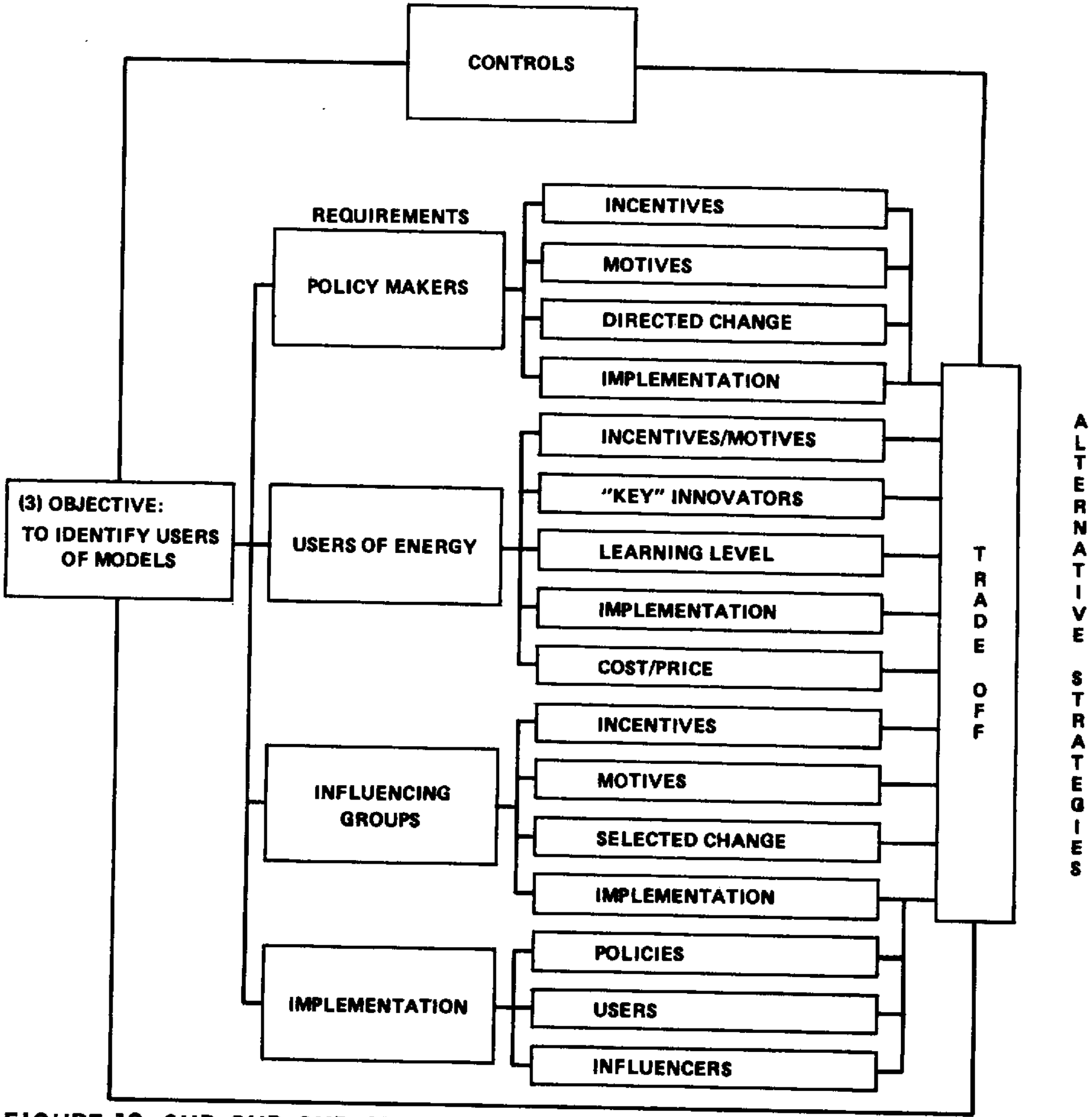

FIGURE 12. SUB-SUB-SUB-SYSTEM STUDY OF 3RD REQUIREMENT IN FIGURE 9

report in the proper context. Hopefully, the report is a contribution to the literature but its main function was to serve as a teaching device for the 1973 NASA-ASEE Engineering Systems Design Summer Faculty Fellowship Program.

Table 1

CONTROLS FOR THE DESIGN PROJECT

1. Operational/Administrative Controls
   a) Program funding
   b) Time allowed for program
   c) Number of participants
   d) Other factors
2. Functional/System Controls
   a) Beneficial impacts will result from the design group study in regard to high visibility, implementation feasibility and wide spectrum of audience coverage.
   b) The general application areas of solar energy will be addressed to establish a frame of reference for the project.
   c) The main thrust of the project will be toward the application of solar energy in the United States, although reference to the world context will be noted.
   d) The area of heating and cooling in buildings will be the focal point to indicate both the specific and broad implications of the use of solar energy.
   e) Specific illustrative examples will be used to indicate the potential of solar energy utilization.
   f) Effort will be directed toward the formation of a national energy policy.
   g) Social, cultural, economic, political, environmental, educational and technical interactions will be evaluated.

ACKNOWLEDGEMENTS

The successful completion of project TERRASTAR would have been impossible without the enthusiastic cooperation of the offices and personnel of the Marshall Space Flight Center and the many government agencies, private industries and individuals who participated in the program. It is impossible to give recognition to each individual; however, we have attempted to list certain speakers and others who have been most instrumental in the success of the project. These contributors are listed in the front portion of this report and summaries of the speaker's remarks are given in Appendix B.

We wish to express our thanks to Dr. Rocco Petrone, Director of MSFC; Dr. W. R. Lucas, Deputy Director; Mr. J. S. Potate, Deputy Director; Col. E. Mohlere, Assistant to the Director; Dr. J. T. Murphy, Director of Program Development; Mr. David H. Newby, Administrative and Technical Services Director; Dr. Ernest Stuhlinger, Associate Director for Science; Mr. Marion Kent, University Affairs Office and Dr. George Bucher, Deputy Associate Director for Science. Mr. Georg von Tiesenhausen and Mr. Walter Whitacre our NASA Co-Directors deserve our particular appreciation.

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The success of any program depends on the library services available and the willingness of librarians to serve the user. The NASA Regional Information Center is run by a dedicated group as is the Redstone Scientific Information Center. These two centers have, over the years and especially this summer, gone to great lengths to support the NASA/ASEE programs and we sincerely appreciate the efforts of all the professionals in the center, who support us, especially Ms. Charlotte Dabbs.

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INTRODUCTION

In the beginning God created the Heaven and the Earth. And the Earth was without form, and void, and darkness was upon the face of the deep.----- ------And God made two great lights; the greater to rule the day and the lesser the night-------- And God saw that it was good---

Genesis I

In this the first book of the Old Testament,man's dependence upon the sun is described in a very clear manner. It remained for modern geology, however, to define in a clearer fashion how much work the sun had done on the Earth prior to the coming of man.

The sun through the hydrological cycle and photosynthesis had placed large amounts of hydrocarbons in the form of oil, coal and gas in storage near the surface of the Earth. Early man, however, relied to a very small degree on these fossil fuels and instead used the sun directly to light his path, warm his body, and help grow his crops. He was therefore directly dependent upon the sun and as a result his lifestyle and culture were patterned about the sun and the seasons determined by the sun. Many early civilizations worshiped the sun and some offered human sacrifice to it.

Modern man, however, has,through his technology and utilization of fossil fuels, decreased his direct dependence upon the sun. Man now can create his own light and heat as well as power his industries through the burning of fossil fuels.

Given this freedom from direct dependence on the sun, why try in 1973 to find methods of utilizing the sun as a prime energy source? The reasons for this shift in attitude are many but are primarily: the rapid depletion of fossil fuel resources, an incipient energy crisis, some unanswered questions about nuclear energy and its safety, and a heavy reliance upon imported oil and gas with a resulting balance of payments deficit. It is anticipated that when advanced technology is applied to the utilization of this readily available source of energy it will ultimately provide the world with an ample supply of energy to sustain modern society.

It may come as a surprise to the reader that solar energy has been a subject of study for about 90 years and actually powered electrical plants in Egypt in 1913, has heated homes in many areas of the world, has heated water and been used to distill water for entire islands near Greece. More exotic research has been directed toward the use of solar cells to supply electrical power to most of the nation's space vehicles. Given this past research effort the question may well be asked, "Why hasn't solar energy been widely utilized?" The prime reason is that it was being developed in a period of very low fuel costs and thus could not compete in the energy marketplace. Additional reasons are that there hasn't been a concentrated, coordinated R&D effort, and that many of the concepts preceeded the necessary materials development.

The changing scene in the supply and cost of fuels has sparked interest in solar energy on the part of the federal government. This interest was focused in the recent solar energy panel sponsored by NSF-NASA and its publication "Solar Energy as a National Energy Resource." It is in this changing energy environment that TERRASTAR was researched and prepared by an interdisciplinary group of 20 college faculty members under the auspices of NASA-ASEE.

The TERRASTAR report is presented to show the role that solar energy could play in the future energy picture of the United States. The report defines that role by analysis of the total energy consumption and supply sectors, and projections of how they will change in the future. The competing fuel resources are presented to illustrate how solar energy measures up in terms of quantity, reliability and location. A description then follows of all solar energy systems and applications that have been proposed, utilized or researched to show the large range of applications possible. The final part of the report discusses the strategies required to gain acceptance of solar energy as a resource and what impacts, both positive and negative, would result from its utilization. A key part of the strategy is the formulation of a national energy policy which would set the stage for optimum utilization of all of our natural resources. Finally, the TERRASTAR report concentrates on the solar heating and cooling of buildings and envelops a strategy for the acceptance of this specific concept. This concept was chosen by the group and it is their opinion that this is the concept which is furtherest along in its development and is the first application of solar energy utilization that will be offered to the American people. The TERRASTAR report closes with a section of conclusions and recommendations which summarizes the findings of the authors.

PART I ENERGY OVERVIEW

In order to give the reader an overview of the energy situation in which the nation stands, the energy consumption history of the United States is presented along with a projection to the year 2020. Then, three possible scenarios of future energy consumption are given along with supply constraints. Each scenario defines the "energy crisis" in a different way, in magnitude and duration. The end use of energy is considered along with possible changes in end use. Finally, a survey of all energy resources is presented.

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CHAPTER I. ENERGY CONSUMPTION - PAST, PRESENT, FUTURE

The energy consumption history of the United States and the changes which could take place in our consumption characteristics in the next 50 years have been studied and are presented herein.

1-1. HISTORY OF TOTAL ENERGY CONSUMPTION

The United States has often been criticized as being "power hungry"; with only 6 percent of the world's population, we are presently using 33 percent of the world's energy. Figure 1-1, which represents energy consumption in the period 1900-1970, suggests several distinct periods of growth, as follows:

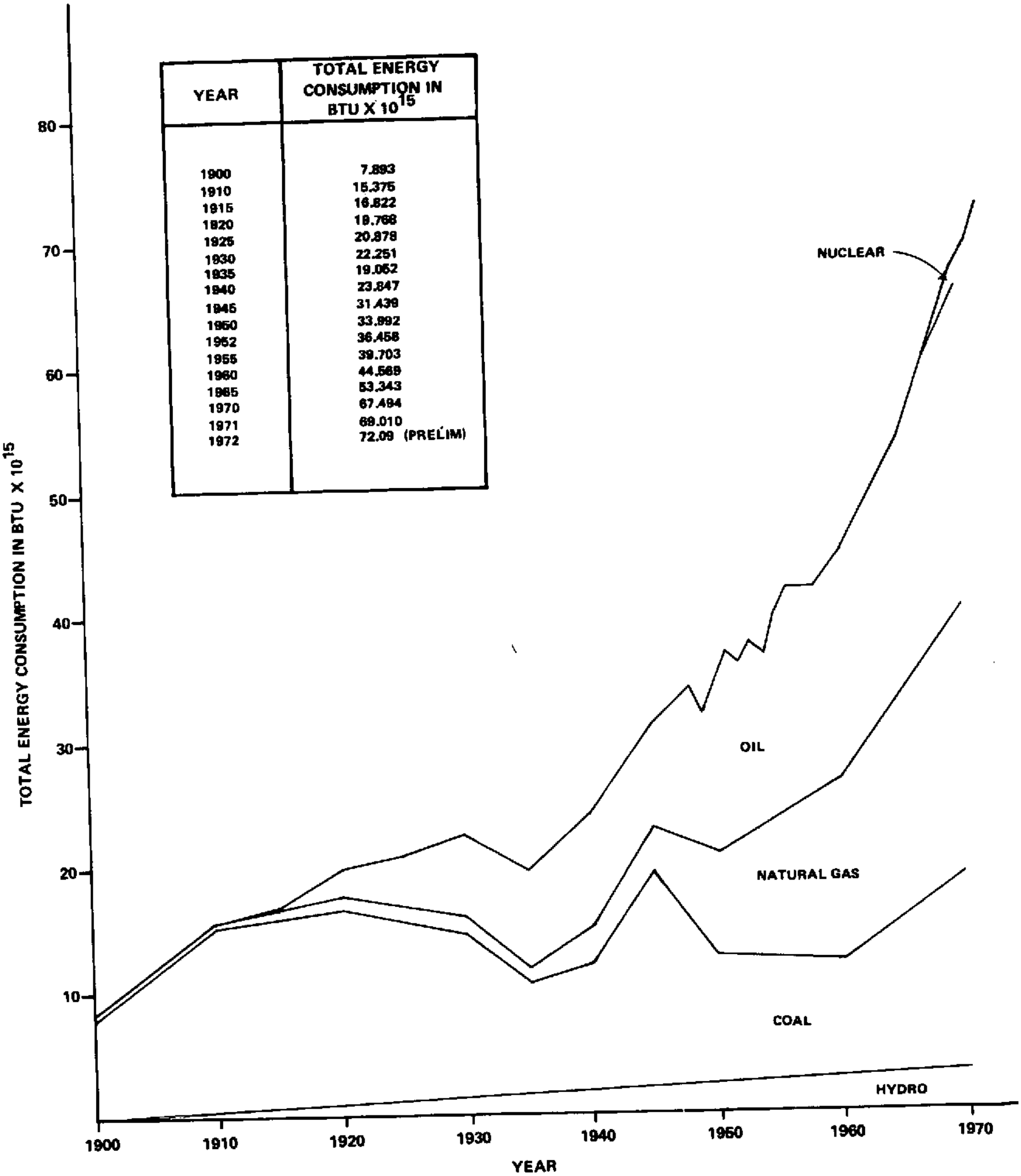
Period	Average Annual Increase
1900 - 1920	0.51×10^{15} Btu/year
1920 - 1930	0.25×10^{15} Btu/year
1930 - 1935	-0.70×10^{15} Btu/year
1935 - 1945	1.24×10^{15} Btu/year
1945 - 1950	0.71×10^{15} Btu/year
1950 - 1965	1.30×10^{15} Btu/year
1965 - 1970	3.00×10^{15} Btu/year

The effect of a war, economic depressions, and postwar transition periods on energy consumption are apparent in this list. Also, the changing nature of war (i.e., more energy intensive) can be seen by comparing the periods 1915-1920, 1940-1945, 1950-1951 and 1965-1970 which approximately covers WWI, WWII, The Korean Conflict and the Vietnam War (major U.S. involvement). The energy growth rates for these periods are as follows:

WWI	- 1915 - 1920	0.58×10^{15} Btu/year
WWII	- 1940 - 1945	1.52×10^{15} Btu/year
Korean War	- 1950 - 1951	2.78×10^{15} Btu/year
Vietnam	- 1965 - 1970	3.00×10^{15} Btu/year

All postwar periods show a definite decrease in the rate of energy growth. This casts some doubt on most current projections, which assume an increasing rate of growth for the current post Vietnam War period, even though the latest statistics show only a 2.3% increase for 1971 as compared to the 6% increase in 1968.

When viewed in broader perspective, Figure 1-1 reveals three distinct periods of growth. From 1900-1920, growth occurred at 0.5×10^{15} Btu/year; 1920-1935 was a no-growth period; and 1935-1965 shows a growth rate of 1.2×10^{15} Btu/year. Many projections of future energy



YEAR	TOTAL ENERGY CONSUMPTION IN BTU X 10^{15}
1900	7.893
1910	15.375
1915	16.822
1920	19.768
1925	20.878
1930	22.251
1935	19.052
1940	23.847
1945	31.439
1950	33.992
1952	36.458
1955	39.703
1960	44.569
1965	53.343
1970	67.494
1971	69.010
1972	72.09 (PRELIM)

FIGURE 1-1
TOTAL ENERGY CONSUMPTION BY SUPPLY VS. YEAR

needs are based on the Vietnam War growth rate for 1965-1970 of 3.0×10^{15} Btu/year (a maximum of 3.5 in 1968), even though this is twice that of any previous period in our history, excluding the Korean War.

1-2. SOURCES OF ENERGY

Figure 1-1 also indicates the primary energy sources that man has utilized from 1900 to 1970. The consumption of petroleum products (gas and oil) was virtually non-existent in 1900 but by 1970 accounted for approximately 76 percent of our energy supply. In 1970, wood had virtually disappeared as a source of energy while nuclear power, which was in its infancy, amounted to only 0.2 percent of the total. Other minor sources utilized by man in certain regions are tidal, geothermal and, to a very limited degree, solar.

1-3. ENERGY PROJECTIONS

The forecasting of future energy consumption is at best an inexact science. The evaluation of such forecasts is also very difficult. The staff of the Committee on Interior and Insular Affairs of the United States Senate noted with regard to major available energy studies that "... the underlying assumptions were so thoroughly concealed that the projections of supply and demand could not be reliably normalized among the reports considered."

In order to better define our energy demands for the next 50 years, various governmental agencies have commissioned studies to correlate existing projections. The reports of the three main studies are described below:

- <u>The U.S. Energy Problem</u> - by the Intertechnology Corp. for NSF-RANN -- November 1972.

  This report surveyed 56 separate projections and with curve fitting techniques developed a total "energy-time equation":

  $$E_T = (65.5739 \times 10^{15}) \times (1.02806)^{(Year - 1970)} \text{Btu/year}$$

  This continues the exponential growth curve of the past 30 or more years. The forecasts surveyed in this study were made in the early-to-mid 1960's. Many of them projected trends only to 1980, and just three of them to the year 2020.

- <u>A Review and Comparison of Selected U.S. Energy Forecasts by Pacific Northwest Laboratories of Battelle Memorial</u> Institute - December 1969.

This report surveyed 19 forecasts selected by the Energy Policy Staff of the Office of Science Technology. The selected forecasts were made between 1960 and 1968. The study is very complete in analyzing the assumptions made by each forecaster, as well as identifying the limitations of each. However, it did not recommend any specific projection.

- Federal Power Commission Study - 1971.

  This study surveyed eleven forecasts selected by the Senate Committee on Interior and Insular Affairs, following the same approach as the Battelle study. The forecasts analyzed by the FPC were made in 1970 or 1971. This study did not recommend a specific projection.

Several other projections have been made since late 1971 and are shown along with the previously mentioned forecasts in Table 1-1.

Virtually all of the forecasts analyzed are extrapolations of the post World War II experience of the United States and are based upon a common set of assumptions as follows:

- The Gross National Product will increase at 3 to 5 percent per year.
- Population will increase at 1 to 1.6 percent per year.
- Fuel costs will remain at their current level relative to other fuels and to prices in general.
- Fuels will be available in sufficient quantity to meet demand.
- Nuclear energy will increase.
- The cold war will continue.

The forecasts also implicitly make the following assumptions:

- The demand for energy will be inelastic (increases in price have little effect on demand).
- National awareness of potential energy crisis will not change consumption habits.

These assumptions accurately reflect the national experience of the past 30 years, and if past conditions were to remain unchanged over the next 50 years, the forecasts based upon them would be acceptable. However, as Lewis Mumford has said, "Trend is not destiny." As a nation we have the opportunity and the responsibility to modify these trends. Strong currents of change are already discernable today in national thought and circumstances. The inclusion of these changes which are occurring or

Table 1-1. TOTAL ENERGY CONSUMPTION IN UNITS OF 10^{15} BTU

PROJECTOR	1970	1975	1980	1985	1990	1995	2000	2005	2010	2015	2020
U.S. Energy to the Year 2000 Dept. of Interior Dec., 1972	68.98	80.26	96.02	116.63	136.0	160.0	191.9				
U.S. Energy Outlook, National Petro. Counc., 1972	67.83	83.48	102.6	124.9			200.0				
The U.S. Energy Problem, InterTechnology Corp. Nov. 1972	65.57	75.30	86.48	99.31	115.0	130.05	149.0	172.0	200.0	227.0	264.0
The 1970 National Power Survey, FPC Dec. 1971	68.80	82.51	98.94	118.65	142.29						
The National Energy Outlook Shell Oil, March 1973	68.80	82.4	100.00	118.10	143.5						
Outlook for Energy in the U.S. to 1985, Chase Manhattan Bank, June 1972	69.82	87.0	108.43	134.88							
"Energy, Economic Growth and the Environment." RFF April, 1971.	68.80	81.97	95.14	114.92	134.7	162.35	190.01				
Assessment of Energy Tech. AET-8, 1972, Assoc. Univ. Inc. Upton N.Y. (Brookhaven)				117.0			177.0				300.0
Battelle Northwest Survey December 1969 (Range)	NA	73.00 79.60	85.93 97.82	118.1 119.6			135.2 174.0				
Intertechnology Corp. Study for NSF-RANN (Range) Nov 1972	NA	63.00 88.0	73.00 105.00	110.0 130.0	102.0 140.0		105.0 187.0				155.0 210.0
Projection Based Upon Population and per capita energy Proj. (Range)	69.0	79.7 80.2	82.4 96.6	85.8 119.2	88.8	91.2	93.1 206.0	99.8	96.4	97.3	98.3 377.2

beginning to occur in the mid-1970's leads to a new projection of energy consumption.

The assumptions upon which the energy consumption projection planned growth curve contained in this report is based are as follows:

- U.S. population growth will follow the Census Bureau Series E projection of an annual rate of growth of 0.6 percent [1-1].*

- The Gross National Product will continue to rise at 3 percent.

- Fuel costs will increase at rapid rates relative to other commodities. (President Nixon expects energy prices to double by 1985 [1-2]). Reference [1-3] suggests that the cost of electricity will increase by 50 percent and the cost of fossil fuels may increase by 100 percent in the next several decades; the Federal Power Commission [1-4] estimates a 19 percent increase in the cost of electricity.

- Energy demand will be price-elastic in the long run and increasingly elastic as prices rise. (This assumption is being accepted by more and more decision-makers and is a significant deviation from the conventional assumption of the past.) [1-5, 1-6, 1-7].

- Petroleum products, oil and gas, will be in short supply despite increasing prices.

- Energy conservation will be stressed by government, industry, and educational institutions.

- The federal government will adopt a national energy policy which will tend to optimize the utilization of our national resources.

- The thaw in the cold war will continue and expenditures on defense as a percent of the national budget, will decrease. (The Defense Department currently (1971) utilizes 7.7 percent of the U.S. petroleum products and 3.2 percent of the total U.S. energy consumption [1-8]. These are direct Department of Defense usage rates and do not include the energy utilized to manufacture weapons.)

This set of assumptions differs greatly from that adopted by most forecasters of the 1960's. However, it is believed to be more in keeping with the transitional phase that the country is going through with respect to energy utilization.

* References are at the end of each Chapter.

In order to place the forecast of total energy consumption in better perspective, curves A and B are shown in Figure 1-2 as extensions of Figure 1-1. Curve "A" represents a lower bound on projected energy consumption and is arrived at by multiplying the projected 1975 per capita energy consumption (371.4 x 10^6 Btu/year/capita) by the Series F (lower bound) population projections of the Bureau of the Census given in Table 1-2. Curve "B" represents an upper bound and is arrived at by multiplying the projected per capita energy consumption of the Department of Interior [1-9] by Series C (upper bound) population projection [1-1] of the Bureau of the Census from Table 1-2. The energy values thus obtained are shown in the bottom row of Table 1-1 and in Table 1-3.

Table 1-2. U.S. POPULATION PROJECTIONS[1] (10^3 PEOPLE)

Year	Series C	Series D	Series E	Series F
1950[2]	---152,300---			
1960[2]	---180,700---			
1970[2]	---204,879---			
1972[2]	---208,837---			
1975	215,872	215,324	213,925	213,378
1980	230,955	228,676	224,132	221,848
1985	248,711	243,935	235,701	230,913
1990	266,238	258,692	246,639	239,084
1995	282,766	272,211	256,015	245,591
2000	300,406	285,969	264,430	250,686
2005	321,025	301,397	273,053	255,209
2010	344,094	318,156	281,968	259,332
2015	367,977	335,028	290,432	262,631
2020	392,030	351,368	297,746	264,564

[1]U. S. Bureau of the Census, Series P-25, No. 493, December 1972.
[2]Actual

Curve "C" on Figure 1-2, can be considered to be a target or a "planned growth curve". It is based upon a qualitative decision that assumptions C through G will exert sufficient downward pressure on the growth of per capita annual energy consumption so that it will increase only to 500 x 10^6 Btu by the year 2000. Analysis of Figure 1-3 shows that large per capita increases have only occurred during wartime. The annual per capita consumption was almost constant at about 190 x 10^6 Btu from 1910-1940 and relatively constant around 225 x 10^6 Btu from 1949-1955 at 248 x 10^6 Btu for 1956 to 1961. Figure 1-4 indicates

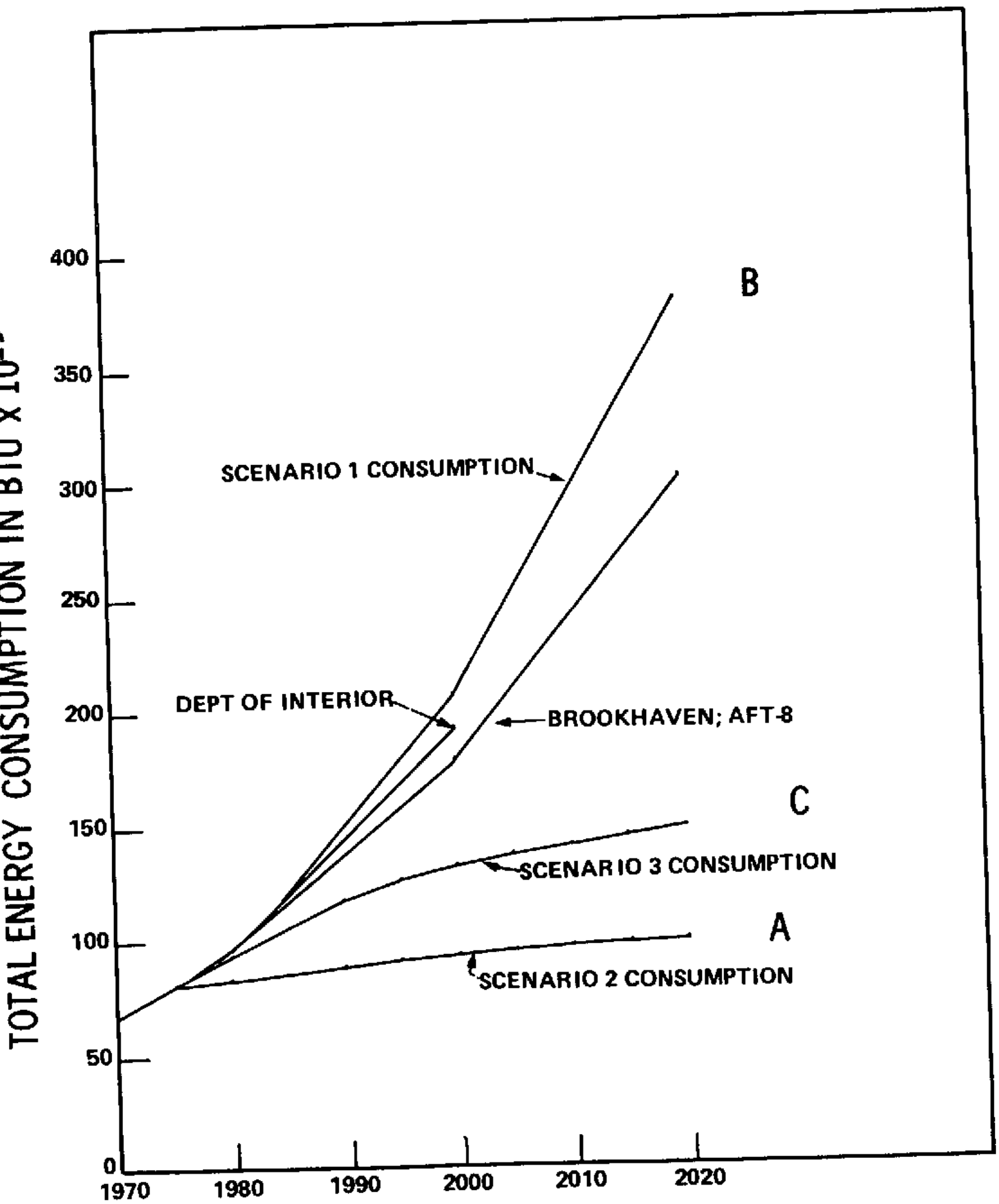


Figure 1-2. SCENARIO AND OTHER ENERGY PROJECTIONS

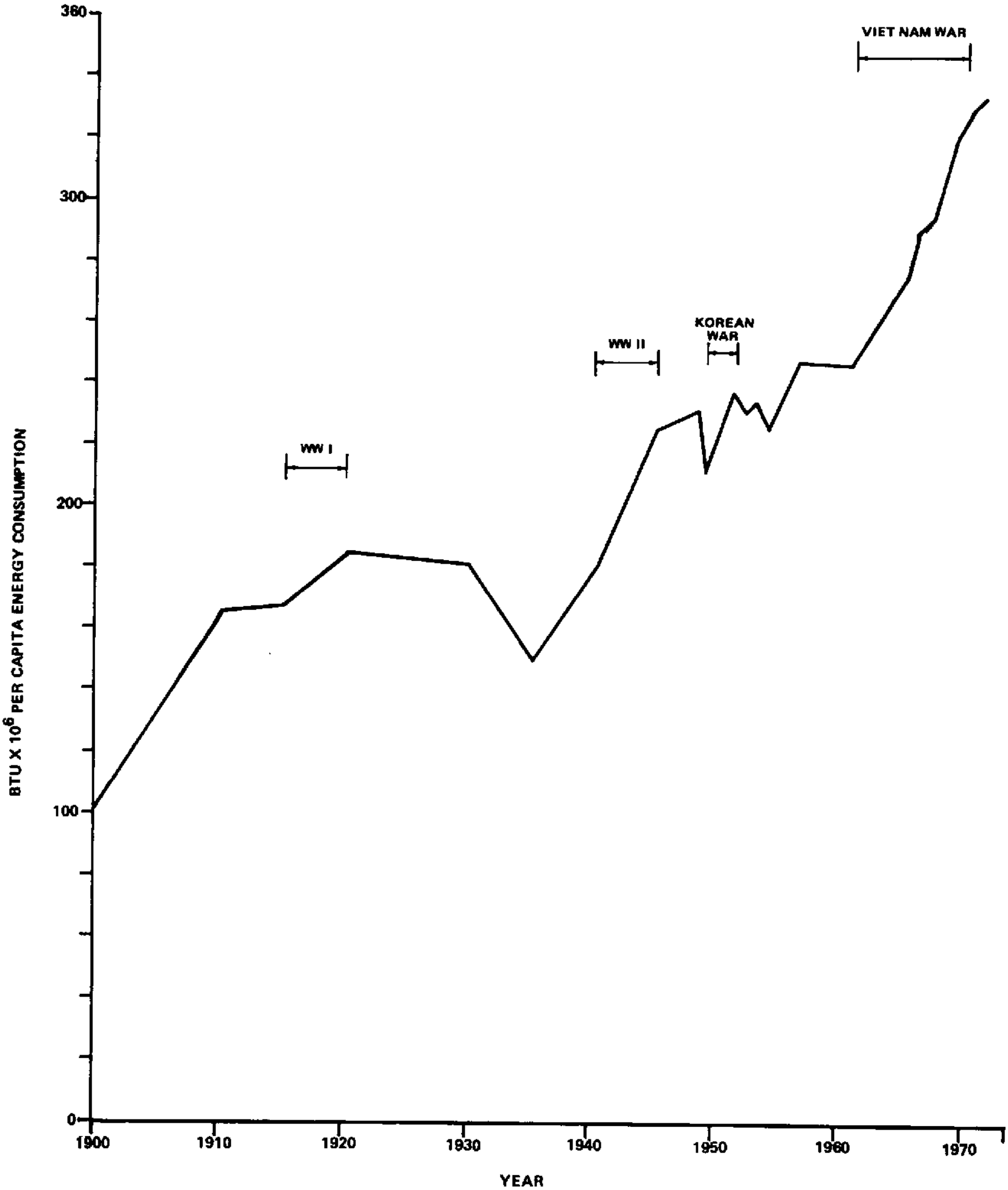


FIGURE 1-3.

TOTAL PER CAPITA ENERGY CONSUMPTION 1900 - 1971

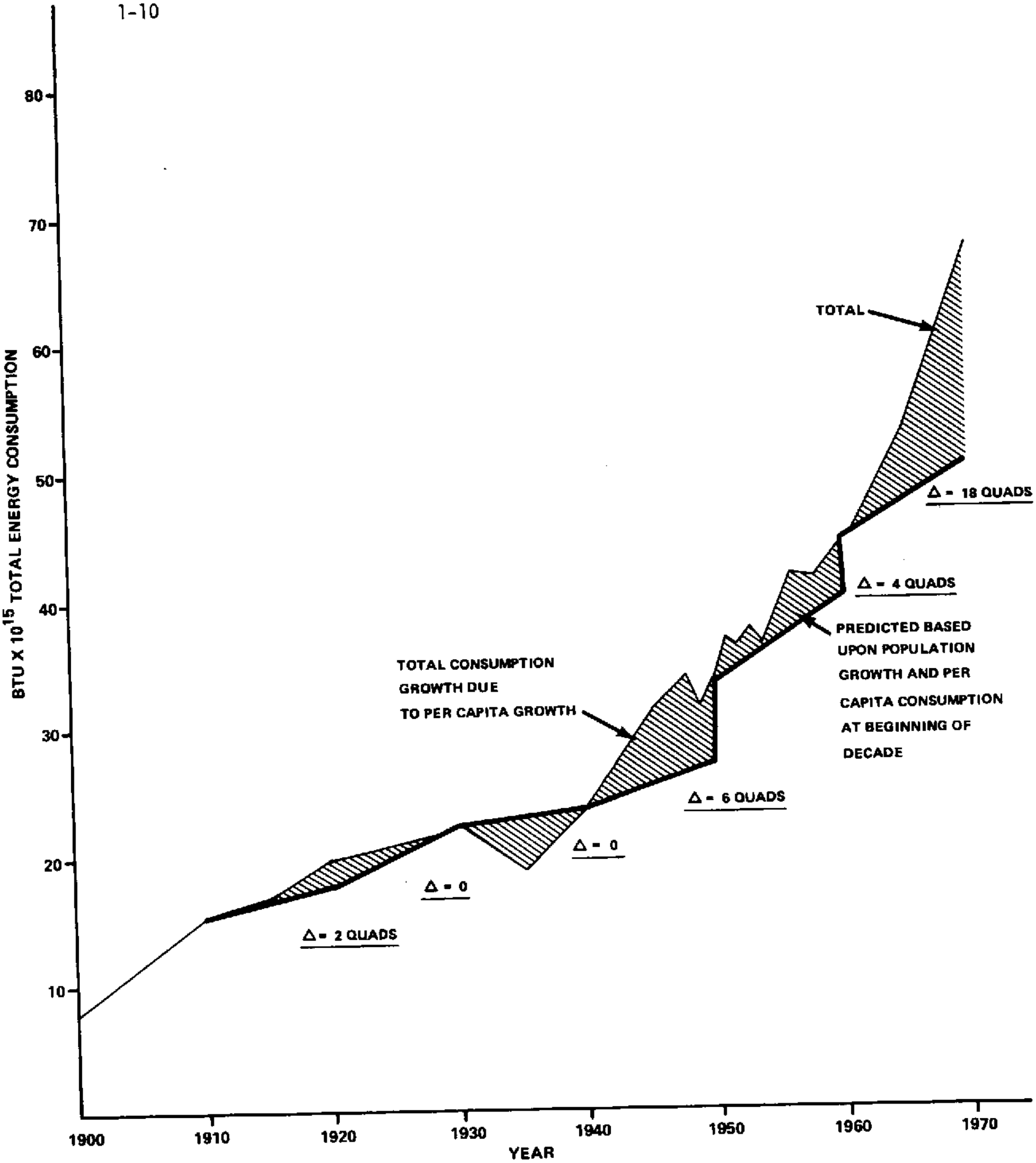


FIGURE 1-4.

TOTAL ENERGY CONSUMPTION VS. TIME IN YEARS

Table 1-3. ENERGY PROJECTION SCENARIOS (10^{15} Btu)

Year	Scenario 1[1] "Upper Bound"	Scenario 2[2] "Lower Bound"	Scenario 3[3] "Mid Course"
1971[4]	69.0	69.0	69.0
1975	80.2	79.7	79.7
1980	96.6	82.4	93.0
1985	119.2	85.8	106.0
1990		88.8	118.0
1995		91.2	126.0
2000	206.0	93.1	132.2
2005		94.8	136.5
2010		96.4	141.0
2015		97.5	145.2
2020	377.2	98.3	148.8

1. Using highest Bureau of Census projection (Series C, Dec., 1972) and projected per capita consumption.[5]

2. Using lowest Bureau of Census projection (Series F, Dec., 1972) and constant per capita consumption of 371.4 x 10^6 Btu/person[5] from year 1975 onward.

3. Using an intermediate Bureau of Census projection (Series E, Dec., 1972) and constant per capita consumption of 500 x 10^6 Btu/person[5] from year 2000 onward.

4. Actual

5. Includes fuel and non-fuel uses of fossil energy.

that even in these constant per capita consumption periods, the total energy consumption increased due to population increases. It is only in the war decades that growth has occurred due to large per capita consumption growths.

It should be emphasized that the 500 x 10^6 Btu per capita figure used in Scenario 3 is an increase of 50% over the 1971 figure.

The total energy consumption curve of this Scenario from 1900 to 2020 follows very closely the classic LOGISTIC of the Belgian mathematician Verhulst, which predicts 1975 as the point of maximum slope. Using an annual consumption of 79.7 (10^{15} Btu) in 1975 (building from zero at 1900), his curve would predict a maximum value of 159.4 Quads in the year 2020. The so-called logistic curve describes the manner in which nature limits animal population, and therefore is perhaps a guide to rational behavior for man. It is also interesting to note that with its present rate of increase, the United States is heading toward a zero population growth (ZPG) at approximately the year 2040 which is about the same year that we could reach a status of approximately zero energy growth (ZEG).

The figures in Table 1-3 show that the severity of the "Energy Crisis" depends significantly on which consumption curve the United States follows in the future. To place each projection in better perspective, a complete scenario for each of the three projections is presented below.

The assumptions common to all scenarios are:

- Commercial fusion reactors will have no significant effect on energy supply before the year 2020.
- Breeder reactors will be available commercially by the year 1990.
- No major wars with direct U.S. involvement will occur before the year 2020.
- The federal government will relax its restrictions on the price of natural gas in interstate commerce.
- Foreign oil and gas will be available, sometimes intermittantly, but the price will increase considerably as our demand increases.
- As the price of a fuel increases, relative to alternative fuels, its supply will become more elastic (the supply will increase), because the increased price will make exploration and production more attractive.

- The usage of domestic oil and gas which is recoverable at today's prices will be decreased to 10×10^{15} Btu/year by the year 2020 to conserve the remaining reserves for non-fuel uses (plastics, pharmaceuticals, asphalt, synthetic rubber, etc.) This policy would insure at least a 100 year reserve of domestic oil and gas for non-fuel uses beyond the year 2020.

- Hydropower cannot economically be made to supply more than 6×10^{15} Btu/year by 2020.

- Regardless of how much projected energy demand is reduced by the year 2020, R&D effort must be exerted toward the utilization of a variety of energy resources, including:

  a) Oil from shale
  b) Coal gasification and liquification (coal is now plentiful)
  c) Secondary and tertiary oil and gas recovery
  d) Solar power

  Even if these sources are not absolutely required by the year 2020, as in Scenario 2, emergencies may occur that could require such backup technology. This backup also may be required if the breeder reactor is delayed in development. Solar energy must be developed for two main reasons: (1) fossil fuels are finite, and (2) fusion may not be technically feasible for many years after 2020.

Scenario 1: Upper Bound on Consumption.

This scenario represented in Figure 1-5 and Table 1-4 assumes in addition to the above, that the projected consumption (gross total inputs) can be supplied through the year 2000 with the same allocation of energy sources as assumed by DOI [1-9], supplemented by geothermal and solar power and less-readily obtainable domestic oil.

Each energy source is projected to satisfy as much of the consumption as it possibly might, consistent with interactive system considerations of technology, politics, society, economics, and the environment. Thus: A further discussion of the assumptions used to allocate the energy sources follows:

- Hydropower will be pushed to its limit - 6 Quad.

- Geothermal power will be used to supply roughly half of that proposed in Table C-6, Appendix C in the "Intensive R&D Effort" column.

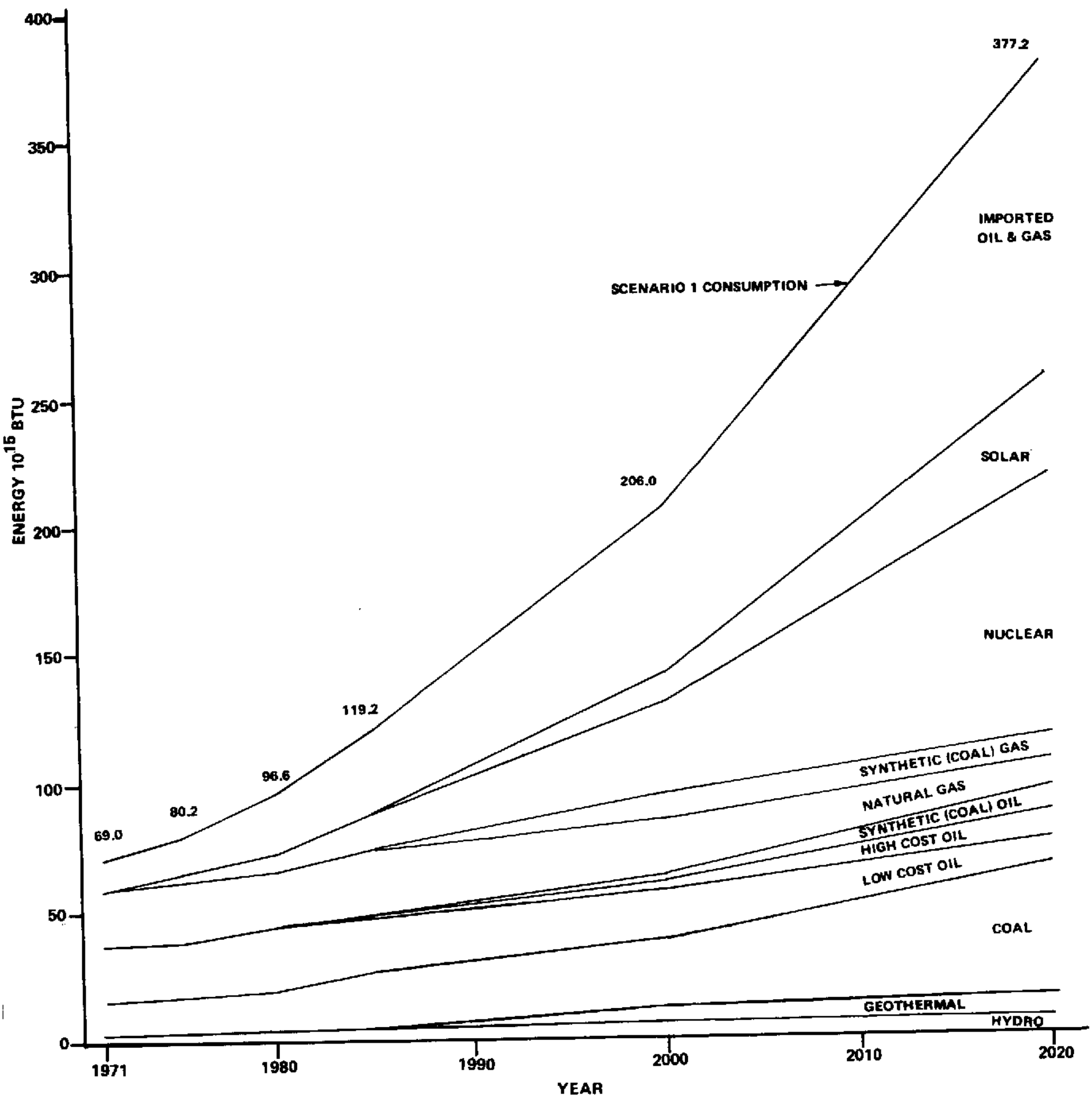


FIGURE 1-5

SCENARIO 1 (UPPER BOUND) CONSUMPTION AND SUPPLY

Table 1-4 SCENARIO 1 (UPPER BOUND) CONSUMPTION AND SUPPLY PROJECTIONS (10^{15} BTU)

Energy Source	1971	1975	1980	1985	2000	2020
Domestic						
Coal	12.6	13.8	15.4	19.5	25.9	50.0
Higher Grade Oil	22.6	22.1	23.8	22.6	19.2	10.0
Lower Grade Oil	-	-	-	1.0	5.0	10.0
Synthetic (coal) Oil	-	-	-	1.0	2.0	10.0
Natural Gas	21.8	22.6	23.0	22.5	22.9	10.0
Synthetic (coal) Gas	-	-	.7	2.0	5.5	10.0
Nuclear Power	.4	2.6	6.7	11.8	49.2	100.0
Hydropower	2.8	3.6	4.0	4.3	6.0	6.0
Geothermal Power	-	-	.5	2.0	5.0	10.0
Solar Power	-	-	-	.2	6.0	40.0
Subtotal	60.2	64.7	74.1	86.9	146.7	256.0
Foreign Imports						
Oil and Gas	8.8	15.5	22.5	32.3	59.3	121.2
Total	69.0	80.2	96.6	119.2	206.0	377.2

- Direct use of coal will be increased four-fold by 2020. Although pollution abatement devices will be well-developed long before 2020, they will still be expensive to buy and use and, hence, will discourage the use of coal to some degree. Strip mining legislation will hinder the mining of coal which will also discourage the use of coal.

- The use of presently recoverable (lower priced) domestic oil will be decreased to 10 Quads by 2020.

- Higher priced oil (off-shore, secondary recoverable, shale oil, etc.) will have to be used. Off-shore oil will not be developed as fast as technology would allow because of environmental pressures. Processes for commercially extracting oil from shale will become more economically viable because of technological advances and rising fuel prices.

- The production of 10 Quads of oil from coal will be commercially feasible by 2020.

- The use of domestic natural gas will be decreased to 10 Quads by 2020.

- Commercially obtaining 10 Quads of gas from coal will be economically feasible by 2020.

- To obtain 49.2 Quads of nuclear power (1200 gigawatts output) by year 2000 and 100 Quads (2500 gigawatt) by 2020 would require a major federal and societal effort, but it can be done. (Of course, building plants at this rapid rate increases the chances of a nuclear accident.)

- Solar power (which will be discussed in considerable detail in Chapter 8), although having potential for supplying more than 40 Quads of energy by the year 2020 as projected by the NSF/NASA panel [1-11], is limited in its growth because it has to compete for the limited R&D and capital investment funds available. Nuclear power and coal research having a greater impetus and an existing bureaucracy (AEC and Office of Coal Research) give them a greater advantage in obtaining governmental funds and private capital than does the fledging solar power "industry".

- Imports of gas and oil will have to increase from 8.8 Quads in 1971 to 121.2 Quads by 2020.

The probable impacts on the U.S. of Scenario 1 would be as follows:

- An energy crisis (and related crises) would truly occur.
- A major federal program in terms of legislation, R&D funding, taxation, financing, incentives, etc. would have to be developed to insure that this level of consumption could be supplied.
- Because of the large, crash R&D effort required to attain the levels of energy required from each source and because of the limited R&D funds available, non-energy R&D efforts would have to be curtailed.
- Investment capital would become extremely difficult to obtain. The Federal Reserve would have to relax deposit requirements and decrease interest rates. The federal government might have to establish priorities relative to who gets the available funds. The prospect of capital rationing will exist.
- Well over a trillion dollars in capital will be required to build just the nuclear plants projected prior to year 2020. To obtain this amount of money, utility rates will have to be revised to make the earnings of these companies much more attractive to investors than they presently are.
- The extremely large trade deficit incurred from importing large and ever-increasing amounts of oil and gas will cause the nation to be on the verge of international bankruptcy by 2020.
- Most non-fuel exports from other nations will be too expensive for U.S. consumption because of the extreme devaluation of the U.S. dollar. Our exports will not keep up with our GNP because, although our goods will be competitive in foreign markets, these other nations will have advanced their products to the point where our products are less attractive.
- The amount of natural resources required merely to construct and fuel new energy plants would severely deplete many of the already limited U.S. reserves.
- The manufacturing capability of many U.S. industries (mining, steel, aluminium, copper, glass, fabrication, and construction) will have to be increased greatly to provide the materials for these plants.

- The pollution standards for burning fossil fuels will have to be relaxed initially until anti-pollution devices can be developed and installed. Also nuclear waste storage will become an increasingly touchy problem and will probably not be resolved before 2020.
- The large quantity of imported oil and gas required will necessitate the building of a large fleet of super-tankers and several deep-water ports at a tremendous expense. Roughly 550 super-tankers (250,000 DWT each) will have to be built by the year 2000 [1-12], and twice that many by 2020. We have none now and we cannot rely on foreign tankers solely, from an economic, reliability and defense point of view, to handle this load in the future.

This list of impacts could be expanded, but it should be clear by now the insanity of proposing to maintain the present per capita consumption growth rate. While this rate of increase could be maintained for some time, it must eventually decline because of the impacts described above.

Scenario 2: Lower Bound on Consumption.

Under this scenario, the projected energy consumption is supplied by the energy resources as allocated in Figure 1-6 and Table 1-5. This allocation is assumed to be as forced as in Scenario 1 but to have less deleterious economic, societal and environmental effects.

A more detailed discussion of the assumptions used in this scenario are as follows:

- Hydropower is not pushed to its limit, as in Scenario 1, but is leveled off to 5 Quads by the year 2000.
- Geothermal power is kept at the lower level of development as shown in Table C-6 , Appendix C.
- Direct coal use is expanded slowly to double its present value by 2020.
- Presently recoverable (lower priced) oil use is eventually decreased to 10 Quads by 2020.
- Although not needed in this scenario, some higher priced oil (off-shore, shale oil, etc.) is used to advance the required technology.
- Coal liquification, although not essential, is also available through advances in technology.

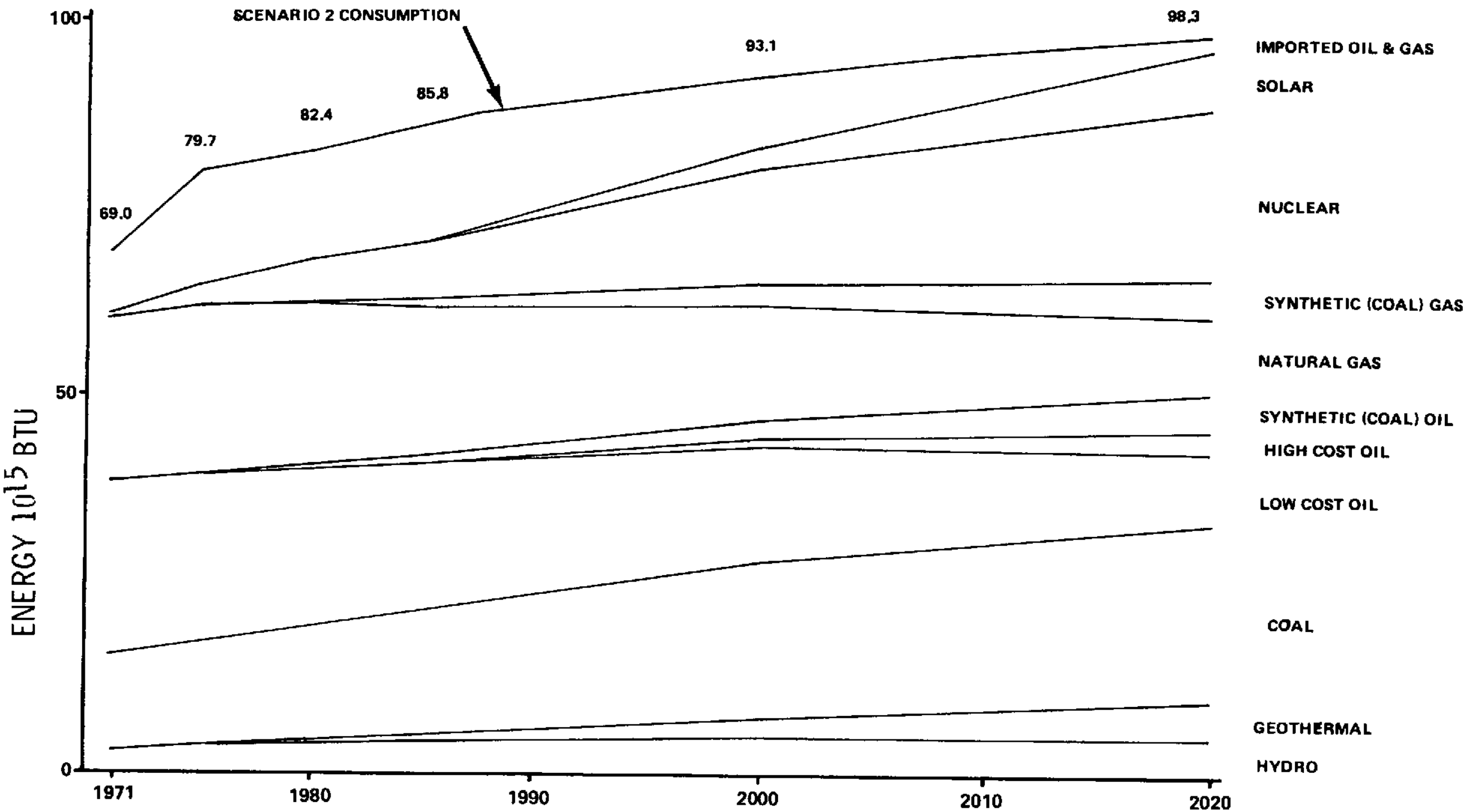


FIGURE I 6.
SCENARIO 2 (LOWER BOUND) CONSUMPTION AND SUPPLY

Table 1-5 SCENARIO 2 (LOWER BOUND) CONSUMPTION AND SUPPLY PROJECTIONS (10^{15} BTU)

Energy Source	1971	1975	1980	1985	2000	2020
Domestic						
Coal	12.6	13.8	15.0	16.2	19.9	23.0
Higher Grade Oil	22.6	22.1	20.8	19.5	15.5	10.0
Lower Grade Oil	-	-	-	-	1.0	3.0
Synthetic (coal) Oil	-	-	.5	1.0	2.5	5.0
Natural Gas	21.8	22.6	21.2	19.8	15.6	10.0
Synthetic (coal) Gas	-	-	.5	1.0	2.5	5.0
Nuclear Power	.4	2.6	6.7	10.0	15.1	23.0
Hydropower	2.8	3.6	4.0	4.3	5.0	5.0
Geothermal Power	-	-	.3	.6	2.5	5.0
Solar Power	-	-	-	.1	3.0	8.0
Subtotal	60.2	64.7	69.0	72.5	82.6	97.0
Foreign Imports						
Oil and Gas	8.8	15.0	13.4	13.3	10.5	1.3
Total	69.0	79.7	82.4	85.8	93.1	98.3

- Natural gas usage will be decreased to 10 Quads by 2020.
- Coal gasification, again, not needed, but available.
- Nuclear power plants will be built at a fairly slow rate, 23 Quads (560 gigawatts) by the year 2020. However, through 1985 our nuclear power expansion has been more or less committed.
- Solar energy will make a small contribution of 8 Quads.
- Imports will double by 1975 but will eventually taper off to 1.3 Quads by 2020.

The probable impacts of the above consumption/supply assumptions are as follows:

- No energy crisis would exist in the long run. The presently impending oil and gas import problem will grow somewhat worse by 1975 and then taper off by 2020 when 1.3 Quads must be obtained from imports. (The present oil and gas problem could be managed by a modest, crash, governmental conservation program).
- This scenario may be no less forced than Scenario 1, but its effects are much less drastic. This scenario would require considerable control in two areas:

  a) Population: to assure that we follow the lower population curve, a moderately increased birth control program would be required. More stringent immigration policies could force this now.

  b) Per Capita Consumption: to keep this constant at 371.4×10^6 Btu/year would require strong federal control - probably fuel rationing.

- Fixed per capita consumption at the 371.4×10^6 Btu/year could put a serious damper on GNP and industrial growth - possibly even effect large scale, emergency defense efforts. The increase in the rise of our standards of living could be retarded somewhat.

  Considerable conservation of energy (decreased usage and increased efficiency) would be essential to assure growth in many areas.

- The trade deficit in oil and gas would not be overly burdensome and could be managed during its short duration.

- Nuclear power will be installed slowly enough so that sufficient time is available to solve the waste storage problems.
- The R&D required to perfect shale oil extraction, coal gasification, and liquification, geothermal power and solar power will be done at a "leisurely" rate, as compared to Scenario 1, and will not require a major crash R&D effort. Present federal R&D funding levels could support our needs.
- The level of imports will require only a small investment in super-tankers and one or two deep-water ports.
- Manufacturing industries and natural resources will not be pushed to meet this demand.
- Pollution levels thus produced can easily be controlled.

Scenario 3: Rational Mid-Course Consumption - Planned Growth.

The allocation of the supply sources in this scenario, shown in Figure 1-7 and Table 1-6, is entirely feasible and will have a stabilizing effect on society and the environment. An interactive systems approach (considering technology, economics, politics, society and the environment) was used to make the allocations of energy sources. These, briefly, are as follows:

- Hydropower will not be developed to its ultimate limit, but will level off at 5 Quads by the year 2020.
- Geothermal power will increase only to the lower level of output as shown in Table C-6 , Appendix C.
- Direct coal use will be expanded to slightly less than three times its 1971 usage, its highest rate of growth occurring between 1985 and 2000.
- The usage of presently recoverable (lower cost) oil will decrease to 10 Quads by 2020.
- Extraction of the more costly oil (off-shore, shale, secondary recovery, etc.) will increase to 8 Quads.
- Coal liquefication R&D will be prodded to produce 8 Quads by 2020.
- Natural gas usage will decrease eventually to 10 Quads
- Coal gasification will provide 8.5 Quads by 2020.

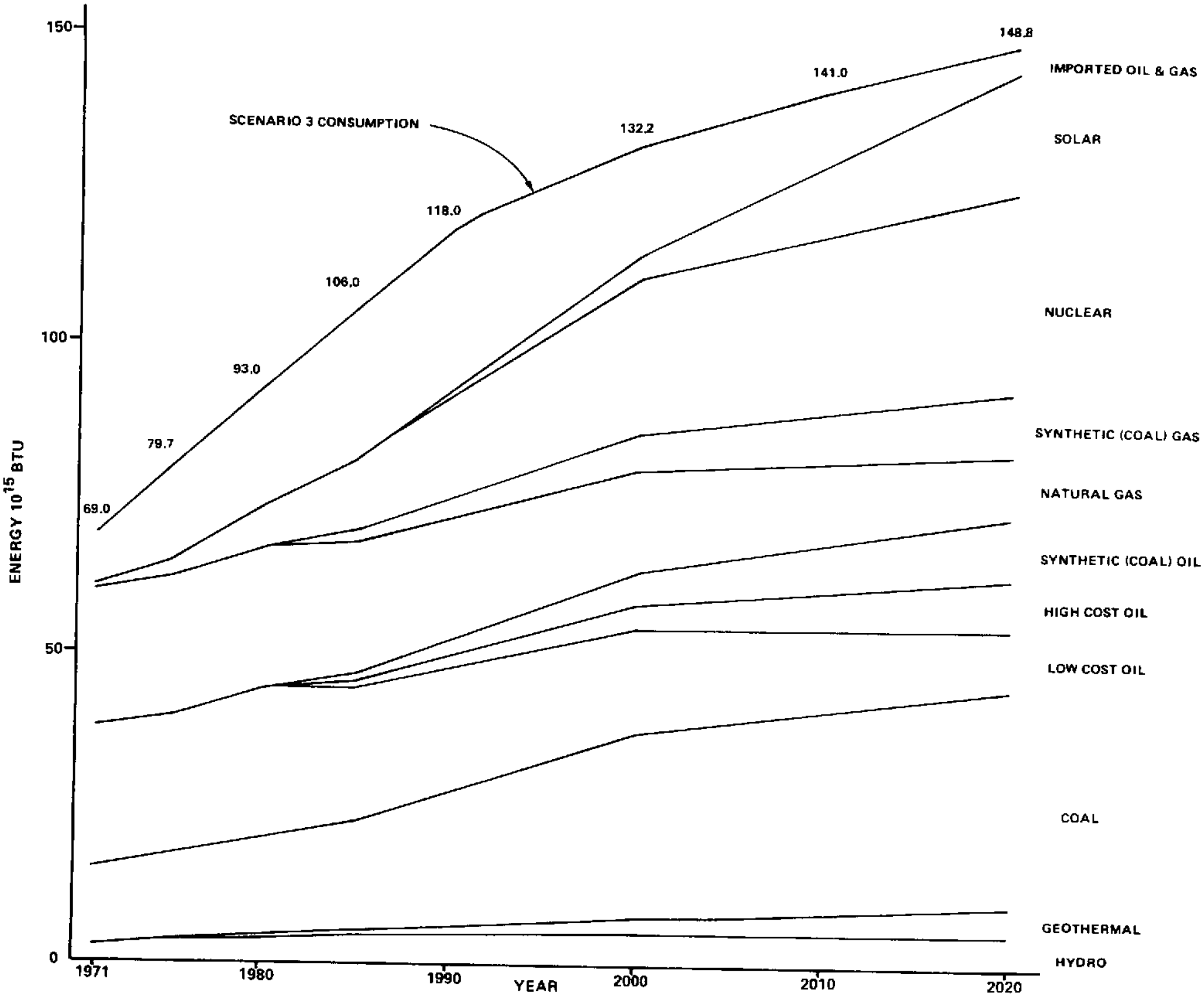


FIGURE I-7 SCENARIO 3 (RATIONAL) CONSUMPTION AND SUPPLY

Table 1-6 SCENARIO 3 (MID-COURSE) CONSUMPTION AND SUPPLY PROJECTIONS (10^{15} BTU)

Energy Source	1971	1975	1980	1985	2000	2020
Domestic						
Coal	12.6	13.8	15.4	17.9	30.2	35.0
Higher Grade Oil	22.6	22.1	23.8	22.1	16.9	10.0
Lower Grade Oil	-	-	-	1.0	4.0	8.0
Synthetic (coal) Oil	-	-	-	1.3	5.1	8.0
Natural Gas	21.8	22.6	23.0	21.4	16.5	10.0
Synthetic (coal) Gas	-	-	.7	2.0	5.4	8.5
Nuclear Power	.4	2.6	6.7	10.9	25.5	35.0
Hydropower	2.8	3.6	4.0	4.3	5.0	5.0
Geothermal Power	-	-	.3	.6	2.5	5.0
Solar Power	-	-	-	.1	3.5	20.0
Subtotal	60.2	64.7	73.9	81.6	114.6	144.5
Foreign Imports						
Oil and Gas	8.8	15.0	19.1	24.7	17.6	4.3
Total	69.0	79.7	93.0	100.0	132.2	148.8

- Nuclear power capability will be moderately increased to 25.5 Quads by the year 2000 (only 52% of that projected by DOI [1-9]) and to 35 quads by 2020.

- Solar power will be slowly increased to 3.5 Quads by 2000 and then fairly rapidly increased to 20 Quads by 2020, as R&D efforts bear fruit.

- Imports of oil and gas will triple by 1985, but will then decline to 4.3 Quads by the year 2020.

The probable impacts of Scenario 3 are as follows:

- Since per capita consumption increases to 500 x 10^6 Btu/year (a 50% increase over the 1971 figure) by the year 2000:

  a) High energy users could at least maintain their usage (saturation is almost reached by many in this group now) and low energy users would be able to increase their usage - a redistribution would not be necessary as there would be in Scenario 2.

  b) Industrial growth would not be stifled. However, improved conservation of energy would be advantageous to the industries themselves.

- The moderate amount of R&D funding and capital investment which would be required would not necessitate a major, national crash energy program with its associated legislation, funding, taxation, etc. as Scenario 1.

  However, the federal government would be required to moderately increase its efforts in the areas of R&D funding, particularly in the areas of coal gasification and liquification, nuclear power (breeder and fusion) and solar power.

- The rate of expansion in the use of all energy sources can be managed without any crash programs in industry - industry can grow naturally at this rate with proper planning.

- This scenario's occurence does not depend on any major technical breakthroughs, since all processes are now technically feasible and will only require moderate government funding to become economically feasible.

- Our material resources, fuels and construction materials would not be overly taxed. Nevertheless, increased conservation should be encouraged.

- The oil and gas import requirements will grow worse until 1985. Because of the built-in momentum of U.S. energy growth, only drastic governmental intervention with consequent disruption of the economy, could prevent this use of imports. They will start to decline after 1985 when increased coal and nuclear power will be made available through the results of present R&D efforts.

  Up through the year 2000, the U.S. should build supertankers and deep-water ports at a modest rate, using foreign tankers to handle most of the needs until then. Then, by the year 2020, when the import needs are small, the U.S. will have a more than adequate fleet of its own to handle the normal needs and contingencies. (if, on the contrary, the U.S. builds as large a fleet as contemplated in Scenario 1 and advocated by some spokesmen, it would have, by the year 2020, a mammouth fleet of white elephants.)

- Expanding energy usage at this moderate rate will allow pollution-abatement devices to be perfected and economized without resorting to an expensive crash program as is required in Scenario 1.

Based upon consideration of these three scenarios, it is the opinion of this group that a national energy policy for the United States be drafted which promotes a rational, conservation oriented, utilization of energy such as described in Scenario 3.

REFERENCES

1-1. Population Estimates and Projections, U.S. Department of Commerce, Bureau of the Census, Series P-25, No. 493, December, 1972.

1-2. Message from the President of the United States to the Congress Concerning Energy Resources, April 18, 1973, 93rd Congress, First Session, House Document Number 93-85.

1-3. Summary Report of the Cornell Workshop on Energy and the Environment, Committee Print, Feb. 22-24, 1972, p. 153.

1-4. The 1970 National Power Survey, Federal Power Commission, Part I, December, 1971.

1-5. Nash, R. T. and Williamson, J. W., "Energy Use in the United States 1880-1966", Fuels, February, 1972.

1-6. Mount, J. J; Chapman, L. D. and Tyrrell, T. J., "Electricity Demand in the United States an Econometric Analysis", Oak Ridge National Laboratory, ORNL-NSF-EP-49, June, 1971.

1-7. Chapman, D; Tyrrell, T. and Mount, T., "Electricity Demand Growth and the Energy Crisis", Science, Vol. 178, No. 4062, Nov. 17, 1972.

1-8. Sullivan, R. W., et. al., "A Brief Overview of the Energy Requirements of the Department of Defense", Battelle Columbus Laboratories, August, 1972.

1-9. Dupree, W. G., Jr. and West, J. A., United States Energy Through the Year 2000, United Stated Department of the Interior, J. S., Government Printing Office, Washington, D. C., 1972, 66 pages.

1-10. Geothermal Energy Resources and Research, Hearings before the Committee on Internal and Insular Affairs of the United States Senate, Serial No. 92-31, June 15 and 22, 1972.

1-11. Solar Energy as a National Energy Resource, NSF/NASA Solar Energy Panel, Dec., 1972.

1-12. Lees, L., "Why the Energy Crunch Came in the '70's", Foreign Policy Implications of the Energy Crisis, Hearings before the Subcommittee on Foreign Economic Policy, 92nd Congress, 2nd Session, September 21, 26, 27, October 3, 1972.

N74-12676

CHAPTER 2. ENERGY AND RESOURCE CONSUMPTION

Having established that the demand for energy in the U.S. will continue to rise for many years in the future, a look at the ways that this demanded energy is used will help in determining the way or ways in which it must be provided, and perhaps also provide some insight into what must be done to insure that maximum benefit from the use of this energy is obtained.

Information on this subject is limited in both quantity and quality and as a result any study of end-use consumption is at best subject to various errors of approximation. Notable among recent literature resources is the comprehensive study performed by the Office of Science and Technology which focuses on developments in energy consumption between 1960 and 1970 [1]. Basic "raw" information is reported in various sources. Examples are: U.S. Bureau of the Census, Statistical Abstracts of the U.S. and the U.S. Bureau of Mines energy consumption data.

For simplification of discussion the following various end-use sectors of energy in the U.S. will be considered:

- Industrial (including manufacturing)
- Residential
- Commercial (including institutions)
- Transportation

2-1. TOTAL ENERGY END USE BY SECTOR

Fuel quantities and electric power consumption are here characterized by a common unit of energy, the British Thermal Unit (Btu). In the case of electric power, the Btu equivalent is the heating value of the fossil fuel supplied to the electric generating station. The figures therefore include generation, conversion and distribution losses as well as the energy supplied to the consumer.

The most recent analysis of total energy consumption in the U.S. is for the year 1968. The breakdown sector is: [2-1]

	Consumption (Quads)	Growth Rate (Percent)	Percent of Total
Residential	11.6	4.8	19.2
Industrial	25.0	3.9	41.2
Commercial	8.8	5.4	14.4
Transportation	15.2	4.1	25.2

Of the more than 100 identifiable uses of energy, only a few applications collectively account for a significant proportion of total energy consumption. Listed below are the significant end uses: [2-1]

End Use	Percentage of Total
Transportation (fuel; excludes lubricants)	24.9
Space heating (residential, commercial)	17.9
Process steam (industrial)	16.7
Direct heat (industrial)	11.5
Raw materials, feedstocks	7.9
Electric drive (industrial)	5.5
Water heating (residential, commercial)	4.0
Air conditioning (residential, commercial)	2.5
Refrigeration (residential, commercial)	2.2
Lighting (residential, commercial)	1.5
Cooking (residential, commercial)	1.3
Electrolytic processes (industrial)	1.2
Other (individual uses less than one percent)	2.9
Total	100.0

It is most significant to note that the first 5 categories account for over three-fourths (78.9 percent) of the total energy consumption.

Industrial/Manufacturing End Use of Energy. Industrial use of energy accounts for 41.2 percent or 25 quads of the total energy consumption in the United States. Analysis of patterns of end-use consumption is based on the Standard Industrial Classification. The industrial sector is divided into 20 major end use groups. Six groups in this classification account for two-thirds of the industrial consumption of energy: [2-1]

Industrial Group	Percent of Total
Primary metal	12.2
Chemicals and allied products	20.0
Petroleum refining	11.3
Food processing	5.3
Paper	5.2
Stone, clay, glass, concrete	4.9
Sub total	67.7
All other industries	32.3
Total	100.0

Residential End Use of Energy. The residential sector accounts for 19.2 percent or 11.6 quads of the total energy consumption in the United States. Figure 2-1 indicates the distribution to the various end-uses. The relative percentage of various end uses is:

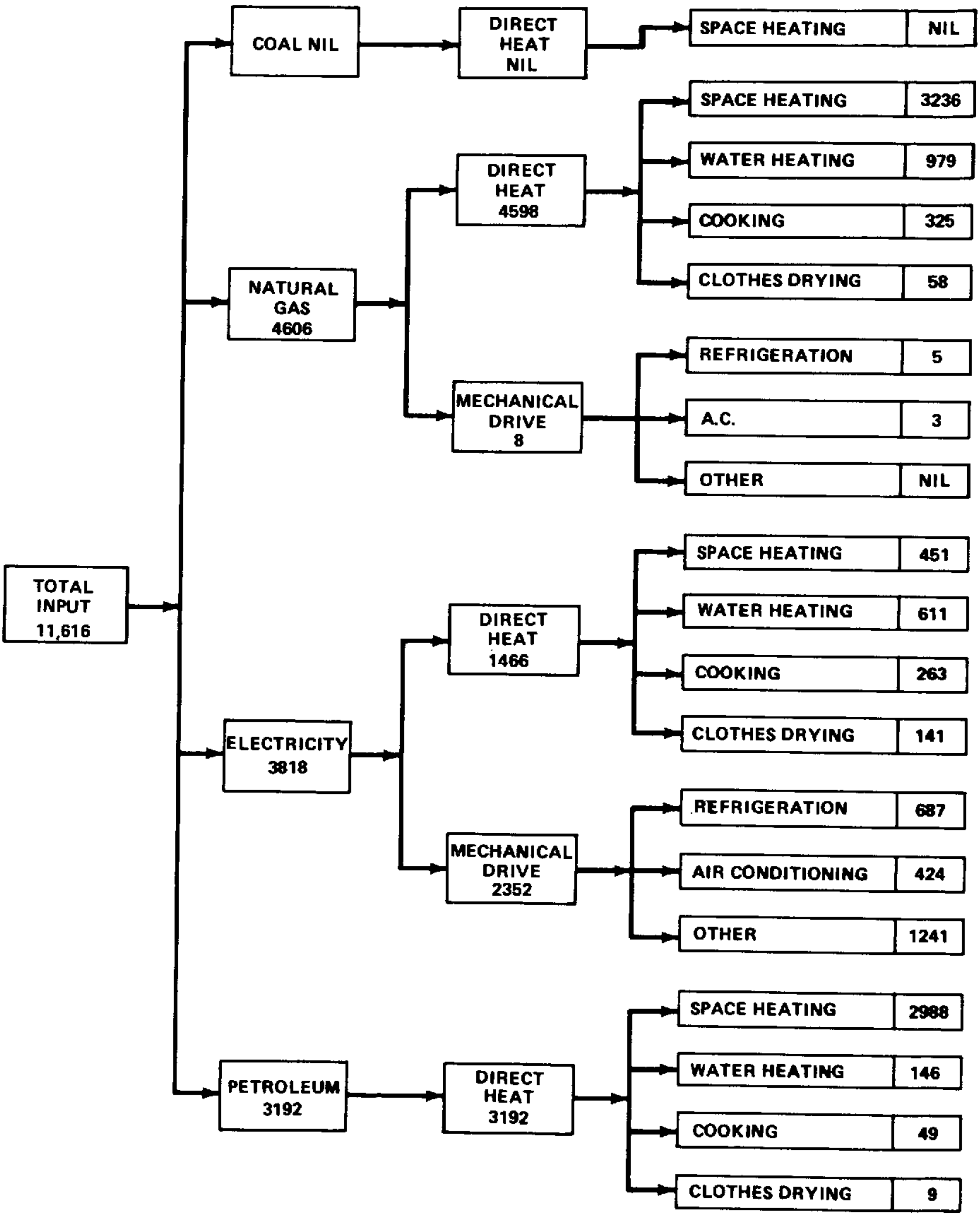


Figure 2-1. RESIDENTIAL END USE OF ENERGY
(Trillions, 10^{12} Btu)

End Use	Percent of Total
Space heating	57.5
Water heating	14.9
Cooking	5.5
Refrigeration	6.0
Air Conditioning	3.7
Television	3.0
Clothes Drying	1.7
Food Freezing	1.9
Other	5.8
Total	100.0%

Commercial/Institutional End Use of Energy. The Commercial/Institutional sector is an agglomeration of various unrelated activities: wholesale and retail trade, hotels, health services, schools, museums, art galleries and all government institutions.

Consumption of energy in this sector accounts for 14.4 percent or 8.8 quad of the total U.S. energy consumption. As in the residential sector, a major reason for the increased commercial share of energy is due to the growing use of electricity and its associated conversion losses.

Again, as in the residential sector, space heating, water heating and space cooling (air conditioning) accounts for between 2/3 and 3/4 of the energy use in the sector. The "other" category includes such items as lighting, mechanical drive (computers, escalators, office machinery, etc.) and perhaps electric heat. The relative amount in each category is:

End Use	Percent of Total
Space heating	47.7
Asphalt and road oils	11.2
Space cooling	12.7
Water heating	7.5
Refrigeration	7.6
Cooking	1.6
Other	11.7
	100.0

Transportation End Use of Energy. The transportation sector accounts for 15.2 quad or 25.1 percent of total U.S. energy consumption. The relative quad importance of individual fuels is shown in the following:

Fuel	Percent of Total
Coal	nil
Natural gas	4
L. P. G.	1
Jet fuels	13
Gasoline	68
Distillate fuel	8
Residual fuel	5
Lubricants	1
Electricity	nil
Total	100%

Energy End Use for Creature Comfort. Since the time man discovered that fire would warm his cave he has worked toward maintaining his living and working habitat at a "comfortable" level at all times. Included in the "comfortable" level is bathing and laundering in water at other than "stream temperature". Although space cooling is at present a small part of the energy used for internal environmental control, statistics show that it is growing at a very rapid rate.

Space Heating. Space heating for residential, commercial, and industrial sectors is the largest single end use of energy. The total is close to 20 percent, with a growth rate of 4 percent per year which approximates that for all energy growth.

Water Heating. Water heating accounts for 4 percent of total energy consumption. Water heating is growing at 5.2 percent per year in the residential sector and 2.3 percent per year in the commercial sector.

Space Cooling. Air conditioning, or space cooling, amounts to 2.5 percent of the total energy demand but the growth rate is 10.2 percent per year.

Sector End Use Predictions. When one looks at energy consumption statistics for the year 1970 it is seen that usage is approximately divided equally between residential and commercial, industrial, transportation and electricity producing utilities[2-1]. As the total energy consumption curve follows its predicted rise, residential consumption total volume stays relatively uniform, industrial decreases somewhat but transportation and electrical generation usage increases greatly. Figure 2-2 shows the predicted pattern while the following tabulation shows the differences in the 30 year span:[2-1, 2-3]

End Use Sector	1970 Percentage	2000 Percentage
Residential and Commercial	20.4	12.2
Industrial	31.7	9.0
Transportation	24.0	36.0
Electrical Generation	23.9	42.8

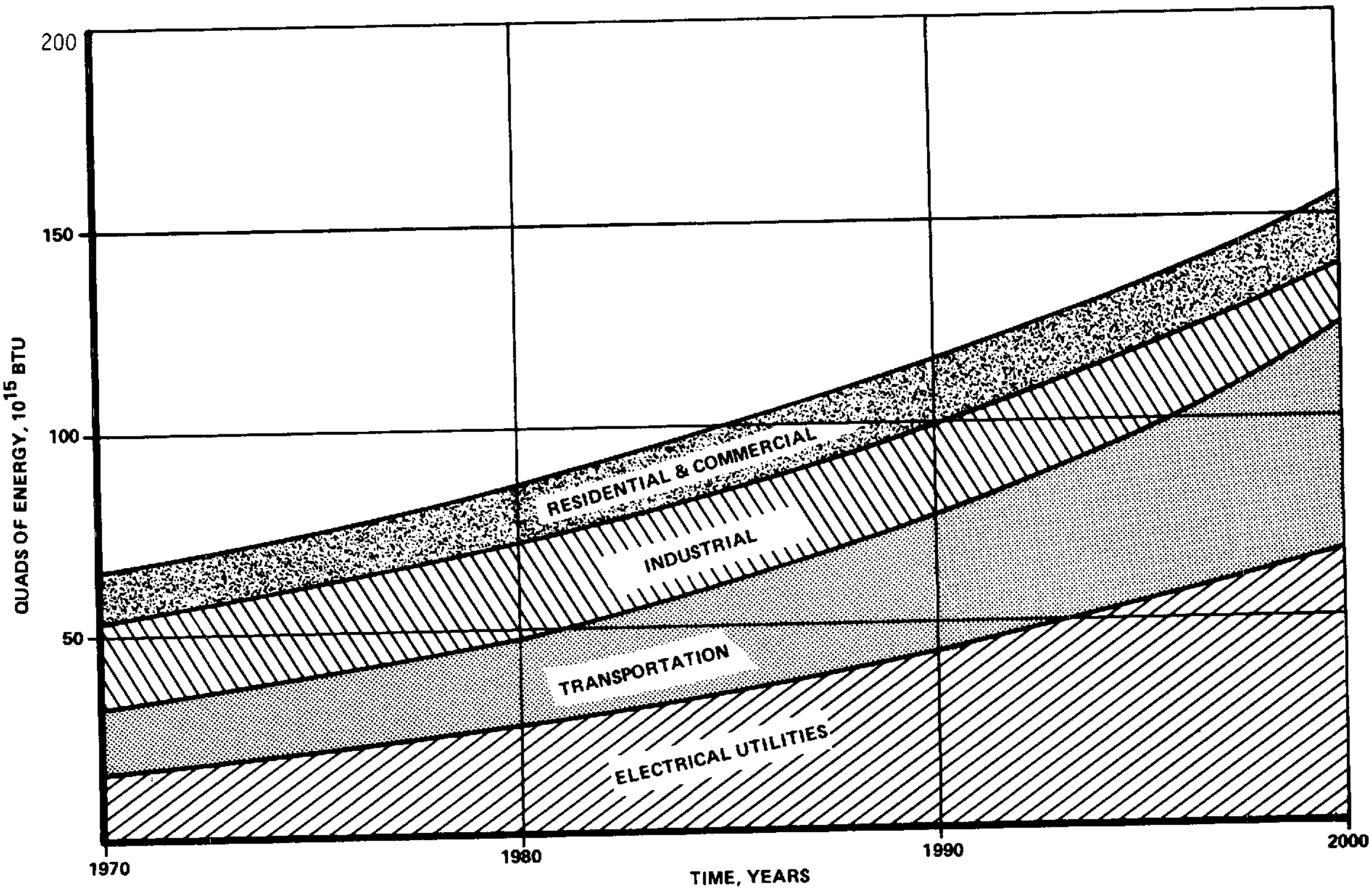


FIGURE 2-2. TOTAL ENERGY CONSUMPTION BY USER 1970-2000

It must be kept in mind that although the electrical generating utilities appear to be using a larger and larger segment of energy producing resources, the energy they transform is used mainly by the Residential, Commercial and Industrial consumers. Therefore it is unfair to label the electrical generating utilities as "the bad guys" because everyone is using the energy they produce.

2-2. OTHER DEMANDS FOR CURRENT ENERGY

The energy consumption and demand sectors of the U.S. have been divided into the categories: residential and commercial, transportation, industrial and electrical generation (utilities). All sectors except electrical generation utilize varying amounts of fossil fuel resources for non-energy purposes. Listed below are the three identifiable non-energy use sectors of the U.S. with the end uses identified.

Residential and Commercial

- Asphalt
- Road Oil

Industrial

- Special Napthas
- Lubricants
- Waxes
- Petroleum Coke
- Petrochemical Feedstock Offtake

Transportation

- Lubricants
- Waxes

The highest percentage of non-energy use by sector is industrial with 71.3%. The household and commercial sector uses 28.4% and transportation about 0.3%. From the industrial sector, the "petrochemical feedstock off-take" is the major raw material input for the manufacture of products that play an important role in our present life-style. Among these products are plastics, building materials, fertilizers, cosmetics, and medicines (drugs). New technologies can undoubtedly satisfy man's energy demands after our fossil fuels are gone, but the raw material for these petrochemical products will be obtained only at a greatly increased, perhaps prohibitive, cost. Table 2-1 is a summary of the projected fossil fuel demands for non-energy uses, and the percentage of the total fossil fuel used for non-energy purposes, from Dupree and West [2-2]. Their underlying assumptions are:

- The population growth rate will be one percent. This is the midpoint of the D and E series (Chapter 1) estimated by the Bureau of Census.
- Industrial production will increase at a rate of five percent annually until 1980, and at 4.4 percent thereafter.

Table 2-1. PROJECTED NON-ENERGY CONSUMPTION OF FOSSIL RESOURCES [2-2]

	Bitumious Coal and Lignite		Petroleum		Natural Gas		Total		
Year	Non Energy Use(b)	% of Total Coal	Non Energy Use(b)	% of Total Petroleum	Non Energy Use(b)	% of Total Natural Gas	Non Energy use(b)	% of Total Fossil Fuels	% of Total Energy(c)
1973 (a)	0.14	1.1	3.4	10.5	0.69	2.9	4.30	6.0	5.7
1975	0.15	1.1	3.80	10.8	0.70	2.8	4.65	6.3	5.8
1980	0.20	1.2	4.46	10.6	0.75	2.8	5.41	6.3	5.6
1985	0.33	1.5	4.85	9.6	0.80	2.8	6.35	6.3	5.4
2000	1.40	4.5	8.44	11.8	0.90	2.6	10.74	7.8	5.6

(a) Extraplolated from 1971 data and projected 1975 data

(b) 10^{15} Btu Equivalent

(c) Total energy used by U.S., all sources

- The supply of fossil fuels will be limited by various factors. The forecast takes into consideration all supply limitations for fuels. It is, therefore, a forecast of consumption rather than demand.

- The only major change in energy technology between now and 1985 will be the development of commercial techniques for coal gasification and liquefaction and control of sulfur oxide emissions. Only evolutionary increases in the efficiency of utilization of energy were assumed. The major technological change expected between 1985 and 2000 is the commercial introduction of the breeder reactor.

- The present slow trend toward a more service-oriented economy will continue. The impact on energy consumption is considered minimal.

Conclusion. The only conclusion that can be arrived at from the preceeding documentation is that the U.S. as a nation uses an enormous amount of energy in its lifestyle. Both emphasize the fact that all possible sources of energy must be utilized and that the efficiency of transformation, distribution and utilization must be taken to the highest possible value. There are many ways of generating energy that the U.S. could utilize. Some of these are practical and some are not. But, whether or not the production method is "practical" depends on the degree of necessity.

REFERENCES

2-1. -----Patterns of Energy Consumption in the United States, Office of Science and Technology, Executive Office of the President, Washington, D.C., 1972.

2-2. Dupree, W. G., Jr., and West, J. A., United States Energy Through The Year 2000, United States Department of the Interior, U.S. Government Printing Office, Washington, D.C., 1972.

2-3. -----The U.S. Energy Problem, Appendix A, InterTechnology Corporation, Warrenton, Virginia, 1971. Distributed by National Technical Information Service, Springfield, Virginia.

N74-12677

CHAPTER 3. ENERGY RESOURCES

The previous chapter has drawn attention to the importance of the preservation of fossil resources for non-energy uses in maintaining our present standard of living. Of more growing concern is the inherent danger in the continuing exponential growth in energy demands consuming our non-renewable fossil resources. When considering the desirability of efforts to reduce the growth rate of our energy consumption, a major point is the adequacy of our resource base - both domestic and foreign - for supplying our requirements.

3-1. FOSSIL FUELS - DOMESTIC

The determination of the quantity of fossil fuel resources for energy is not a simple one, since most of these materials lie hidden in the earth. Adding to the complexity of the problem is the fact that the amounts recoverable are constantly changing as the advance of technology permits recovery of energy materials that were once too low grade or too inaccessible to mine, and utilization of materials that were not previously conceived as economical sources of energy.

The concept that supplies of usable fossil fuel resources are extended by the advance of technology provides three conclusions pertinent to preparation of resource estimates: (1) Even though resource estimates are prepared, they can never represent a final inventory of the amount of the resource in question, but are at best a quotation reflecting the status of knowledge of resources at the time the estimates are made; (2) in making and interpreting estimates of fossil fuel resources, it is necessary to differentiate between deposits that are known and closely appraised and those that are either not closely appraised or are not as yet discovered but are believed to exist on the basis of geological evidence; (3) it is necessary to distinguish between deposits that are minable or recoverable at present costs and those that cannot be mined now but might be recovered under more favorable economic or technological conditions.

In Table 3-1, Perry's classification [3-1] is used to tabulate fossil fuel resources of the United States. Natural gas liquids and oil in bituminous rocks represent a small percentage of our total fossil fuel resources. Shale oil will represent a large energy influx only when its extraction becomes economically competitive with that of petroleum. Therefore, only petroleum, natural gas, and coal are covered in this synopsis of the domestic fossil fuel resources in detail.

Table 3-1. ESTIMATES OF U. S. FOSSIL FUEL RESOURCES [3-1]

(Quads, 10^{15} Btu)

Fuel	Known Recoverable	Undiscovered Recoverable	Known Marginal or Submarginal	Undiscovered Marginal or Submarginal	Total
Coal	4,600	---	29,000	55,000	88,600
Petroleum	280	1,160	230	1,710	3,380
Natural Gas	280	1,210	---	880	2,370
Natural Gas Liquids	30	140	---	280	450
Oil in Bituminous Rocks	10	---	---	60	70
Shale Oil	290	---	11,600	23,200	34,090
Total	5,490	2,510	40,830	81,130	128,960

Using the data from Table 3-1, an attempt is made to anticipate the adequacy of the larger resource bases, i.e., coal, gas, and oil. Two mistakes are commonly made in discussion of the adequacy of fossil fuel resources: (1) fuel reserves generally are underestimated, with inadequate allowance for new, as yet undiscovered, reserves, and (2) available resources generally are compared with resource consumption at a single point in time instead of considering the very considerable growth in consumption each year. Figures 3-1 through 3-3 take into account these common mistakes by calculating several growth patterns in demand and comparing these patterns against the previous tabular estimates of ultimately recoverable resources for each type of fossil fuel.

Over the past decade, demand for natural gas and petroleum has been growing at about 6% and 4%, respectively, per year, [3-2]. If these growth rates continue into the future, as suggested by the NSF/NASA Solar Energy Panel [3-3], and if the demand is met entirely from domestic supplies, all ultimately recoverable domestic supplies of natural gas will be exhausted by the year 2000. Domestic petroleum resources would be depleted around 2003 to 2007. Coal then is our most important fossil fuel in terms of use and availability. Presently coal resources are adequate for centuries to come. However, the environmental consequences of present technologies for mining and burning coal are severe in that society has chosen to regulate and restrict the results of the use of

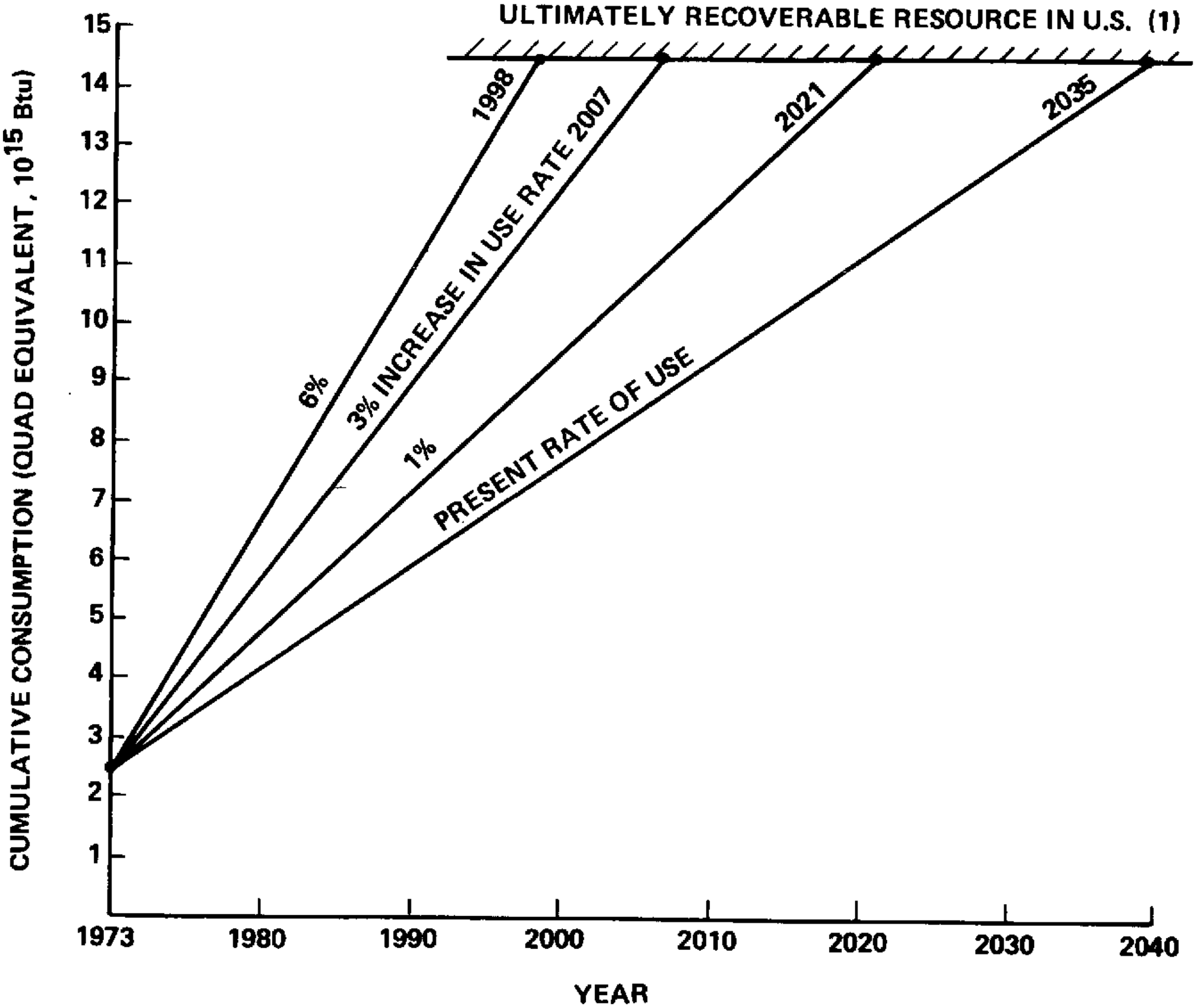


FIGURE 3-1. CUMULATIVE U. S. REQUIREMENTS FOR PETROLEUM

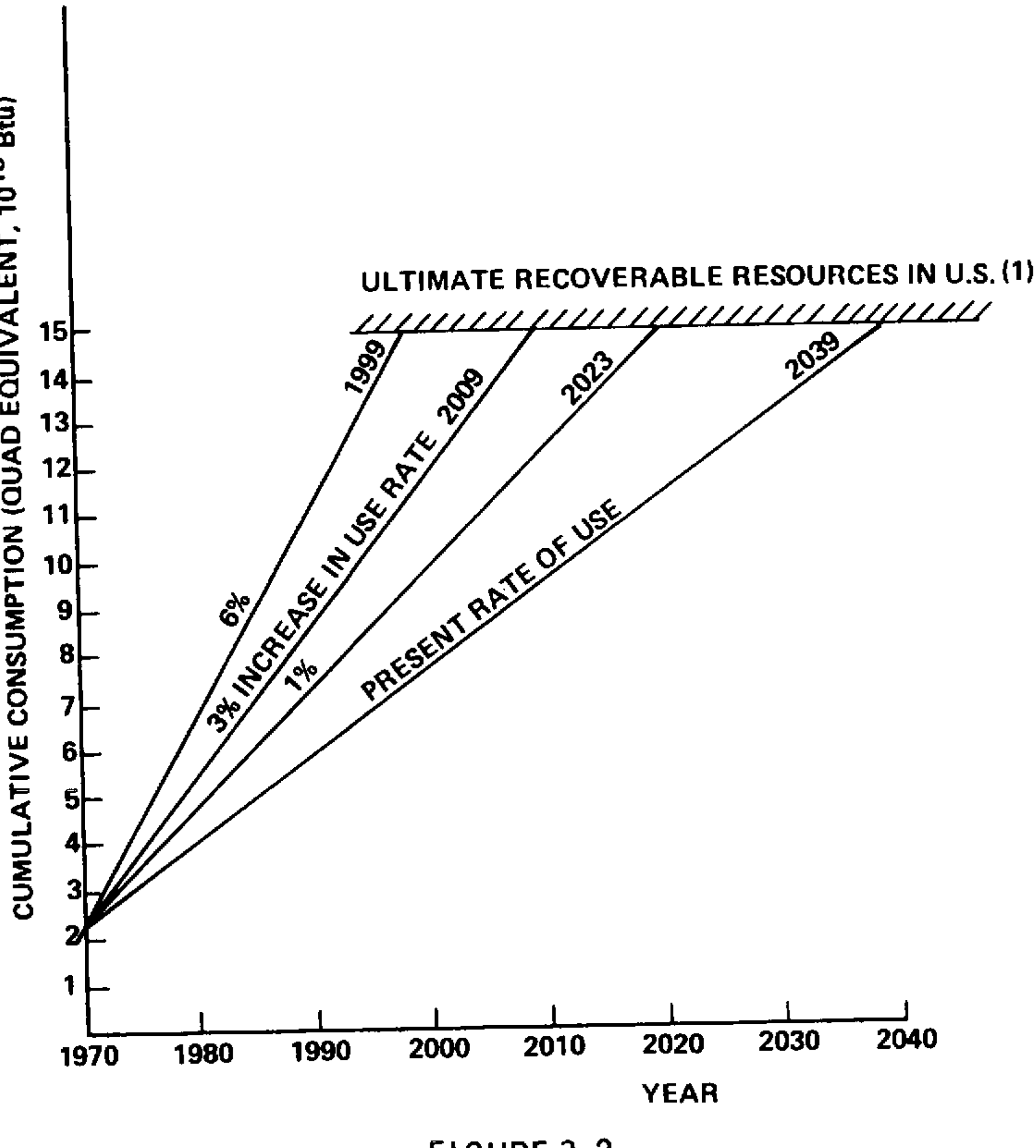


FIGURE 3-2.
CUMULATIVE U. S. REQUIREMENTS FOR NATURAL GAS

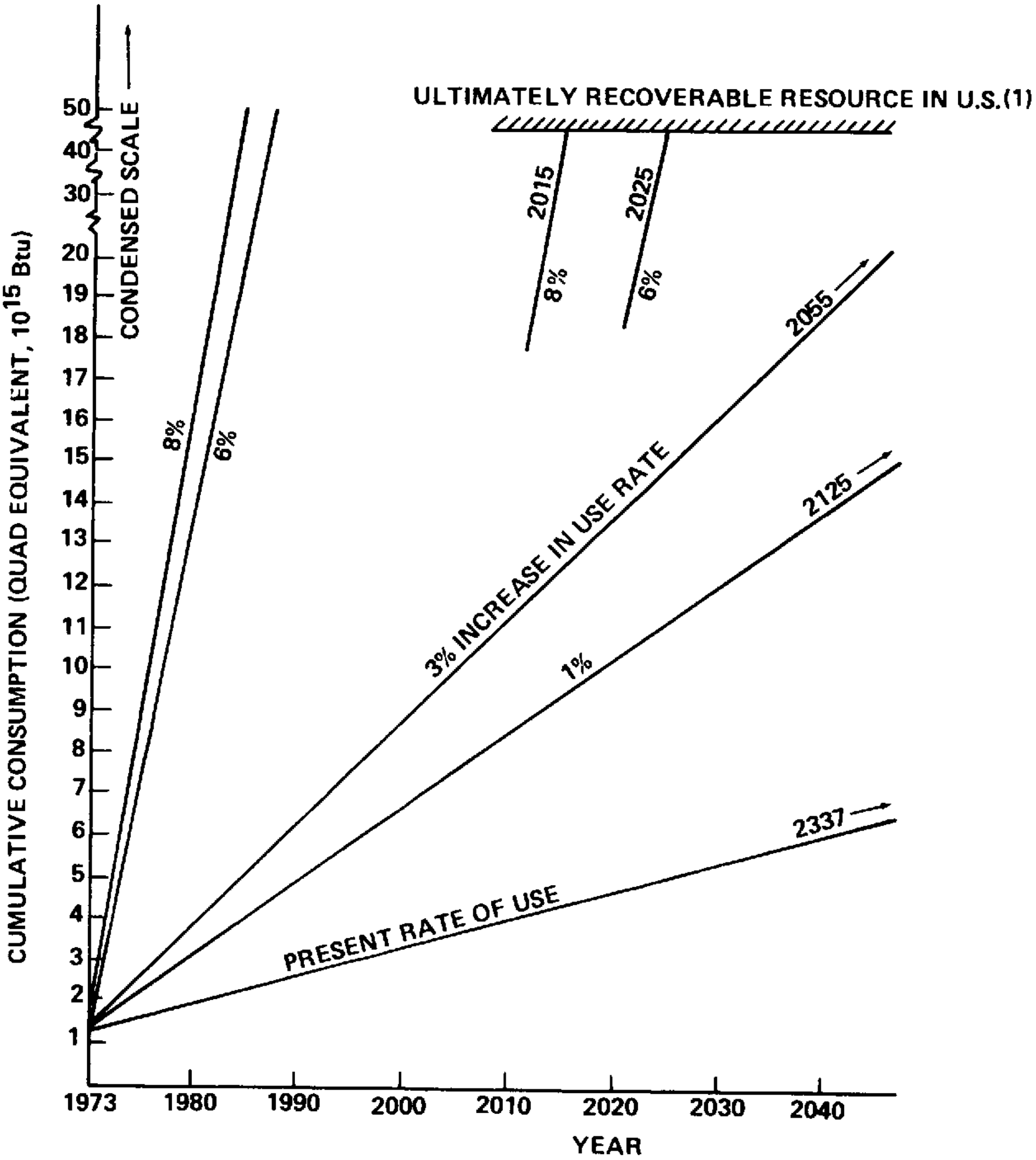


FIGURE 3-3. CUMULATIVE U.S. REQUIREMENTS FOR COAL

coal. The goals for research relating to coal can be stated simply as: the development of technologies to (1) mine and process coal without unacceptable effects to the environment and (2) convert coal to clean gaseous and liquid fuels.

Synthetic Fuels from Coal. The manufacture of synthetic gas or oil from coal is a new process as far as commercial production is concerned. The commercialization of this process, along with the soaring use of coal by the electric utilities, can greatly effect the quantity of coal reserves.

Coal Gasification [3-4]. One of the most important goals relative to coal research and development for the next few years is the gasification of coal to help reduce the short fall between anticipated demand and limited domestic supplies of natural gas. Two prospects appear promising, if the requisite technologies can be quickly developed and demonstrated:

- The manufacture of gas from coal which can be a replacement for natural gas in terms of energy content - the so-called "high" Btu gas.
- The manufacture of gas that contains less energy - "low" Btu gas - that would be suitable as fuel for steam. Electric power plants or industrial users located in the vicinity of "low" Btu gas could reduce the demand on natural gas, conserving the latter for residential and commercial uses.

Coal Gasification State-of-the-Art:

- Principal responsibility for R and D: U.S. Department of the Interior and American Gas Association.
- Approximate funding:

  Current rate: 30 million dollars per year, (20 million dollars federal, 10 million dollars industry).

  Future: 30 million dollars per year for next four (4) years, approximately 175 million dollars in succeeding 4-year period.
- Current state of development: Pilot plant stage.
- Next objective: Build and operate demonstration plant(s).
- Major problems: Development of optimized process(es) and scale-up.
- Import to energy crisis:

The development of a commercial capability to gasify coal will have a significant impact on the energy economy of the U.S. in that it will allow the increased utilization of a plentiful resource (coal) in an environmentally acceptable fashion.

Coal Liquefaction [3-5]. In general, coal liquefaction is not receiving the amount of emphasis in research and development that is placed on coal gasification. The following status on the state-of-the art reinforces this statement:

- Principle responsibility for R and D: U.S. Department of the Interior.
- Approximate funding: Current rate: 10 million dollars per year. Future rate: 10 million dollars per year.
- Current state of development: Pilot plant.
- Next objective: Operate present and planned plants together and analyze data needed to achieve commercialization.
- Major problems: Materials handling and equipment problems and process simplification to achieve lower unit costs.
- Import to energy picture.

The development of a commercial coal liquefaction capability would allow increased utilization of our coal resources and avoid "most" of the environmental problems associated with the direct combustion of coal. Viable coal liquefaction technology could have considerable effect on future U.S. liquid fuels import policy.

In summarizing, various scenarios on resource depletion estimates for the fossil fuels of the United States are given in Table 3-2. These scenarios were constructed by the Cornell Workshop on Energy and the Environment [3-5]. Four basic cases for each of the models of growth in demand (an extrapolated growth model - EGM - which assumes past exponential growth in demand for natural gas, petroleum, and electricity continues at 6.2%, 3.9%, and 6.1% per year, respectively; and a reduced growth model - RGM - which assumes that growth in total demand for gas, petroleum, and electricity drops to 3%, 3%, and 4% per year, respectively.)

The four cases are:

- Neither imports nor synthetic fuels are available - all demands must be met by domestic supplies;
- Imports are not available but synthetic fuels production

begins phasing into the supply picture in 1980, and grows until it meets all of the annual incremental demand for petroleum and gas by 2000;

- Synthetic fuels are not available but imports increase according to the National Petroleum Council estimates until they supply 60 percent of domestic demands, and remain at 60 percent thereafter; and
- Both synthetic fuels and imports are available as previously described.

Table 3-2. RESOURCE DEPLETION ESTIMATES FOR VARIOUS SCENARIOS [3-6]

Fuel and Case Description	Year in Which All Ultimately Recoverable Resources are Depleted			
	Low Estimate		High Estimate	
	EGM (a)	RGM (b)	EGM	RGM
Natural Gas				
No imports, no synthetic fuel (c)	1989	1991	2000	2007
No imports, synthetic fuel	1990	1992	2008	2016
Imports, no synthetic fuel	1993	1997	2010	2025
Imports, synthetic fuel	1996	2000	2037	2050+
Petroleum				
No imports, no synthetic fuel	1988	1988	2011	2014
No imports, synthetic fuel	1989	1989	2027	2030
Imports, no synthetic fuel	2001	2003	2031	2038
Imports, synthetic fuel	2006	2008	2050+	2050+
Coal				
No synthetic fuel	2050+	2050+	2050+	2050+
Synthetic fuel	2032	2050+	2044	2050+

(a) extrapolated growth model
(b) reduced growth model
(c) synthetic fuels from coal gasification and liquefaction

Thus, the outlook for fossil fuel supply is not very bright if we assume that a continuing exponential growth in demand must be met. However, the introduction of new technologies using totally different energy sources such as the utilization of solar energy, geothermal energy, hydrogen-based sources, ocean thermal gradients, etc., are desirable candidates. Not only are these sources more desirable environmentally than current energy sources, but in addition, they do not depend on scarce resources such as the fossil fuels.

3-2. FOSSIL FUELS - IMPORTED

The three major fossil fuels that will be imported to meet current and future energy demands are natural gas, liquified natural gas, and petroleum (crude and natural gas liquids). Presently, we are importing 4 percent of our natural gas, primarily from Canada and Mexico, and 26 percent of our petroleum supply from Canada, Venezuela, and the Middle Eastern countries. Recently, supplies of Liquified Natural Gas (LNG) have been imported from Canada and Algeria [3-6]. Experts generally agree that imports will increase markedly over the next decade [3-7]. For instance, the National Petroleum Council [3-2] projects United States petroleum and natural gas imports at 60 percent and 30 percent, respectively, of domestic consumption in 1985. Using the data from the Department of Interior, Table 3-3 was constructed in order to project the percentage of fossil fuel imports to the year 2000.

Table 3-3. PROJECTED IMPORTATION OF FOSSIL FUELS TO THE UNITED STATES [3-8]

Fossil Fuel	Year				
	1971 %	1975 %	1980 %	1985 %	2000 %
Natural Gas	4	8	11.2	13.6	19.3
Liquified Natural Gas	0	2.2	3.3	5.7	8.9
Petroleum (Crude plus natural gas liquids)	26	36.9	43.0	53.4 (a)	70.3 (a)
Total Percentage of Fossil Fuels to be Imported	16.6	28.1	32.1	40.7 (a)	55.3 (a)

(a) From imports, synthetic fuels (coal gasification and liquefaction) and oil shales

Although Liquified Natural Gas has not previously been imported for energy consumption, many companies in the energy business consider it to be a rich energy source of the future [3-6]. James A. Akins [3-6] of the State Department has indicated that dozens of companies are presently negotiating with anyone around the world who has surplus gas to sell or even a chance of finding any. The transport of liquid natural gas will coincidently bring an extra benefit, in that the fleet of tankers necessary to transport the fuel under cryogenic conditions will be built in the United States [3-6]. The construction of these ships will revive America's shipyards, regenerate the Merchant Marine, and provide many jobs for the U.S. labor force. Most important, it is thought that these new untapped reserves of gas around the world will postpone the physical shortage of gas indefinitely into the future. For example, the Soviet Union has tentatively agreed to furnish the United States 10 percent of the gas supply which represents 3 percent of the current total energy supply.

It should be pointed out that these import requirements of fossil fuels are variable in that the United States will depend on foreign countries, primarily, the Middle Eastern countries, for the supply. Therefore, the consumption projections may "demand" these necessary supplies of fossil fuels, but it ultimately will depend on the United States international policies and the necessary capital to purchase the supply.

3-3. NUCLEAR ENERGY

Nuclear energy for electrical generation is becoming a very important fraction of our energy inventory. It seems capable of handling any short term energy requirements and with proper developments it might become a relatively long term answer to our energy needs.

There are two types of nuclear reactions which can provide energy:

- Fission--Heavy nuclei split (either spontaneously via their radioactivity or by neutron-induced reactions) to yield energetic fission products and neutrons.

- Fusion--Light nuclei are forced together (at high temperatures) to form a heavier nucleus with the release of energy. The first uncontrolled demonstrations of these reactions occurred in 1945 (atom bomb) and 1952 (hydrogen bomb). Today controlled nuclear fission is of great economic importance in the generation of electrical power--and portends to become the dominant energy supply in that area by the year 2000, while the technical feasibility of controlled fusion reactions has yet to be demonstrated. Should certain negative environmental impacts of nuclear energy be overcome (e.g., long-term storage of highly radioactive wastes, the release of radioactivity to the biosphere in rare accidents, and black-market uses of plutonium), the impressive potential of nuclear energy resources--1,200 years' supply at economically acceptable prices for fission power at the anticipated usage rate in the year 2000 [3-9] and approximately 5 million years' supply for fusion power [3-10] -- indicates that the twenty-first century may well be the "century of nuclear energy."

The next three figures 3-4, 3-5, and 3-6, describe graphically the capabilities of nuclear energy to handle our demands. The "most likely" projection of Figure 3-4 is used to estimate the requirements shown in figure 3-5. The next Figure, 3-6, illustrates projected costs for nuclear fuel as compared to the cost of steam coal. The effort the U.S. is making to tackle our energy needs is best illustrated in Table 3-4.

Table 3-4. FEDERAL ENERGY R&D FUNDING [14]
($ millions)

Process	Years					Funding Agency
	1969	1970	1971	1972	1973	
Fission						
LMFBR (a)	132.5	144.3	167.9	236.6	259.9	AEC
	---					TVA
Other Civilian Nuclear Power	144.6	109.1	97.7	90.7	94.8	AEC
Fusion						
Magnetic Confinement	29.7	34.3	32.3	33.2	40.3	AEC
Laser-Pellet	2.1	3.2	9.3	14.0	25.1	AEC
Total Funding	361.0	362.2	405.2	524.7	621.6	

3-4. GEOTHERMAL ENERGY

The internal heat of the Earth is due to primeval heat, the decay of radioactive materials and frictional forces within the mantle. Geothermal energy is a consequence of this natural heat flowing from the interior through the Earth's crust to the environment.

Thermal energy ultimately reaches the surface by conduction through rock layers, and by convection in volcanoes and hot springs. According to Hubbert (1971) the flow of heat by conduction from the interior of the earth to the surface amounts to 0.063 watt per square meter on a world-wide average, with the total heat flow for the globe to 32×10^{12} watts. By convection, the rate of heat flow via volcanoes and hot springs is estimated to be about $.3 \times 10^{12}$ watts.

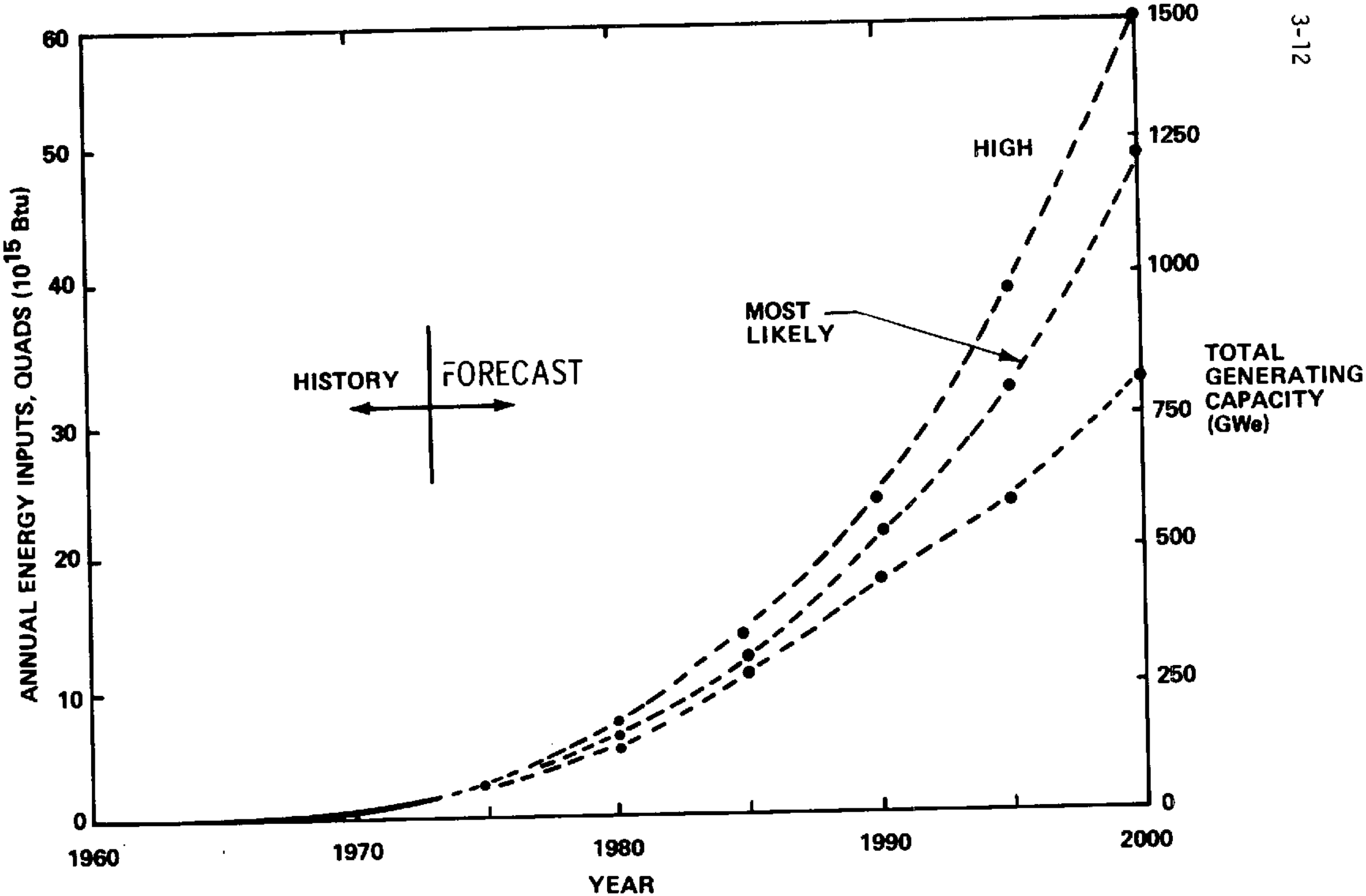


FIGURE 3-4. ENERGY INPUTS AND INSTALLED CAPACITY FOR THE NUCLEAR ELECTRICAL GENERATING INDUSTRY, HISTORY AND FORECAST [3-11]

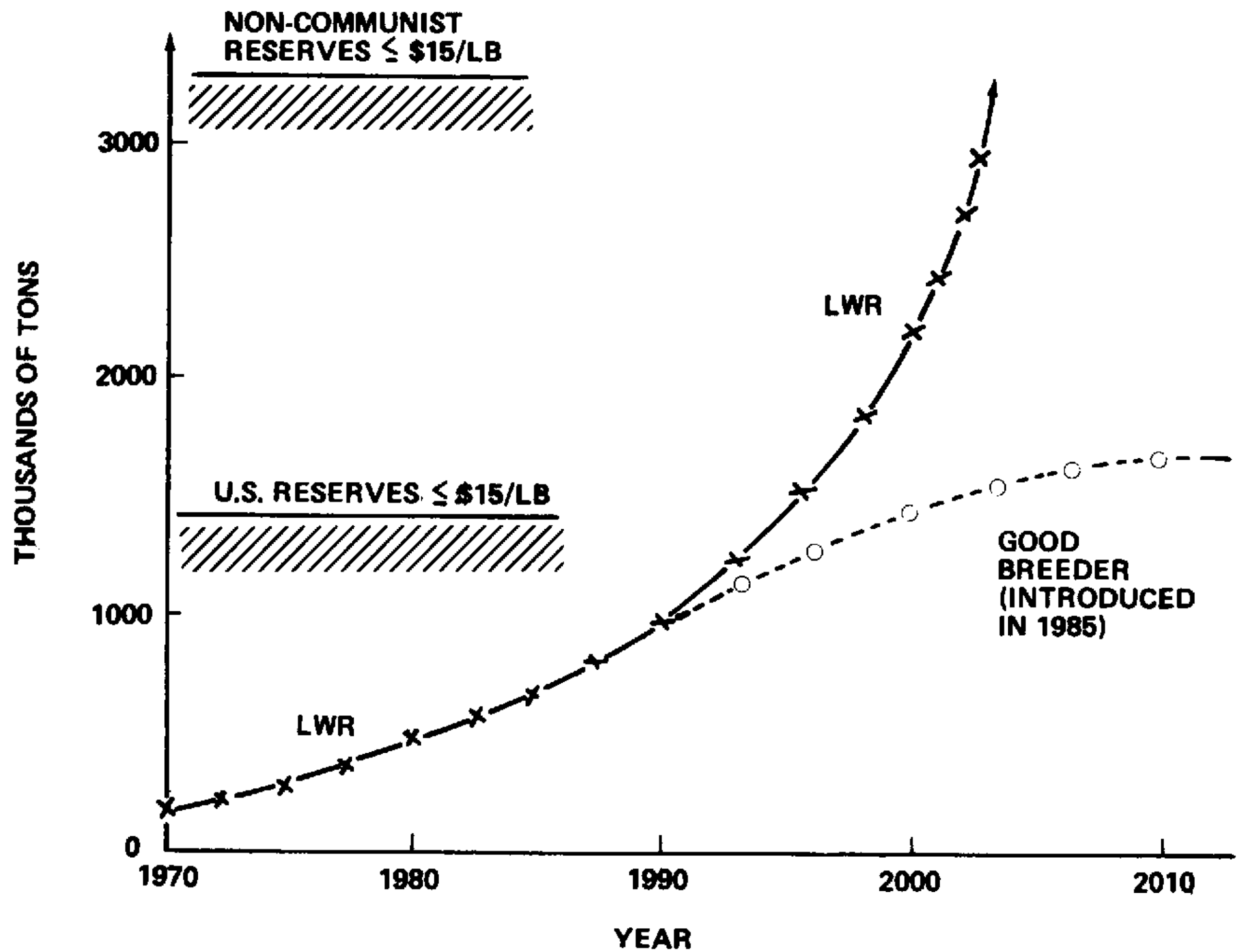


FIGURE 3-5. CUMULATIVE REQUIREMENTS FOR U_3O_8 (YELLOWCAKE), ESTIMATED U. S. [3-9]

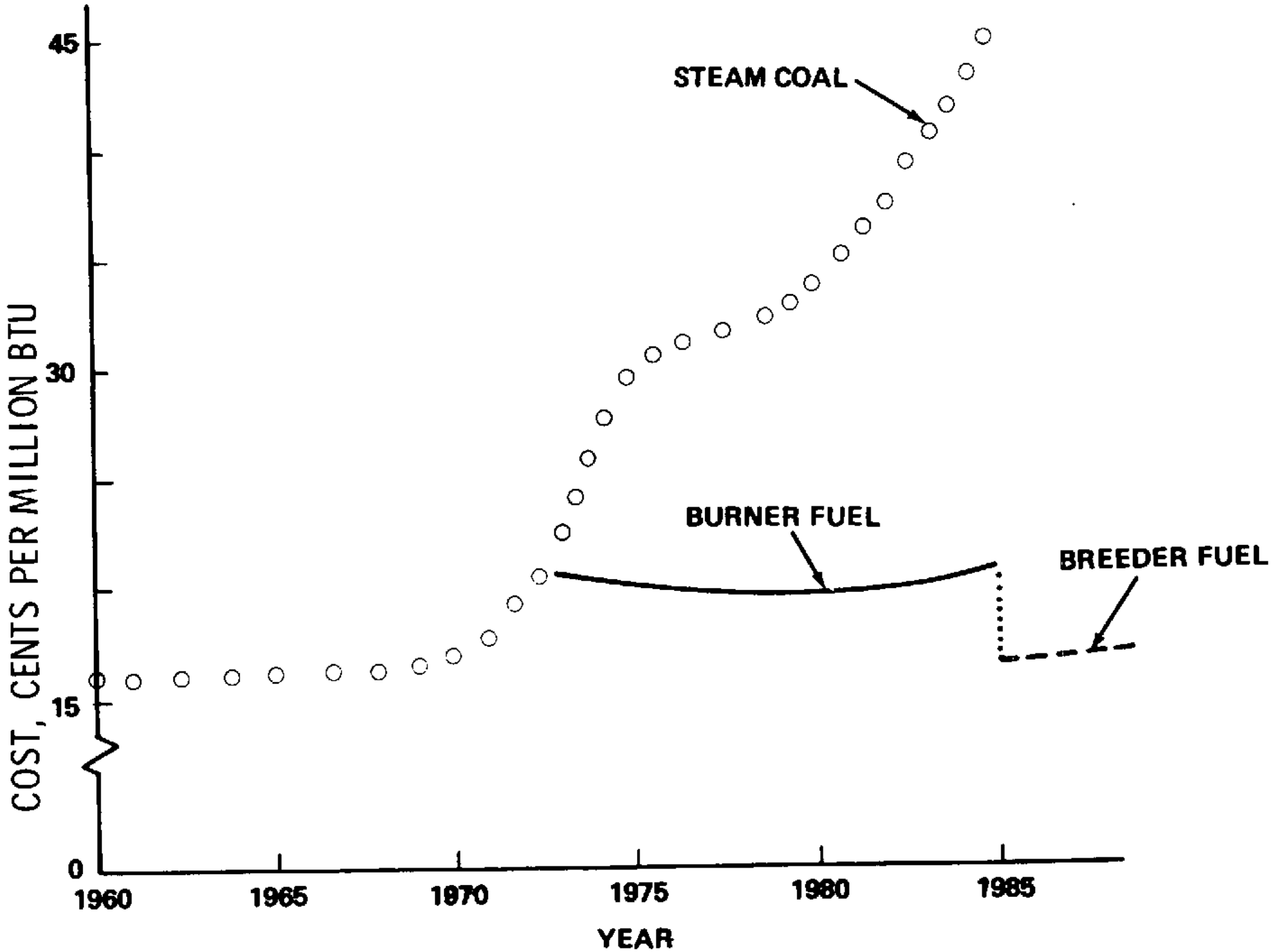


FIGURE 3-6. PROJECTED FUEL COSTS [3-10]

However, usable geothermal power is obtained only from reliable high temperature concentrations of the heat flow. Thus the potential of geothermal energy as a power source for man lies in the heat store at varying depths beneath the surface, in natural underground reservoirs of steam, hot water, and hot rock.

This heat store results from the action of large bodies of molten rock (magma) that have been pushed up into the earth's crust by great pressures in the mantle. The magma heats the rocks in the crust near the surface, which then heats groundwater in porous or fractured rocks to temperatures in the range of 500° F. This water may be trapped beneath relatively impermeable rock at depths of 2-3 kilometers and kept as a liquid by high pressure. Under certain conditions the hot water can escape through fissured rock toward the earth's surface where it begins to boil and a portion of it converts to steam. Geothermal energy can then be tapped by wells driven through the impermeable rock capping these reservoirs.

All three sources of recoverable geothermal energy-steam, hot water, and hot rock are being considered for utilization. Utilization of geothermal energy is in a primitive level of development and only gross estimates of its potential can be given:

- STEAM. Steam may be recovered by tapping two different types of fields: Dry Field -- characterized by low pressures and relatively high temperatures (natural steam at geysers is at 355°F and 100 psi); Wet Field -- superheated water, above its boiling point at atmospheric pressure, in the range of 180-370°C (when tapped, flashes to steam and water at lower temperature and pressure).

- HOT WATER. These are fields of lesser heat content consisting of water at temperatures below the boiling point (at atmospheric pressure); known as a "low-temperature" field, there are large pockets of water in the range of 50° to 82° C.

- HOT ROCK. Underground water systems not in contact with these near-surface heat deposits (magna chambers that never erupted to the surface) heat range may be 300° - 700° C at depths between 2000 - 7000 meters.

3-5 TIDAL ENERGY

The source of tidal energy is the combined kinetic and potential energy of the earth-moon-sun system. Tidal power is derived from the oscillatory flow of water in the filling and emptying of partially enclosed coastal basins during the twice-daily rise and fall of the sea. The energy available from this action has been estimated at 3×10^{12} watts [3-10] on a world-wide basis.

Ocean tidal ranges, the height between high and low tides, vary throughout the world. The greatest tidal ranges exceed 15 meters and occur at the head of the Bay of Fundy off the eastern coast of Canada. The movement of oceanic tides within 200 miles of the coast of the United States represents a theoretical power supply of magnitude on the order of 10^{11} watts. However, only a small part of this corresponds to tidal energy in bays and estuaries where it could be harnessed, probably not more than 10^{10} watts. These values were obtained by rough estimation of the underlying physical quantities and are corroborated within an order of magnitude by Hubbert [3-10].

3-6. SOLAR INSOLATION

Fed by its own internal nuclear furnace, our sun radiates energy outward in all directions in space. At the earth's distance away, this flux of energy amounts to just over 1350 watts per square meter (430 Btu per hour per square foot) on any surface which faces the sun outside of the atmosphere [3-15]. At the ground some of this energy is absorbed or scattered from the incoming beam as it travels down through the earth's atmosphere. The amount lost depends on the length of the path in the atmosphere and on how much water vapor and dust are present. The minimum path length occurs for the point on earth where the sun is directly overhead. At such a location, if the sky is clear, the flux of energy remaining in the incoming beam is about 1100 watts per square meter (350 Btu per hour per square foot) of level surface. If the sun is some distance from the zenith, directly overhead, the energy flux on level ground is smaller because of the greater path length and the loss in the atmosphere and also because the energy traveling down within a given beam or column spreads over a larger area of ground if the beam is slanting. So there is less incident energy per unit level area. This means that, even if the sky is perfectly clear, the solar energy available per unit area in the United States is greatest in the south and least in the north. Other climatic factors, particularly clouds, combine to make the average annual irradiance greatest in the southwest (Arizona, New Mexico, southern California, and western Texas), somewhat less in the southeast, and least near the Great Lakes, in the northeast, and in far northwest, as shown in Figure 3-7. The average annual total for the entire U.S. is $4{,}500 \times 10^{15}$ Btu or 510,000 Btu per square foot. This means the amount of solar energy falling on the roof of a typical house in the U.S. is several times the amount needed to heat and cool it. The variation with locality and season is indicated in Table 3-5 which gives mean values in Btu per square foot per day. The data is based on the Climatic Atlas of the United States [3-16].

Table 3-5. MEAN DAILY SOLAR IRRADIANCE (Btu per sq. foot per day)

Area	December	June	Entire Year
Arizona	1,000	2,600	1,900
New England	400	1,600	1,100
Entire U.S.	700	2,200	1,400

Day to day variation can be quite large. A study based on actual data found that the mean of the daily irradiance for three cities in the southeast, during the fourteen year period from 1950 to 1963, varied from 330 to 1130 Btu per square foot per day in December and from 1700 to 2500 Btu per square foot per day in June [3-17].

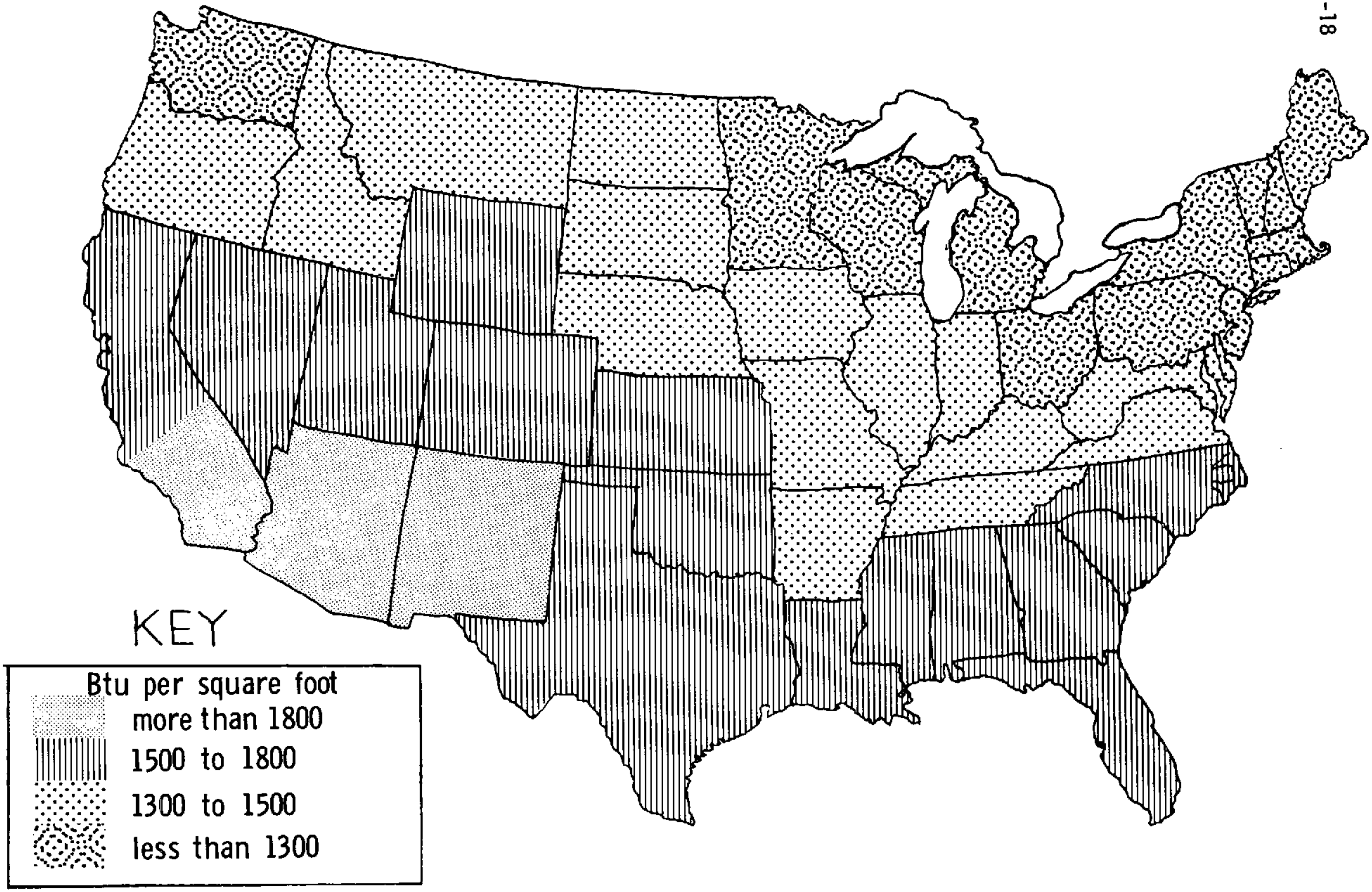


Figure 3-7. ANNUAL MEAN DAILY SOLAR IRRADIANCE

Direct and Diffuse Components. Solar engineering calculations generally require more detailed information about the solar radiation than just the mean daily irradiance. One consideration which is often important is the direction from which the radiation comes.

The position of the sun, at any given location, is easily calculated for any specified date and hour by using standard astronomical tables and formulas which are easily incorporated into computers.

However, because of atmospheric scattering, radiant energy comes from all parts of the daytime sky. The total irradiance on a horizontal surface, measured on a regular basis at many weather stations, is the sum of this "diffuse" component and the "direct" radiation which comes from the direction of the sun. The relative magnitudes of these components vary, depending upon the condition of the sky and the height of the sun. On a cloudy day nearly all the irradiance will be diffuse (up to 690 watt per square meter or 220 Btu per hour per square foot) whereas on a clear day the diffuse component will probably be less than 10% of the total, though this varies widely, depending on atmospheric clarity. A possible range from 7 to 140 watts per square meter has been suggested [3-18].

In general, more diffuse radiation comes from some parts of the sky than from others and the engineer may need to also take this into account, although the variation is relatively small if the sky is clear. In particular, the performance of solar "concentrators", such as lenses or mirrors, depends on the detailed directional character of the "circumsolar radiation" which comes from the sky near the sun. The determination of sky brightness distribution has been approached by theoretical calculation [3-19, 20, 21] and some experimental observations have been made, but more work is needed for solar energy applications.

Time Variation. The most obvious variation of solar radiation with time is the 24-hour cycle due to the rotation of the earth. The radiation intensity, which is essentially zero at night, increases rapidly at first as the sun rises in the sky and then more slowly, reaching its maximum value at or near solar noon, when the sun is at its highest point, due south of the observer. Passing clouds can cause large and rapid changes. For accurate prediction of system performance, the solar engineer needs to have the data on an hourly basis. Obviously, it is impossible to predict sky conditions for specific days far in the future, so he uses "typical" conditions obtained from weather records. To obtain the typical hourly variation, however, the weather and insolation data must have been recorded hourly. Normal weather conditions may vary greatly with the season of the year, of course, so what the designer probably needs for his calculations is a "typical year". The proper establishment of typical year weather data requires guidance from weather experts [3-23].

Apart from weather, the dominant annual variation of solar insolation is due to the changing declination of the sun, which changes the height of the sun's path across the sky. The maximum elevation of the sun above the horizon, at solar noon, is (90° - L + D), where L is the latitude of the place and D is the sun's declination, which varies from minus 23.5° on December 21 to plus 23.5° on June 21. For example, in Washington, D.C., latitude 39°, the sun's maximum elevation on December 21 is (90 - 39 - 23.5) = 27.5°, and on June 21, it is (90 - 39 + 23.5) = 74.5°. (This formula is for latitudes north of the equator.) The points at which the sun rises and sets also vary with season. During northern spring and summer, for example, the sun shines somewhat on the north side of vertical structures during part of the morning and part of the afternoon each day.

Spectral Distribution. A prism reveals that sunlight consists of a range of colors, which correspond to various wavelengths of light. These include wavelengths which are shorter than those of visible light (ultraviolet light) and also longer (infrared radiation). The "spectral distribution" is the way in which the energy of the light is apportioned among the various wavelengths of this spectrum. One reason it is important is because surfaces, paints, and coatings may absorb, reflect, and emit energy differently in different parts of the spectrum. To capture solar energy for conversion into heat, it is advantageous to have a surface which strongly absorbs radiation at those wavelengths where the solar radiation is greatest (the visible and near-infrared) and which has a low emissivity at long infrared wavelengths, to reduce its tendency to reradiate the absorbed energy. The problem of making such surfaces is an important part of solar engineering technology.

Man's knowledge of the solar spectrum at the earth's surface is largely based on experiments carried out by C. G. Abbot of the Smithsonian Institute in the first third of the century. The existing data were correlated in a classic paper by Parry Moon in 1940. More recent data on the solar spectrum above the atmosphere have been obtained in high-altitude experiments [3-24] and corresponding modifications in Moon's sea-level values are easily made because, in effect, his data gives the transmittance of the atmosphere at various wavelengths. His 1940 paper still remains the standard reference for the spectrum below the atmosphere.

3-7 SOLAR INSOLATION DATA COLLECTION

The National Climatic Center at Asheville, North Carolina, currently collects and processes insolation data from some 86 stations located throughout the United States, shown in Figure 3-8. Sixty of these are operated by the U.S. Weather Service; the remainder are "cooperative" stations. All stations record the "hemispheric solar radiation", which is the total irradiance, direct and diffuse, upon a horizontal surface. Nineteen stations, all of them Weather Service Stations, record this data hourly. None of these are located west of Kansas except at Albuquerque and El Paso. The other stations supply daily totals only. However, the National Climatic Center expects that hourly data will be available from all 60 of the Weather Service stations with the installation of new automatic recording equipment which is to be completed by the end of 1976.

FIGURE 3-8. SOLAR RADIATION STATIONS JULY 1973

Four stations also record separately the radiation received through a tube which has a small circular field of view, of angular diameter 5.7°, centered on the position of the sun. This is called the "normal incidence" radiation and represents the direct component of the irradiance. Its value at solar noon and at solar hour at angles of 60, 70.7, 75.7, and 78.7 degrees on either side of solar noon are tabulated and published. These stations are at Madison, Wisconsin; Omaha, Nebraska; Albuquerque, New Mexico; and Tucson, Arizona.

Accumulated daily and hourly hemispheric radiation data can be purchased on magnetic tape from the National Climatic Center. Unfortunately, data accuracy has been brought into question by the discovery that observed long-term decreases in the measured radiation values were caused, at least in part, by gradual deterioration of the absorptive coating on the sensitive elements of the observing instruments (pyranometers). Consequently, regular publication of the data in the periodical "Climatic Data: National Summary" has been discontinued. The National Climatic Center is in the process of determining appropriate corrections.

Data System Study. Our present solar insolation measurement system, as described above, supplies much useful data, but more is needed for the accurate solar engineering design calculations which are required in order to determine the potential of solar energy utilization on a national scale. Presently available data is not adequate even for standard heating and cooling load calculations. A recent engineering design manual states, "Because of limited availability of solar radiation data, it is suggested that solar radiation be estimated by applying the cloud cover modifier (which is based on simple weather data) to the cloudless day radiation (calculated theoretically)" [3-25].

If a long lead time is acceptable, the data for a particular site might conceivably be obtained by setting up observing instruments right there for a year or more, a period which may or may not reveal the typical and extreme conditions which are likely to occur. Alternatively, a nationwide network of closely-spaced observing stations could be built. Very likely, the optimum solution lies somewhere between these two approaches, with the ideal number of regular network stations increasing as solar energy utilization becomes more widespread.

How much data should be taken? Accurate engineering calculations generally require data values at hourly intervals. Also, they may require knowledge of both the "direct" and the "diffuse" radiation, which are now observed regularly at only four stations in the U. S. But data acquisition is not free, so it is important to determine how much is really needed.

Such questions suggest a thorough systems study. The specifications for such a study can be put into the generalized systems approach format (Preface Fig.I), as follows:

The objective is to design an optimum solar insolation data collection system for the United States.

The Tentative requirements are:

- Determine what solar data is desired by solar design engineers.
- Determine the incremental value of incremental increases of detail and precision in the data, in terms of the probable future cost effectiveness of the systems designed.
- Determine the probable degree of future predictibility of climatic factors as they affect solar engineering design. (Climatic unpredictability tends to limit the value of detail and precision in past solar data.)
- Determine the rate of variation of solar insolation data with geographic location throughout the country, or in selected regions of greatest potential utilization, to determine how closely-spaced the observing stations must be.
- Identify and characterize present data collection facilities, instruments and procedures.
- Estimate the feasibility and cost of new facilities and instruments.

Such a study would provide a rational basis for designing a cost-effective solar data collection system.

3-8 INDIRECT SOLAR ENERGY

Solar radiation incident on the earth gives rise to the hydrological cycle, the winds, and large temperature differences between the deep and surface waters of the tropical oceans. Each of these is an energy resource.

Hydropower. Some twenty-three percent of the solar radiation received by the earth goes into the evaporation of water. This water subsequently returns to the earth's surface as precipitation. That which falls on land above sea level has gravitational potential energy which can be extracted by water wheels or turbines as the water flows back to the sea. Generally it is used to generate electrical power.

The inventoried hydroelectric resources of the 48 contiguous states total 146 x 10^9 watts [3-26], with another 20 x 10^9 watts in Alaska and 0.8 x 10^9 watts in Hawaii [3-27].

Installed capacity was 52 x 10^9 watts in 1970 [3-28] and is expected to reach 82 x 10^9 watts by 1990 [3-29]. Large increases beyond that seem unlikely, because the remaining sites are in general smaller and less economic than those already developed and also because further development will increasingly conflict with environmental concerns; for example, as embodied in the Wild and Scenic Rivers Act of 1970 [3-26]. The figures given exclude pumped-storage, which is a way of storing energy and is not an energy resource.

The energy obtained from hydroelectric plants is less than the installed generating capacity because the latter is never fully utilized throughout the year. The energy actually generated determines the "load utilization factor", which was 0.55 for hydroelectric plants, overall, in 1971 [3-30]. Assuming the same value for 1970, the energy generated during that year was 55% of 52 x 10^9 watt-years, which is 2.5 x 10^{11} kw-hrs or 0.86 x 10^{15} Btu (0.86 Quads). However, because of thermal losses, fuel-burning plants would have had to consume fuel equivalent to 2.6 x 10^{15} Btu (2.6 Quads) to produce the same amount of electrical energy, using the 1971 input-output ratio of 10,500 Btu per kw-hr. It is expected that the load factor will gradually decrease, as new sites are developed, to 0.45 in 1985 and 0.40 in 2000, while the thermal efficiency of fuel-burning plants is expected to increase, decreasing the input-output ratio to 8500 Btu per kw-hrs in 2000 [3-30]. Using the estimated load factor and fuel-burning plant efficiency for the year 2000, and neglecting all economic and environmental limitations, the fuel equivalent of the ultimate hydroelectric capacity of 146 x 10^9 watts is 4.4 x 10^{15} Btu (4.4 Quads) per year. If Alaska and Hawaii are included, the total is 167 x 10^9 watts, with fuel equivalent of 5.0 x 10^{15} Btu per year.

<u>Wind Power</u>. Aeolian energy shares many of the advantages and disadvantages of its parent, primary solar energy. It is widely available, inexhaustible, clean, and free. It is also discontinuous and variable, and low density. Like hydroelectric power, it is high grade mechanical energy which can be used directly (as for pumping water) or transformed into electrical power, without the large losses associated with thermal to mechanical energy conversion.

<u>Potential</u>. Estimates of the maximum power obtainable from wind vary widely. One author suggests for the entire world 0.1 x 10^{12} watts, which is the power generated from 8 x 10^{15} Btu (8 Quads) of fuel per year, and for the U. S. power equivalent to 0.8 x 10^{15} Btu (0.8 Quads) of fuel per year [3-31]. He estimates that one-tenth of these amounts could be realized by the year 2000. The Interdepartment Energy Study Group gave 20 x 10^{12} watts (1600 Quads) of fuel per year, for the ultimate world potential [3-32]. The set of assumptions underlying these two contrasting estimates are no doubt different. It may be that the smaller estimate is based on only wind over land, whereas the larger one includes wind over the oceans. Installations which tap the moderate-to-strong winds which prevail over large areas off the eastern coast of the United States are recommended by

Dr. W. E. Heronemus of the University of Massachusetts [3-33]. He envisions wind turbines on either floating platforms or towers producing electrical power which would be used to generate hydrogen by electrolysis of water. It is hoped that hydrogen will prove to be a convenient medium for storing, transporting and distributing energy. He estimates that such an off-shore windpower system for New England could produce 159 billion (0.159×10^{12}) kilowatt-hours of electricity in 1990 at 2.5 cents per kilowatt-hour, and that there is enough wind energy available to double that capacity by 2000 to some 300 billion (0.3×10^{12}) kilowatt-hours. Steam plants would require about 2.5×10^{15} Btu per year of fossil fuel to generate that amount of electricity, at the then-anticipated rate of 8.5 Btu per watt-hour.

Other large regions of relatively strong winds of interest for the United States occur in the Great Plains and the Aleutian Islands. Dr. Heronemus suggests that among our natural energy processes having the greatest promise, the use of wind power follows immediately after the use of primary solar energy for climate control and water heating.

Data Collection. Proper siting of a windpower machine on land requires year-long observation of winds at different possible locations and heights above the ground. The average wind speed can vary significantly from place to place, depending upon local topography. Careful siting is important because the windpower available is proportional to the cube of wind speed. This means for example, that wind at 25 miles per hour can yield nearly twice as much power as it can at 20 miles per hour. One investigator has said that it is not necessary to know the wind speed on an hourly basis in order to evaluate a site's suitability, but that the average over a full year is sufficient. This can be obtained using a simple counter attached to a rotating anemometer to give the total run of the wind. This average annual wind speed can be translated into the output power obtainable from a machine of given design with the help of standard curves [3-34]. However, today's automatic data collection and processing techniques may make it feasible to obtain the increased information and precision available from hourly data. Perhaps it may eventually be possible to compute the behavior of the wind at any proposed site and height within a given region from detailed topographic data for the vicinity. Information as to vegetation, especially trees, would have to be included. The question of wind data collection and processing demands thorough study before large-scale utilization of wind power on land can be achieved.

Knowledge of the maximum wind speeds that may occur is necessary, since the machine must be designed to stand up to these. Other climatic factors must also be considered, since the machine is inevitably exposed to all weather. Maintenance will be essential. The operation of a 1.2 megawatt wind-driven generator in Vermont which produced electricity economically for four years in the 1940's was terminated due to fatigue failure of the stainless steel blade root [3-35]. Enhancement of reliability through design, by regular inspection, and possibly by systematic renewal of critical parts, may become standard practice.

Ocean Thermal Gradients. Of the 81,000 x 10^{12} watts [3-36] of incident solar radiation absorbed by earth surfaces, more than 70% falls on the oceans. However, the most significant portion of incoming solar energy intercepts the region of the globe lying between the Tropic of Cancer and the Tropic of Capicorn, and it is here that 90% of incoming solar radiation reaches the oceans. Thus most of the solar energy received by the earth goes into heating sea water.

The effect of the rotation of the earth's poles on ocean currents is to circulate cold water from the direction of the poles along the ocean floor toward the tropics; while water warmed in the tropics becomes a separate current flowing back toward the poles. Within the tropics, the cold water provides a nearly infinite heat sink at about 5° C at a depth as shallow as 1000 m [3-37]. The ocean surface collects heat from the sun and within the tropics stays almost constantly at 25° C because of the equilibrium between heat gained from solar radiation and the heat lost by evaporation.

To extract power from these thermal gradients, say 5° to 25° C, the two currents must be in close proximity to each other. There are many places within a few miles of land in and near tropical waters such as the Caribbean Sea and the Gulf Stream (e.g., the Straits of Florida, between the coastline and Little Bahama Bank, about 25 km. from Miami), where ocean currents of vast magnitude run within 600 to 900 meters of each other. It is estimated that the Gulf Steam by itself carries northward heat sufficient to generate over 75 times the total power production of the U.S. [3-38]. To derive the same amount of energy from 1 kilogram of seawater flowing through an ocean power plant with a thermal gradient of 20° C, a hydroelectric plant would have to possess a pressure differential corresponding to 93 feet of elevation.

According to Heronemus [3-39] recent studies suggest that the ocean thermal differences process would be highly competitive with central plants whose costs are now in the neighborhood of $200 - $400/kw installed [3-39]. This suggests that at current cost figures, solar sea power is not only economically feasible, but it is possible that it may make advanced reactors, such as the AEC's LMFBR, economically obsolete before their development is complete if a significant investment is made now in developing solar sea power technology [3-40].

3-9 RENEWABLE CLEAN RESOURCES

An additional consideration of the utilization of solar energy involves the processes of hydrogen generation and bioconversion of living organic material and waste materials of organic origin into direct heat energy or fuels. Although these processes are considered to provide a clean energy source, it should be pointed out that this is not always true with respect to the combustion of organic materials, however, the combustion of organic materials is cleaner than that of the fossil fuels, such as coal, which are presently used as a major source of energy.

Hydrogen Generation. Hydrogen can be generated by electrolysis, thermal cracking, thermal chemical dissociation, and photolysis [3-41, 42, 43, 44]. Thermal cracking of water into hydrogen and oxygen requires temperatures of 2,500°C to 3,000°C; however, there are many unsolved and unforeseen technical problems associated with this process, such as the containment of high temperature liquids and high pressure gasses and the separation of the hydrogen and oxygen once the water is cracked.

Hydrogen Generation by Electrolysis. Hydrogen and oxygen can be simply generated by electrolysis, a process whereby a direct current is passed through water. The efficiency of converting electrical energy into hydrogen energy varies around 70%. A problem associated with electrolysis is the lost efficiency in converting heat into electricity. The conversion efficiency for this is approximately 30% which gives an overall efficiency of about 20%, thus it would be desirable to directly convert the heat energy into hydrogen.

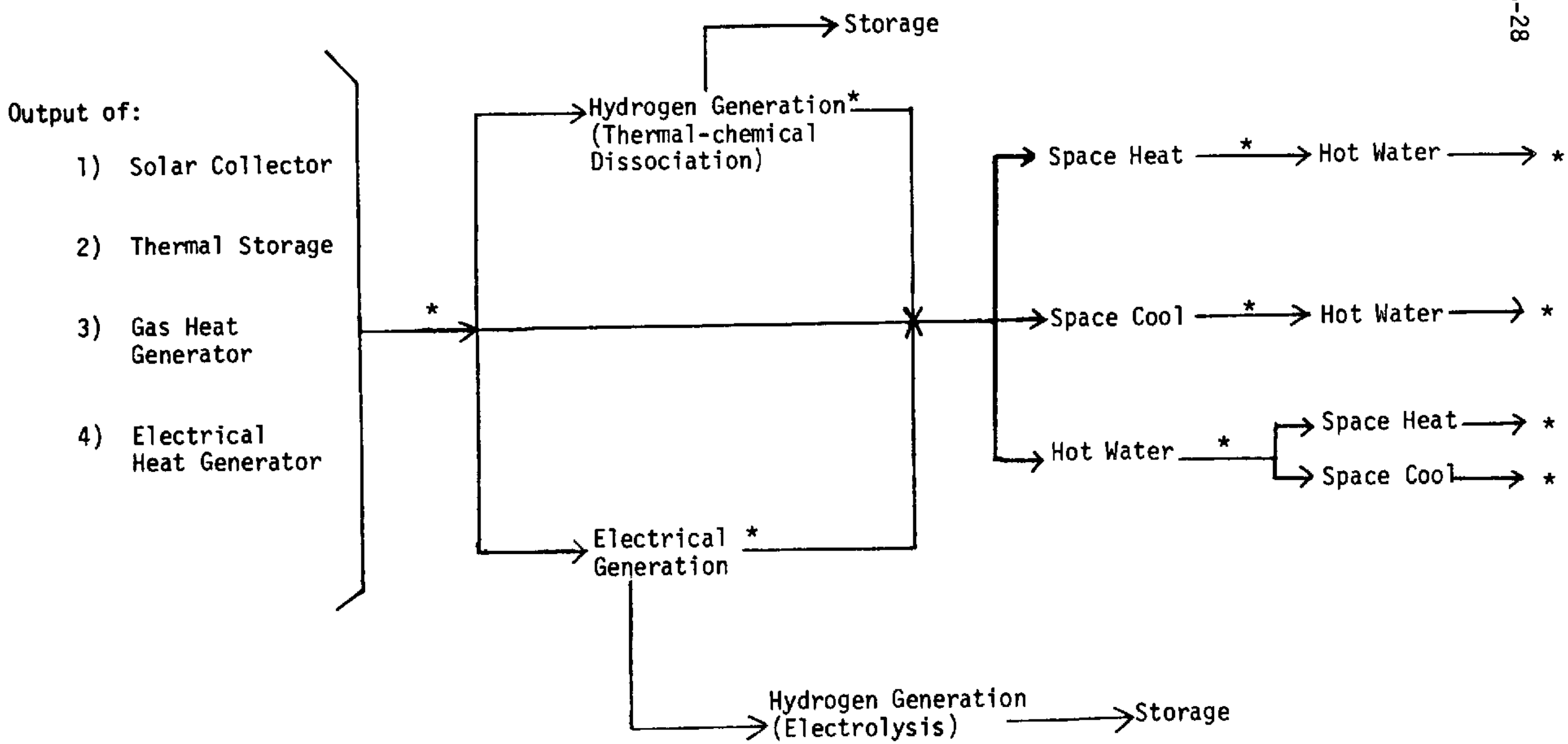
Hydrogen Generation by Thermal-Chemical Dissociation. Hydrogen can be generated in multi-step, thermal-chemical, water decomposition processes [3-41, 42]. These techniques hold promise since they operate at a much lower temperature than thermal cracking, e.g., the maximum temperature of the MARK-1 process is 750°C [3-41]; however, much work needs to be done before an efficient, practical process becomes available which operates economically over the solar collector temperature ranges.

Photolysis. Photolysis is the splitting of water by light via a photosensitizer molecule. In green plants this process is a major biochemical reaction in photosynthesis for liberating oxygen and incorporating hydrogen into organic molecules (glucose). It has been suggested that methods be introduced into this reaction which will trap the hydrogen by various acceptor materials and utilize it as an energy source. Previous research on such systems was carried out during the zenith of space research in order to obtain a self-substaining environmental system.

Other possibilities for utilizing exogenous photosensitizers have been suggested such as Cerium (Ce^{+4}) in a collector system on buildings [3-45]. This would produce hydrogen for operating heating and cooling requirements plus electricity.

Conclusions. Even though hydrogen generation by electrolysis, thermal-chemical dissociation, and photolysis is inefficient, improvement in the overall work cycle can be made by making use of the waste heat, after the generation of electricity, for space heating, space cooling, water heating and/or in thermal storage (Figure 3-9).

Hydrogen storage can be used to augment a thermal storage system or it can constitute the only energy storage. Consideration must be based on cost (both capital and operation), size, and safety. It may not be



* Thermal energy can be taken out and stored.

FIGURE 3-9. A FLOW DIAGRAM FOR POSSIBLE USES OF THE OUTPUT OF A CONCENTRATING SOLAR COLLECTOR (Each step indicates a lower level of heat) practical for the individual home, but it may be practical for a multi-dwelling application or for large buildings. For further detailed evaluation of hydrogen generation, the reader is encouraged to read the report by the Houston/Rice University Systems Design Group [3-46].

Bioconversion. There are several methods for the conversion of organic materials into fuel or heat energy. The more important ones are discussed in the following sections.

Combustion of Organic Materials Directly into Thermal Energy. The methodology for accomplishing the direct combustion of organic materials requires large amounts of land-grown and water-grown vegetation. Through advanced management practices and development of better solar conversion efficiency rates within these combustion plants, a renewable supply of energy resource can be made available. Also, through similar techniques, solid waste materials from agriculture, animals, industries and urban areas could represent a large energy source in certain areas. It should be emphasized that these schemes could be incorporated into present research efforts involved with maintaining the quality of the environment. For example, the Corps of Engineers is spending large sums of money for aquatic weed control, including water hyacinths. These plants could represent a potential energy supply by crop harvesting, thus protecting the environment from excessive use of herbicides.

Organic materials that can be converted directly into thermal energy can also be converted to more concentrated fuels by a number of biological or chemical processes. Four of these methods are briefly discussed in the following paragraphs.

Fermentation - Bioconversion of Organic Materials to Methane. Most organic materials in the presence of some moisture and in the absence of oxygen are subject to natural fermentation in which a large percentage of carbon content in the material is converted into a mixture of 50% to 70% methane and carbon dioxide.

Pyrolysis. Pyrolysis is a process of destructive distillation carried out in an unoxygenated closed system. Pyrolysis has for a long time been used commercially for producing organic by-products such as methanol, acetic acid, turpentine, and residual charcoal. This process would seem to integrate into a total system of re-cycling of materials from waste material into usable fuels, therefore helping to eliminate the problems associated with land fills, open burning, transportation to ocean areas, etc.

Chemical Reduction. Organic materials, when subjected to elevated temperatures and pressures in the presence of H_2O, carbon monoxide, and a chemical catalyst, are partially converted into oil.

Enzymatic Reduction. Closely related to the conversion of organic materials to gaseous fuel by the fermentation process is the conversion of suitable materials to valuable pure products, chemical raw materials or clean fuels by enzymatic action.

The choice of the conversion method is dependent upon the physical nature of the material to be processed. For example, fresh harvested plants contain a high water content and can be converted to a concentrated storage fuel by a biological process that operates in an aqueous medium. However, in other cases where the materials to be processed are dry, a direct combustion technique or pyrolysis would be more advantageous.

In conclusion it is recommended that research and development efforts relative to bioconversion techniques be continued with special attention given to the integration of these various processes into methods for recycling and using solid waste materials or helping to maintain the quality of the environment.

3-10. CONCLUSION

In this chapter it has been shown that there are many more ways to provide energy or generate heat energy than is normally considered. And even if considered for use, many would be discarded because they are not "economically practical". But, it must be remembered that the phrase "economically feasible" is only relative. If people are "freezing to death" and food stuffs are spoiling from lack of refrigeration then the costliness of a process to produce the necessary heat or energy to maintain a "normal" life is not really important.

In TERRASTAR the Design Group chose to look into the application of solar energy to help alleviate the "impending" energy crisis by considering how solar energy could be utilized to heat and cool buildings and looking into the problems involved in the utilization of solar energy by our society.

REFERENCES

3-1. Perry, H., Fuels for Electrical Generation, Summary Report of the Cornell Workshop on Energy and the Environment, A National Fuels and Energy Policy Study, 1972, p. 94.

3-2. McLean, J. G., and Davis, W. B., Guide to National Petroleum Council Report on United States Energy Outlook, Presentation Made to National Petroleum Council, December 11, 1972.

3-3. Donovan, Dr. P., Woodward, W., et. al., Solar Energy as a National Energy Resource, NSF/NASA Solar Energy Panel, Dec. 1972.

3-4. Davis, J. W., et. al., Energy Research and Development, Report of the Task Force on Energy of the Subcommittee on Science, Research and Development of the Committee on Science and Astronautics, U. S. House of Representatives, Dec. 1972.

3-5. U. S. Congress, Summary Report of the Cornell Workshop on Energy and the Environment, Sponsored by NSF RANN Program, Committee on Interior and Insular Affairs, U. S. Senate, Feb. 1972.

3-6. Akins, J. A., "New Myths and Old Prejudices in Energy Supply", Foreign Policy Implications of the Energy Crisis, Hearings before the Subcommittee on Foreign Economic Policy, U. S. Government Printing Office, 1972.

3-7. McCormick, W. T., Seminar at NASA/ASEE/Auburn Summer Design Program, MSFC, August 1971.

3-8. Dupree, W. G., and West, J. A., United States Energy Through the Year 2000, U. S. Department of the Interior, U. S. Government Printing Office, 1972.

3-9. McKetta, J. J., Jr., (chairman), Report to the Secretary of the Interior by the Advisory Committee on Energy, June, 1971.

3-10. Hubbert, M. K., "The Energy Resources of the Earth", Scientific American, Vol. 224, September 1971, pp. 61-70.

3-11. Federal Power Commission, The 1970 National Power Survey, Vol. IV, U. S. Government Printing Office, Washington, D. C.

3-12. Hittman Associates, Inc., Electrical Power Supply and Demand Forecasts For the United States Through 2050, Columbia, Maryland, February 1972; HIT-498, National Technical Information Service, Springfield, Virginia.

3-13. Dupree, W. G. and West, J. A., op. cit.

3-14. Task Force on Energy, Energy Research and Development, Subcommittee on Science, Research and Development, Committee on Science and Astronautics U. S. House of Representatives, December 1972, U. S. Government Printing Office.

3-15. -----Electromagnetic Radiation, NASA SP-8005, 1971, p. 7.

3-16. -----Climatic Atlas of the United States, U. S. Government Printing Office, 1968.

3-17. Kusuda, T., editor, Use of Computers for Environmental Engineering Related to Buildings, U. S. Government Printing Office 1971, p. 202.

3-18. Daniels, G. E., editor, Terrestrial Environment (Climatic) Criteria, Guidelines for Use in Space Vehicle Development, NASA TM X-64589, 1971, p. 2.10.

3-19. Ivanov, Ai. I., et al, Light Scattering in the Atmosphere, Part 2 NASA TT F-553, 1968.

3-20. Feigelson, E. M., et al, Calculation of the Brightness of Light, Consultants Bureau Inc., N. Y. 1960.2.

3-21. Grassel, H., "Calcualted Circumsolar Radiation as a Function of Aersol Type, Field of View, Wavelength and Optical Depth", Applied Optics, No. 10, Nov. 1971, p. 2542.

3-22. Telecon between Dr. Dwain Spencer, Program Manager, NSF/RANN and Dr. Leon Florschuetz, Auburn Design Program Participant, MSFO, 13 July 1973.

3-23. Kusuda, p. cit., p. 202.

3-24. -----Solar Electromagnetic Radiation, NASA SP-8005, 1971.

3-25. Lokmanhekim, M., editor, et al, Procedure for Determining Heating and Cooling Loads for Computerized Energy Calculations, ASHARE, New York, 1971.

3-26. -----The 1970 National Power Survey, Federal Power Commission, U. S. Government Printing Office, 1970, p. I-7-21.

3-27. -----U. S. Energy Study Group, Energy R & D and National Progress, U. S. Government Printing Office, 1965, p. 329.

3-28. Ref. 3-26, page I-7-9.

3-29. Ref. 3-26, page I-7-23.

3-30. Dupree, W. G. and West, J. A., op. cit., p. 19.

3-31. Starr, C., "Energy and Power", Scientific American, September, 1971, p 43.

3-32. Ref. 3-27, p. 334.

3-33. -----Task Force on Energy, Report of December 1972, U. S. Government Printing Office, 1973, p. 137.

3-34. Golding, E., Method of Assessing the Potentialities of Wind Power on Different Scales of Utilization, Proceedings of the International seminar on Solar and Aeolian Energy, Sounion, Greece, September, 1961, Plenum Press, New York, p. 156.

3-35. Stever, H. G., statement, Energy Research and Development, Hearings before the Subcommittee on Science, Research and Development, U. S. House of Representatives, May 1972, p. 181.

3-36. Hubbert, M. K., op cit.

3-37. Metz, W. D., "Ocean Temperature Gradients: Solar Power From the Sea", Science, vol 180, 22 June 1973, p 1266-67.

3-38. Othmer, D. F., "Heat and Power From Sea Water", The Encyclopedia of Marine Resources, Van Nostrand-Rinehold, New York, 1969.

3-39. Heronemus, W. E., The Possible Role of Unconventional Energy Sources in the 1972-2000 U. S. Energy Market", Hearings before the 92nd Congress, 2nd Session, May 1972.

3-40. Zener, C., "Solar Seapower", Physics Today, January 1973, pp 48-53.

3-41. Daniels, F., and Duffie, J., Solar Energy Research, University of Wisconsin Press, 1961.

3-42. -----The Promise of Technology, The President's Materials Policy Commission, Resources for Freedom, Vol. IV, June 1952.

3-43. -----Energy Research and Development, Report on the Task Force on Energy, Serial EE, December 1972.

3-44. United Nations Conference on New Sources of Energy-Solar, 1961.

3-45. Heidt, L. J., Converting Solar to Chemical Energy, Proceedings of World Symposium on Applied Solar Energy, Phoenix, Arizona, 1955, pp 275-280.

3-46. -----JSC/University of Houston/Rice University, Faculty Summer Design Program on Hydrogen Economy, 1973.

3-47. Szego, G. G., Fox, J. A., and Daton, D. R., "The Energy Plantation", IECEC, Paper No. 729168, 1972.

3-48. Oswalk, W. J., and Golueke, G. G., "Biological Transformation of Solar Energy", Advances in Microbiology, Vol. XI, Academic Press, 1960.

3-49. Kaiser, E. R., and Friedman, S. B., "The Pyrolysis of Refuse Components", Annual Meeting of the American Institute of Chemical Engineers, 1967.

3-50. Kok, Bessel, Seminar on Bioconversion Processes, NASA/ASEE/Auburn Summer Design Program, 1973.

BIBLIOGRAPHY

3-1. Atlas, R. A. and Charles, B. N., Summary of Solar Radiation Observations: Tabular Summaries, AD-819306, 1964, The Boeing Company, Seattle, Washington.

3-2. Atlas, R. A., and Charles, B. N., Summary of Solar Radiation Observations: Tabular Summaries, AD-889157, 1964, The Boeing Company, Seattle, Washington.

3-3. Moon, P., "Proposed Standard Solar-Radiation Curves for Engineering Use", Journal of Franklin Institute, Vol. 230, no 5, November 1940, pp 583-617.

3-4. Moon, P., The Scientific Basis of Illuminating Engineering, Dover Publications, New York, revised edition, 1936.

3-5. Threlkelk, J. L., Thermal Environmental Engineering, Prentice-Hall, 2nd edition, 1970 Chapter 13.

PART II. SOLAR ENERGY SYSTEMS

Part II focuses on the technology of components and systems for the utilization of solar energy. Only systems which rely on technological collection of sunlight are considered. Systems involving natural collection were discussed briefly in Chapter 3. Components which are somewhat unique to the utilization of solar energy are discussed along with storage techniques which are often required for solar energy systems.

The application of solar energy to the heating and cooling in buildings is reviewed in detail. This is followed by a brief review of proposals for systems to generate electricity for solar energy.

The treatment contained herein is not intended to be exhaustive but is primarily to acquaint the reader with the broad spectrum of possible concepts for utilization of solar energy with technological collection.

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CHAPTER 4. COMPONENTS FOR SOLAR ENERGY

A requirement for the direct technological utilization of solar energy is a device for capturing and absorbing the available sunlight. These devices are commonly termed collectors. Because of the highly variable nature of sunlight, a facility for storing the collected energy is often essential. A device for direct conversion of light into electricity, which depends for operation on incident sunlight, is the photovoltaic cell.

These components for solar energy systems are considered in this chapter.

4-1 COLLECTORS

Flat plate type collectors are appropriate for relatively low temperature applications. If higher temperatures are required, concentrating or focusing type collectors must be employed. In either case, the use of spectrally selective surfaces may, under some conditions, improve the operation of the collector. In this section, flat plate and concentrating collectors, as well as the use of selective surfaces, are briefly considered.

The flat plate collector typically consists of a surface which is a very good absorber of solar radiation and a means of removal of the absorbed energy for usage elsewhere. The method of heat removal is normally by increasing the temperature of some heat transfer fluid (usually air or water) which either flows over or through the absorbing surface. The surface is made as diffuse as possible so that the collector does not require tracking of the sun. A major difficulty is the large area for heat transfer which gives rise to large losses of the collected energy and, therefore, lowers collector efficiency. To limit these losses, the back of the collector is well insulated. The losses from the upper surface are then suppressed by placing one or more transparent surfaces above the absorbing surface (3/4" or less apart). The transparent surfaces help minimize the convective losses [4-1]. By using materials (low iron-content glass), which are transparent to the major portion of the solar energy (visible) and opaque to the infrared (heat), most of the solar energy reaches the absorber. Since the energy emitted by the absorber is at longer wavelengths (infrared), for which the covers are opaque, the effect is to minimize the outward heat losses (Greenhouse effect). The basic design and evaluation of flat plate collectors was presented in a pioneering paper by Hottel and Woertz [4-2] in 1942.

The flat plate collector has been the subject of extensive research in an effort to further minimize these heat transfer losses. The collectors presently are capable of raising the temperature of the heat transfer fluid to approximately 100°F-150°F above the ambient temperature with reasonable efficiences. However, the efficiency decreases as the collector fluid temperature rises. A common method of raising the collector fluid temperature is by increasing the number of transparent cover plates. Whillier [4-3] gives the following table as a guide to the selection of the number of cover plates.

Collector Temperature Above Ambient	Number of Covers
-10°F to 10°F	none
10°F to 60°F	1
60°F to 100°F	2
100°F to 150°F	3

It is important to note that these values are only guidelines and will vary with the materials and configuration of the collector. Tybout and Löf [4-4] found that the use of two covers is economically best for heating in most of the U.S.

The flat plate is widely recognized as a very promising method of collecting solar energy for space heating purposes. However, its usage in cooling has been limited by the relatively low temperature achieved by the collector fluid. Further attempts to increase this temperature with reasonable collector efficiencies have included the usage of selective coatings on the absorber surface, low reflectance coatings [4-5] on the transparent cover plates, better insulating materials around the back of the collector and the usage of honeycomb material to suppress convection [4-6]. The usage of selective absorber coating which is a good absorber of the shortwave radiation and a poor emitter of the infrared has results similar to the greenhouse effect mentioned earlier. Many investigators have worked in this area with very good results and NASA Marshall [4-7] has proposed an interesting flat plate collector design using this type of coating. Drawbacks of selective coatings are their instability (particularly at high temperatures) and their high cost. As mentioned earlier, the flat plate collector enjoys the advantage of not requiring tracking to follow the sun. Usage of a tracking device is in general undesirable because of cost and the very probable maintenance problems. However, to utilize the collector under optimum conditions requires that it be oriented in a certain manner. For heating in the Northern Hemisphere, it should be oriented at latitude plus 15° above horizontal, for cooling at latitude minus 8°, and for a combination of heating and cooling the optimum orientation seems to be at an angle equal to the latitude above the horizontal [4-4]. With the usage of good insulating materials and selective absorber coatings the conductive and radiative losses can be minimized to the point that convective heat losses are dominant.

Several investigators have suggested the use of honeycomb materials to suppress convective losses and as pointed out by Tabor [4-6],the desirable honeycomb material would be very thin with the properties of glass. However, Charters and Peterson [4-8] have shown analytically that the usage of honeycomb type materials for convective suppressors will only work for horizontal flat plates. This would render the addition of honeycomb type materials useless for most applications.

Tabor [4-9] suggested that in long rainless periods, the transmission through a tilted glass can drop by half in a few weeks if it is not cleaned. This would seem to be a serious drawback for flat plate collectors since any large scale application would require rather exhaustive maintenance to keep the surfaces clean. However, Whillier [4-3] reports that collector covers that to the eye appear to be extremely dirty after weeks of operation in rainless weather in a highly industrialized area have been found to transmit only 4 percent less than when clean. He suggests that a 2% loss in transmission due to dirt is a reasonable assumption. Clearly more work should be done to explain this discrepency.

The design of the absorber plate itself is well understood and documented in the literature [4-1, 3].

Studies of flat plate collectors with selective absorbers and plastic (Tedlar) covers have also been proposed. These systems offer the advantage of being light weight with the potential for achieving higher collector temperatures. The cost of using this sort of scheme, and the long term effect of the weathering of the collectors have not been determined.

Perhaps the greatest hurdle for immediate solar energy utilization is the cost of the flat plate collector. Current estimates for the collector costs range from $1.50/ft^2 to $10/ft^2 with $4 being a reasonable average value for a collector using conventional technology. Addition of the above mentioned heat transfer suppression techniques would tend to increase this cost. Tybout and Löf [4-4] estimate the $4/ft^2 can be reduced to $2/ft^2 with large-scale production.

Concentrating Collectors are used when temperatures higher than those obtainable by a flat plate collector are desired. Concentrators must follow the sun (i.e., be heliostats) and their heat absorbers are usually placed in evacuated pyrex enclosures. The efficiency of collectors can be increased by means of selective coatings such as thin films of aluminum dioxide and molybdenum, but, unfortunately many of these coatings become unstable at the high temperatures attained. The absorber's absorptivity can also be increased by corrugating the surface. Careful design assures that the pumping energy of the absorbing fluid and positioning energy of the heliostat are minimal.

Concentrators can be reflectors, refractors, or mixtures of reflectors and refractors (e.g., the Schmidt telescope). The great mass of refractors (lenses) with the possible exception of fresnel lenses are disadvantageous and only reflectors will be considered here. These consist of a shaped glass or metal surface with a highly reflective aluminum coating.

In contrast to optical telescopes which specialize in a point focus, solar reflectors can have several focus geometries:

- A point focus for high temperature
- A line focus for medium temperature
- A ring focus for medium temperature

In addition to focus geometry, the reflector shape is an important concentrator attribute. The long evacuated glass cylinder, with part of its surface reflecting light onto a line absorber, can be stacked in a planar array and yields slightly higher temperatures than a flat plate collector. The glass cylinder is a stronger structure than glass plate.

The conical collector consists of a truncated circular cone with a 90° apex angle; its cylindrical absorber is mounted at the cone's axis. By replacing the circular cross-section with a hexagonal cross-section and a mosiac of the hexagon, a wider area can be achieved.

Parabolic cylinders and circular paraboloids produce line and point focus geometries, respectively. By orientating the cylindrical collector axis in an east-west direction, the collector only needs to track the sun seasonally. A ring focus is achieved by rotating a parabola so that its focus is circular. The torus is a simple example of a ring focusing reflector shape.

A cylindrical concentrator's positioning is dictated by heat absorber material phases. Horizontal placement dictates that only the fluid phase can exist in the absorber. If a mixture of fluid and vapor is the goal, as in steam generation, then the cylindrical concentrator axis should be aligned in a more vertical position. If rotary joints cannot be avoided in the heat absorber, then these joints must be leak-proof. High costs and the need for tracking are the major drawbacks of concentrating collectors; the ability to attain high temperatures is their great advantage.

With proper modifications and accessories, medium temperature solar concentrators can be applied to water heating, space heating, steam generation, absorptive refrigeration, cooking, water and alcohol distillation, and thermal storage. Photovoltaics and storage batteries are possible for electrical generation but their high cost at present precludes utilization in all but very specialized applications.

High temperature concentrators are primarily used as solar furnaces to melt materials with a minimum of crucible contamination.

Another application suggested in the past has been to large turbo-generator or magnetohydrodynamic power stations.

Selective Coatings. Selective coatings are one method of improving the performance of solar collectors. For photovoltaic devices, a coating that will reduce the reflectance in the visible wavelengths and increase the infrared reflectance would be quite beneficial. This type of coating would provide more optical energy for transformation into electricity and, by reflecting the infrared (heat) energy, the photocell could operate at lower temperatures, where it is more efficient [4-10].

For thermal collectors, the addition of selective coatings to the absorber surface would allow the collector to operate at higher temperatures and more efficiently [4-5]. The selective coating for this application would be a good absorber of the solar radiation (below 2 microns) and a poor emitter of infrared radiation where the absorber is emitting [4-11]. This is commonly termed a high α/ε ratio, where α is the solar absorptance and ε is the thermal emittance of the absorber surface. However, it is important to note that a high α/ε ratio is not enough to insure that a surface is a good solar absorber. Many polished metals have α/ε ratios which would appear promising but their solar absorptivity, α, is so small as to render them poor materials for use as a solar absorber [4-9]. The most important thermal characteristic when radiation is the dominant mode of the selective surface is that the solar absorptance α be large (as near one as possible).

Many selective coatings become unstable at high temperatures, which prevents their usage in focusing collectors. In addition, since solar and absorber spectral distribution curves overlap more for higher temperatures, the advantage gained for focusing collectors may be more limited. Edwards [4-12] has made a rather complete study of solar selective surfaces.

4-2 ENERGY STORAGE

Almost any attempt to utilize solar energy will require the storage of the energy collected due to the intermittancy of the sunlight available. Energy storage can take the form of chemical storage, thermal storage or mechanical storage. The choice of storage form depends largely upon the form of the energy to be stored, the eventual usage of the stored energy and the economics of the various systems.

Thermal Storage methods generally fall into the categories of raising the temperature of inert substances (sensible heat) and reversible chemical or physico-chemical reaction. Many proposed solar heating systems collect the energy in thermal form and eventually utilize the energy in the thermal form. For these types of systems the storage of energy in the thermal form has the advantage of eliminating the loss that would be incurred through conversion to some other form. Since the success of any thermal storage system is dependent upon the ability to maintain the thermal energy within some container, good insulating materials, small surface-area-per-volume containers, and minimal temperature differences between storage materials and surroundings are of major concern. Unfortunately these factors are not independent and when coupled with economic considerations the choice of the "best" storage system for a given set of physical conditions is difficult to determine.

Obviously, the time or period over which the heat is to be stored influences greatly the storage design. For certain locations it has been suggested that solar energy should be collected in the summer months and stored for use in the winter (long-term), other areas would seem to only need storage from daytime to use at night (short-term storage). In a recent study [4-4] of solar house heating it has been shown that the only system which presently makes sense economically is the partially solar heated house with one-or two-day storage. When the ultimate goal of the system is cooling (building A/C), the choice of storing at a high temperature or lower temperature is available. The materials available, estimated heat loss and economics again are prime considerations.

One of the more promising methods of storing thermal energy is in the form of sensible heat. House heating units have used this approach by raising the temperature of water or rocks which are kept in insulated containers. Water has the advantage of being cheap, plentiful and having a high specific heat. However, water is limited to a temperature range of 0°C to 100°C (32°F to 212°F) to avoid freezing or boiling. Freezing is easily overcome by addition of anti-freeze, but the possibility of boiling causes concern since expensive pressurized containers would be required. Perhaps this "boiling off" problem could be handled by venting the steam to the atmosphere and adding cold water with a level-control valve. Water seems to be a good candidate for the flat plate collectors where the temperatures are between 0°C and 100°C (32°F and 212°F).

Rocks have also been used in the same manner, with air being the energy vehicle between the collector and the storage material. They are also inexpensive and readily available but have a much lower specific heat than water (about 0.2 to 1.0 Btu per pound per degree F). However, a recent study [4-13] has shown that the absorption of water as air flows over the rocks can increase efficiency by about 25%. But, for a specific amount of heat storage the volume of rocks necessary will be considerably larger than a volume of water. In using rock for thermal energy storage one must optimize between a small size for maximum mass and heat transfer and a large size for minimum blower energy use. More information is needed to determine the optimum sizing of rock for usage in thermal storage. The most important physical characteristic for a sensible heat storage material is high heat capacity per unit volume (specific heat). In this regard, metals would be good candidates for sensible heat storage were it not for cost. Tybout and Löf [4-4] estimate the cost of water storage at $0.05/lb of water.

All sensible heat candidates require a large volume. Using materials which undergo physico-chemical change can greatly reduce the storage volume required. In addition, by using materials which change phase at the temperatures of interest, the required storage temperature can be held at a lower value which reduces the heat losses. Low cost salt-hydrates have been used in storage for house heating. Major drawbacks of these materials are the limited rate at which heat may be removed and subcooling of the salts. If subcooling occurs, the material does not part with its stored heat and nucleation agents must be added to promote crystallization [4-14]. The rate of crystallization is slow and this regulates the rate at which heat can be removed. Another problem which occurs is the settling of the crystals which prevents reversibility. Foams and muds have been and are being studied to prevent this settling. Cost is also a definite problem in many phase-changing materials. The complex crystallization mechanism of salts results in large variations in the amount of heat able to be stored and released. Paraffins are being studied for low temperature storage. Problems that have been found are container compatibility and the air entrapment in the solidifying wax causing high insulating characteristics, therefore, poor heat transfer. Paraffins are inherently poor conductors and upon heat removal, an insulating film forms on the heat collection surfaces. Many phase change materials cost as much or more than the entire storage system for water or rock used for thermal energy storage.

Numerous other storage schemes have been suggested in the literature. Solid-solid transitions have been discussed but not utilized. Also, heats of reaction for certain reversible chemical reactions have been suggested as a possible storage technique. Heats of vaporization are quite high for many substances. A major problem that occurs is the increased volume due to vapor formation. One scheme which seems promising utilizes a hot and cold container but the hardware costs would seem prohibitive [4-16].

Another volume reduction technique suggestion is the use of heat of absorption in desiccant materials which absorb water from an air-water vapor mixture which flows through the bed [4-13]. This type of system would seem to have the most promise where drying is an important part of the operation. Currently, materials for this type of storage system are too expensive to make it competitive.

Photochemical reactions of substances [4-17] have been studied as a means of energy storage. In this scheme the photochemical reactions absorb the solar energy incident upon the substance and the products can be combined later under controlled conditions to release heat. More study is needed in this area before it can be a viable energy storage system as the efficiency is low.

<u>Chemical Storage</u>. There are many ways of chemically storing energy [4-18, 19]. Several methods that may be effectively used with solar energy are presented here.

Hydrogen may become a universal fuel in the decades ahead [4-20]. It can be effectively stored both in the form of a gas and in the form of a liquid, or it can be stored in solids.

Hydrogen stored as a gas at low pressure is not practical for small scale applications since it requires large storage areas; however, for large scale uses it could be stored in large abandoned mines as natural gas is now stored. Bacon, when discussing hydrogen storage for use with fuel cells [4-21], suggests storing hydrogen in steel pipes at a pressure of 100 atmospheres.

Storing hydrogen in a liquid form takes much less space, however, it requires very cold temperatures and extensive insulation.

A solution to the liquid hydrogen problem is to convert the hydrogen to ammonia, a fuel with definite possibilities for use in the future [4-22, 23].

Finally, hydrogen can be stored in solids either through adsorption as with palladium, an expensive metal, where one volume will hold up to 800 volumes of hydrogen under pressure and then will release the hydrogen under ambient conditions, or in the form of reversibly hydrogenated organic or inorganic compounds (e.g., hydrides) [4-24].

As stated by Daniels, "The storage of hydrogen for operating fuel cells or engines is a problem deserving considerable research effort [4-25]."

Storage batteries can be characterized by cost, life, specific power and specific energy. The obvious need for better methods of energy storage for eventual electrical usage has generated a keen interest in the development of cheaper and better performing batteries. Hottel and Howard [4-26] recently summarized the status of storage battery development and the following listing summarizes their findings.

(1) Commercially Available Batteries:

- The lead-acid (automotive) battery is moderately priced, reliable, efficient, and rugged. It has a life of 200 cycles and an energy capacity of 15 watt-hrs/lb at low output. Traction batteries have a longer life and lower storage capacity.
- Lead-cobalt batteries have a somewhat increased energy delivery.
- The Nickel-Iron (Edison Cell) battery has a long life (3000 cycles) but lower power output than lead-acid batteries.

- The Nickel-Cadmium has an excellent life and a reasonable energy density. Unfortunately it is expensive and uses materials which are in limited supply.

- The Silver-Zinc battery looks promising with a specific energy deliver of 60-80 watt-hr/lb and costs less than lead-acid batteries.

- Organic-Electrolyte are being considered. They have high, specific energy but the power is not high. Life is a problem.

- Several other suggested batteries look promising but must operate at elevated temperatures. These include sodium-sulfur which operates from 250°C to 350°C and Fused Salt which operates from 600°C to 700°C. The high temperature, of course,causes other problems.

Fuel Cells are an exciting prospect for energy conversion in the future. Electrochemical fuel cells do not function like regular batteries, rather,they use a continuous input of reacting materials to replace the material used in the process [4-27, 28, 29]. Fuel cell efficiency is not limited by the Carnot cycle that limits thermal processes. Efficiencies of 50, 60, and 70 percent have been reported.

Most fuel cells operate with gas, necessitating the use of catalytic electrode surfaces which have, in some cases, operational lifetimes of less than a year. These catalysts are usually rare metals which make the use of these cells for large scale systems impractical. Fuel cells can have a significant effect on energy conversion and storage. Significant experimental research is being carried out on fuel cells [4-30, 31]. For example, waste organic matter is oxidized by electrolytic ions in acid solutions and then a fuel cell is run by the ions.

Mechanical Storage of energy for a short time period by means of flywheels has been utilized to store small amounts of energy for many years; however, with the development of composite materials able to withstand higher stresses, the possibility of storing large amounts of energy in this matter seems worthy of study. Storage of gases under pressure with later utilization of the gas as a fluid under pressure to run turbines, etc. is also quite feasible, with the economics being the controlling factor. A third type of energy storage included in this classification is pumped storage. The storage of energy by pumping water to an elevated reservoir is an old and well understood procedure which is gaining in application [4-26]. All of these processes have potential for storage of large amounts of energy and should be considered in regards to the form of the energy available when storage is required and to the economics; however, their immediate application for storage in solar energy utilization schemes does not seem to be promising.

4-3. PHOTOVOLTAICS

Certain semiconductors when exposed to sunlight convert the energy of the impinging photons (light quanta) directly into electricity by a process called the photovoltaic effect. Neither moving parts nor high temperatures are required. Absorption of light by the semiconductor generates free electrical charges which can be collected on contacts applied to its surfaces. These special semiconductors, known technically as photovoltaic devices, are commonly referred to as solar cells.

The most commonly utilized type of solar cell is the silicon single crystal p-n junction cell. It is the only type which is readily available on the commercial market at the present time. The reliability of these cells has led to their utilization in over 600 U.S. and some 400 Soviet spacecraft as the primary source of electrical power. They are also used in small independent packaged power systems in applications such as remote sensing devices, transistor radios, ocean buoy lights, microwave repeater stations, highway emergency call systems [4-32] and lighthouse power equipment [4-33].

With such a well established technology for space and small scale specialized terrestrial applications, why isn't it used on a wider scale for supplying terrestrial electrical power needs? The answer is that the present cost of the cells is prohibitively high.

According to Loferski [4-34], the current cost of silicon cell arrays as determined by the market for space applications is $7,000/m^2 ($650/ft^2). The principle cause of the high cost of silicon cells is the necessity of making single crystals. While it is possible that cost reduction by a factor of 100 might be attained by making currently conceivable changes in the manufacturing process, it is not clear at present whether silicon systems based on current concepts can ever reach competitive cost levels. Work in progress includes a study of techniques utilizing thin film polycrystalline silicone [4-35].

The cadium sulfide cell is a polycrystalline film (10 micrometers) of CdS on which a film (0.1 micro-meters) of cupric sulfide is grown. According to Boer [4-36], DuPont recently estimated that large areas of this cell could be made for costs of about $5.00/m^2. However the current level of understanding of the photovoltaic effect in this system is not good enough to lead to the controlled fabrication of reliable long-lived cells from CdS.

A possible alternative cost reduction technique is the use of concentrated sunlight on photovoltaic cells at high concentration ratios. However, as concentration ratios increase, passive cooling is not sufficient to keep cell operating temperatures low enough to maintain reasonable efficiencies. At high concentration ratios, active cooling must be provided. It is possible that additional costs of concentration, tracking and cooling may be less than the additional cost of cells required if concentration is not employed. This would result in a reduced installed cost per watt without reduction in cell cost per watt. Even with reduced cell costs, concentration may be advantageous from a cost standpoint and should not be overlooked as a viable option. Schaffer and Beckman [4-37] designed and tested a photovoltaic power system with a 36 cm^2 cell area operating on a concentrated solar flux of 25 watts/cm^2 (a concentration of almost 300) which produced 40 watts of electrical power. A closed loop water cooling system utilizing pin fins on the backs of the cells required 5 watts for pumping the coolant. The system was not optimized and the cell would be correspondingly improved. Russian workers have developed and tested several systems for pumping water in remote areas, which utilize water-cooled cells [4-38, 39, 40].

Glaser [4-41] mentions organic semiconductor compounds on which research is continuing because there does not appear to be a theoretical limit for energy-conversion efficiency. However, the present efficiency of such compounds is about 0.05%, indicating that substantial progress still remains to be made.

Bailey [4-42] has proposed the possibility of creating high efficiency solar-electricity converters utilizing wave-like properties of radiation interacting with absorber-converter elements. The proposal is based on the possibility of extending concepts of power absorbing antennas and converters to the visible light range. However, the concept has not yet been demonstrated in the laboratory for the visible light range.

Further research and development are required before it can be ascertained whether the cost level required for large-scale photovoltaic solar energy conversion will be economically feasible.

REFERENCES

4-1. Hottel, H., and Whiller, A., "Evaluation of Flat-Plate Solar-Collector Performance", Transactions of the Conference on the Use of Solar Energy - The Scientific Basis, 2, part 1A, University of Arizona Press, 1955, pp 74-104.

4-2. Hottel, H., and Woertz, B., "The Performance of Flat-Plate Solar-Heat Collectors", Transactions of the ASME, Vol. 64, Feb. 1942, pp 91-104.

4-3. Whiller, A., "Design Factors Influencing Solar Collector Performance", Low Temperature Engineering Applications of Solar Energy, ASHRAE, 1967, pp 27-40.

4-4. Tybout, R. A. and Lof, G. G., "Solar House Heating", Natural Resources Journal, Vol. 10, April 1970, pp 268-325.

4-5. Hottel, H. C. and Unger, T. A., "The Properties of a Copper Oxide-Aluminum Selective Black Surface Absorber of Solar Energy", Solar Energy, Vol. 3, No. 3, 1959, pp 10-15.

4-6. Tabor, H., "Cellular Insulation (Honeycombs)", Solar Energy, Vol. 14, No. 4, 1969, pp 549-552.

4-7. Middleton, R. L., Seminar at NASA/ASEE/Auburn Systems Design Program, June 1973.

4-8. Charters, W. W. S. And Peterson, L. F., "Free Convection Suppression Using Honeycomb Cellular Materials", Solar Energy, Vol. 13, No. 4, 1972, pp 353-361.

4-9. Tabor, H., "Solar Collectors, Selective Surfaces and Heat Engines", Proceedings of the National Academy of Sciences, Vol. 47, No. 8, 1961, pp 1245-1306.

4-10. Hass, G., Schroeder, H. H. and Turner, A. F., "Mirror Coatings for Low Visible and High Infrared Reflectances", Journal of the Optical Society of America, Vol. 46, No. 1, January 1956, pp 31-35.

4-11. Tabor, H., "Selective Surfaces for Solar Collectors", Low Temperature Engineering Applications of Solar Energy, ASHRAE, 1967, pp 27-40.

4-12. Edwards, et. al, Basic Studies of the Use and Control of Solar Energy, Annual Report, Department of Engineering, University of California, NSF G9505, Report No. 60-93, October 1960.

4-13. Close, P. J., and Dunkle, R. V., "Energy Storage Using Desiccant Beds", 1970 International Solar Energy Conference, Melbourne, Australia, Paper No. 7/24, March 1970.

4-14. Telkes, Maria, "Nucleation of Supersaturated Inorganic Salt Solutions", Industrial and Engineering Chemistry, Vol. 44, No. 6, 1952, pp 1308-1310.

4-15. Ethernigton, T. L., "A Dynamic Heat Storage System", Heating, Piping and Air Conditioning, Vol. 29, No. 12, December 1957, pp 147-151.

4-16. Goldstein, M., "Some Physical Chemical Aspects of Heat Storage", U. N. Conference on New Sources of Energy: Solar, Rome, August 1961.

4-17. Neuwrith, O. S., "The Photolysis of Nitrosyl Chloride and the Storage of Energy", Journal of Physical Chemistry, Vol. 63, January 1959, pp 17-19.

4-18. Daniels, F., "Energy Storage Problems", Solar Energy, Vol. 6, 1962, pp 78-83.

4-19. Landry, B. A., "The Storage of Heat and Electricity", Solar Energy, Vol. 5, September 1961, pp 46-51.

4-20. Hydrogen Energy Systems Study, JSC/Houston/Rice Summer Systems Design Program, 1973.

4-21. Bacon, F. T., "Energy Storage Based on Electrolyzers and Hydrogen-Oxygen Fuel Cells", U. N. Conference on New Sources of Energy, E 35-Gen. 9, Rome, 1961.

4-22. Busch, C. W., Future Portable Energy Systems, M. S. Thesis, University of Wisconsin, 1962.

4-23. Lauck, F. W., et. al., "Portable Power From Non-Portable Energy Sources", Society of Automotive Engineers, Paper 608A, National Power Plant Meeting, Philadelphia, 1962.

4-24. Wiswall and Reilly, "Metal Hydrides for Energy Storage", 7th Intersociety Energy Conversion Engineering Conference, Paper No. 729210, 1972.

4-25. Daniels, F., Direct Use of the Sun's Energy, Yale University Press, 1964. pp 342-347.

4-26. Hottel, H. C. and Howard, J. B., New Energy Technology - Some Facts and Assessments, MIT Press, 1971.

4-27. Young, G. J., Fuel Cells, Reinhold, New York, 1960, Vol. 2, 1963.

4-28. Fuel Cell Technical Manual, American Institute of Chemical Engineers, 1963.

4-29. Proceedings of Annual Power Conference, U. S. Army Signal Research and Development Laboratory, Red Bank, N. J., P. S. C. Publications Committee, 1960-61.

4-30. Leibhafsky, H. A. and Cairns, E. J., "The Hydrocarbon Fuel Cell, Chemical Engineering Progress, Vol. 59, No. 10, 1962, pp 35-37.

4-31. Werner, R., and Ciarlariello, T., :Metal Hydride Fuel Cells as Energy Storage Devices", U. N. Conference on New Sources of Energy, E 35-Gen. 14, Rome, 1961.

4-32. Ralph, E. L., "A Commercial Solar Cell Array Design", Solar Energy Society Conference, Greenbelt, Maryland, May 1971.

4-33. Kobayashi, M. and Kanog, Y., "Improvement of Silicon Solar Cell Power Equipment", International Solar Energy Society Conference, Melbourne, Australia, March 1970.

4-34. Loferski, J. J., "Some Problems Associated With Large Scale Production of Electrical Power From Solar Energy via the Photovoltaic Effect", Paper 72-WA/Sol-4, ASME Winter Annual Meeting, New York, November 1972.

4-35. Fang, P. H., "Low-Cost Silicon Solar Cells for Large Electrical Power System-Growth of Silicon Layer on Steel Substrate, Solar Energy Research Information Meeting of NSF-RANN Grantees, NSF-GI-37124, University of Pennsylvania, March 1973, pp 63-66.

4-36. Boer, K. W., "Large Scale Use of Photovoltaic Cells for Terrestrial Solar Energy Harvesting, Proceedings 9th IEEE Photovoltaic Specialists Conference, Silver Springs, Maryland, May 1972.

4-37. Schaffer, P., and Beckman, W., "Photovoltaic Power Systems Using High Solar Energy Fluxes, Final Report to U. S. Army Electronics Command, Ft. Monmouth, N. J., University of Wisconsin, Engineering Experiment Station, Contract DA-28-043, Madison, Wisconsin, December 1965.

4-38. Landsman, A. P., et. al., "A Solar Energy Power Converter", Geliotekhnika, 1, No. 1, 16-21 (1965).

4-39. Lidorenko, N. S., et. al., "Solar Battery Power Plant Design", Geliotekhnika, 2, No. 2, 20-24 (1966).

4-40. Tarnizhevskii, B. V., et. al., "Results of an Investigation of a Solar Battery", Geliotekhnika, 2, No. 2, 25-30 (1966).

4-41. Glaser, P. E., "The Case for Solar Energy", Annual Meeting of the Society for Social Responsibility in Science, Queen Mary College, London, September 1972.

4-42. Bailey, R. L., "A Proposed New Concept for a Solar-Energy Converter", Journal of Engineering for Power, Transactions of ASME, 94, Series A, No. 2, April 1972, pp 73-77.

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CHAPTER 5. SOLAR HEATING AND COOLING IN BUILDINGS

The dilute and intermittent nature of solar energy has served to inhibit its utilization in many applications. One case where dilution is not as significant a deterrent is in the heating and cooling of buildings. Enough solar energy strikes the roof of the average home each year to provide nearly ten times its annual heating requirement [5-1]. Additional advantages of solar energy for heating and cooling in buildings are its widespread availability and easy conversion to thermal form. Sunshine is available in differing amounts everywhere in the world and the easiest method of capturing it is by absorption in the form of thermal energy (heat). Therefore, it is logical to utilize it directly in the heating and cooling of buildings and avoid losses that would occur by conversion to some other form. It may be emphasized that of the total energy consumed annually in the U. S., about 25% is used for heating and cooling in buildings.

It is generally agreed that of all the possible widespread uses of solar energy, this application has the highest probability of success in the near term. Although there are significant uncertainties associated with some technological and economic aspects, they do not loom as large as those associated with other potentially significant applications, such as electrical power generation. It may, however, be noted that solar electrical power generation at the building site, or at a centralized station is an excellent long term prospect. Approximately 25 experimental solar heated structures have been built in various parts of the world.

Figure 5-1 is a diagram illustrating in general form the functional relationships of the required components for solar heating and cooling in a building and Figure 5-2 is a schematic diagram of a specific example. The collection and storage required to take care of the maximum possible heating/cooling load conditions is far too expensive to be practical, and a supplemental energy source must be provided. However, the supplemental energy source must be capable of supplying the full heating or cooling requirements of the building at the time when the demand is the greatest. The thermal energy available from the collector or storage units can be used directly for space and water heating or to operate a heat actuated cooling unit. As with space heating and cooling with conventional energy sources, various pumps, controls and facilities for circulating air from the heating and cooling units to the conditioned space are required.

Figure 5-3 illustrates a systems approach to achieving the objective of identifying and evaluating systems for space heating and cooling of buildings, including water heating. There are numerous alternatives for satisfying the various requirements.

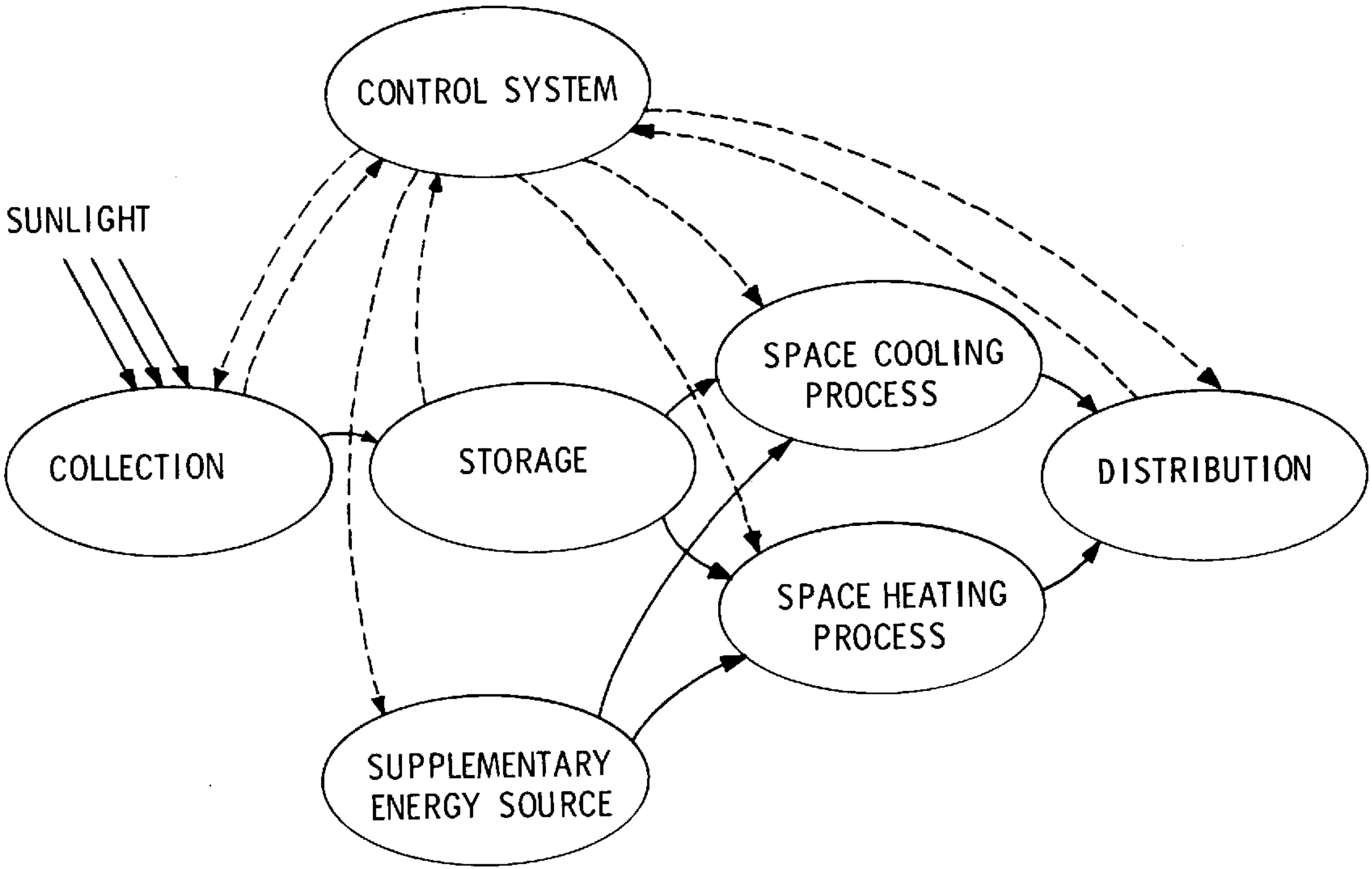


Figure 5-1. SOLAR SPACE HEATING AND COOLING

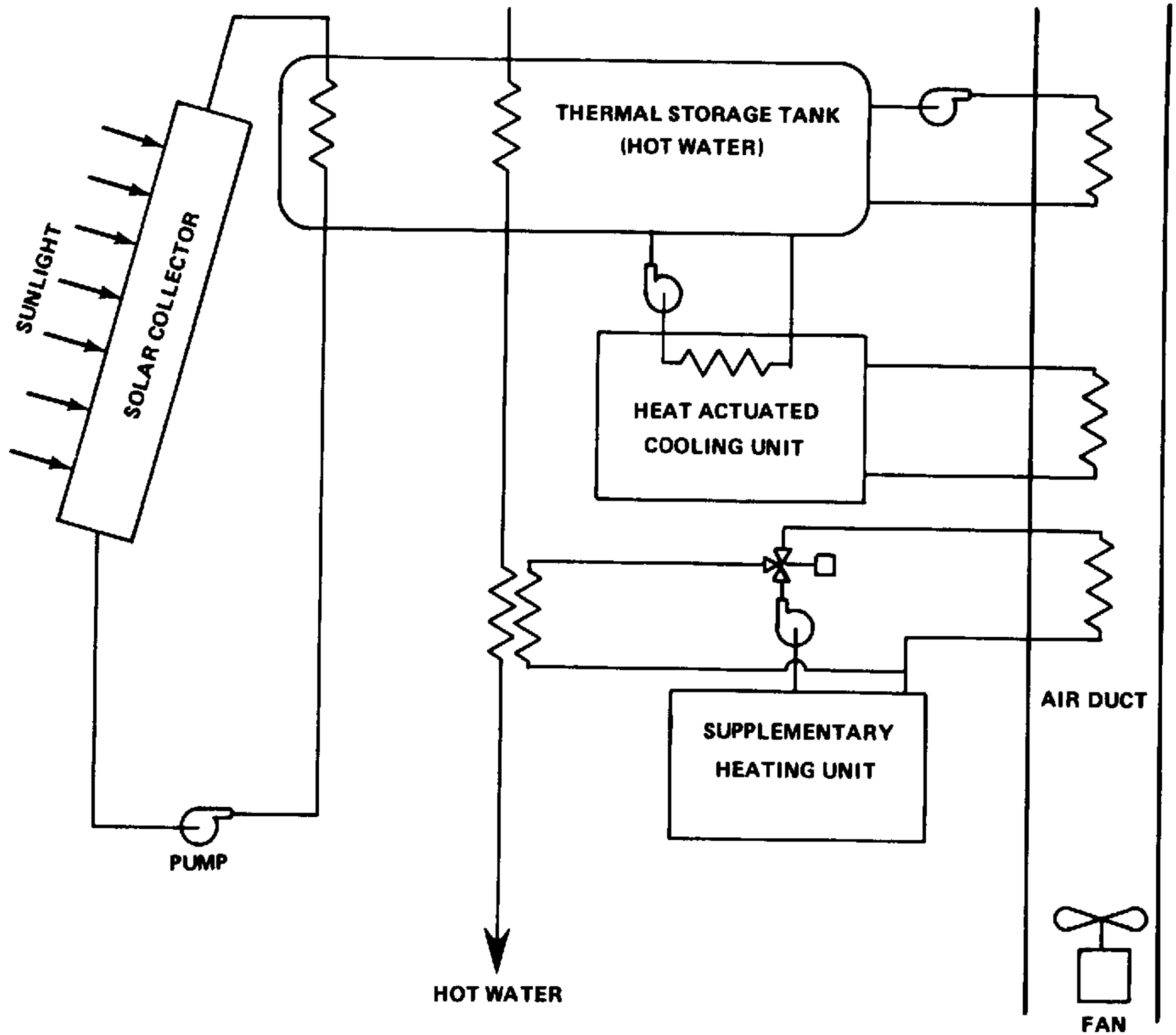


Figure 5-2. COMBINED SOLAR SPACE HEATING AND COOLING SYSTEM WITH HOT WATER STORAGE

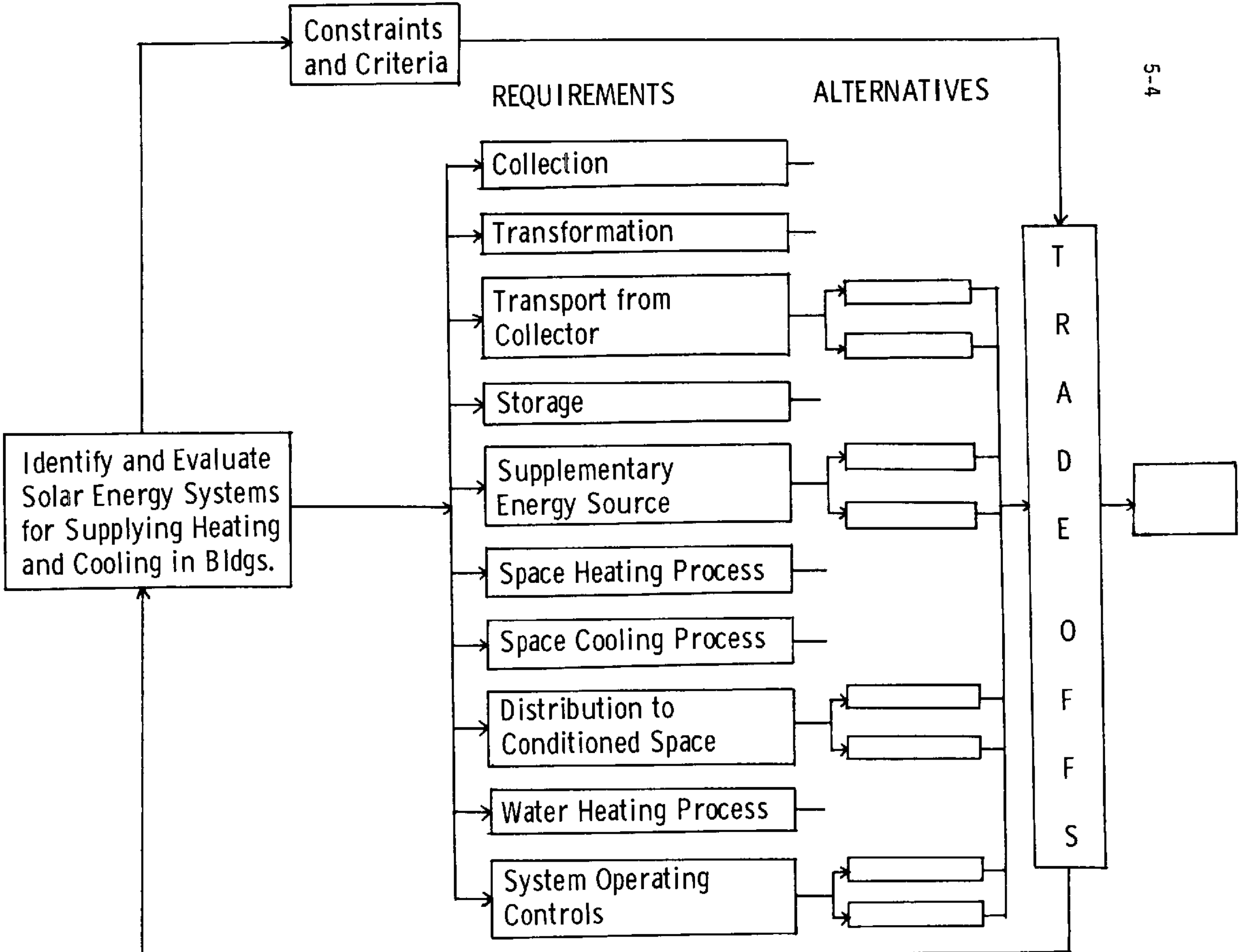


Figure 5-3. SYSTEMS DIAGRAM FOR SOLAR HEATING AND COOLING

The major decisions to be made in terms of collection are whether to use a flat plate or a concentrating type, and whether or not a spectrally selective absorbing surface should be employed. These alternatives are reviewed in Section 4-1.

The solar energy may be collected as thermal energy or transformed at the collector to electricity (e.g., photovoltaics), or both.

Transport of energy from the collector may be as thermal energy via a circulating fluid or as electricity, depending on the transformation occuring at the collector. If thermal energy is transported from the collector, it may be used as thermal energy, or transformed to mechanical or electrical energy by an appropriate conversion device.

The basic alternatives for storage depend on the form in which the energy is supplied and may be classed as thermal, chemical, or mechanical. Specific techniques for each of these categories are discussed in Section 4-2.

The supplementary energy source would ordinarily be electrical power or fossil fuel (coal, oil, or gas).

Particular space heating, space cooling, and water heating processes or devices need to be selected. The alternatives available and their integration with the collection, transformation, transport, storage, and supplementary energy source components are not detailed here but are discussed in the following sections.

Examples of the types of constraints and criteria which may affect the trade-offs made in identifying candidate systems for a particular installation might be:

- Available insolation
- Microclimate characteristics
- Building size
- Building function
- System function
  - a) Space Heating only
  - b) Space Cooling only
  - c) Water Heating only
  - d) Solar electrical power
  - e) Combined System -- any combination of the above four
- Comfort conditions
  - a) Temperature control required
  - b) Humidity control required
- Economically feasible

The approach to the systems identification just outlined focuses on technological considerations. An overriding criterion for practical application arises from the need to achieve economic competitiveness. The present chapter concludes with a discussion of the relationship between the technological and economic considerations essential to the practical implementation of solar heating and cooling in buildings.

5-1 SPACE COOLING WITH SOLAR ENERGY

Current energy use for air conditioning of buildings is only a small percentage of the national energy utilization. On a national level, the energy used for air conditioning of residential structures is about one-tenth of that for space heating.

Nevertheless, there are several reasons why solar cooling development and assessment should be examined just as intensively as solar heating. The demand for cooling is increasing at a greater rate than that for heating. The relative energy demand for heating and cooling is also highly regional and in some areas, e.g., the Southwest, more energy is already used for cooling than for heating purposes.

Cooling applications of solar energy have some inherent advantages over heating applications. Heating needs tend to be out of phase with the sun, both on an annual and a diurnal basis. The cooling load more nearly parallels solar energy supply. Therefore, energy storage requirements are not as significant a factor in cooling as in heating. It is likely that solar utilization for combined heating and cooling systems will be more attractive economically than for systems which only heat or cool. The additional capital investment required for combined solar systems as compared to a system which heats only, would not be as large a proportion of the total expense because cooling installations are inherently more costly than heating systems.

Finally, the costly summer peak electrical demand which occurs in many parts of the U. S. could be significantly reduced if solar cooling could be widely utilized. Even though the energy used for residential and commercial summer cooling is less than 3% of the total national annual consumption, it is 42% of the summer total for these building types.

Alternatives for space cooling processes which may be integrated into solar energy systems for buildings are listed in Figure 5-4. Brief descriptions of these processes are outlined in the following paragraphs, with the exception of architectural control which is outlined in the next section.

The vapor compression system is the most familiar and commonly used cooling system. Most residential and automotive space cooling, and food refrigeration machines in use in the U. S. are of this type.

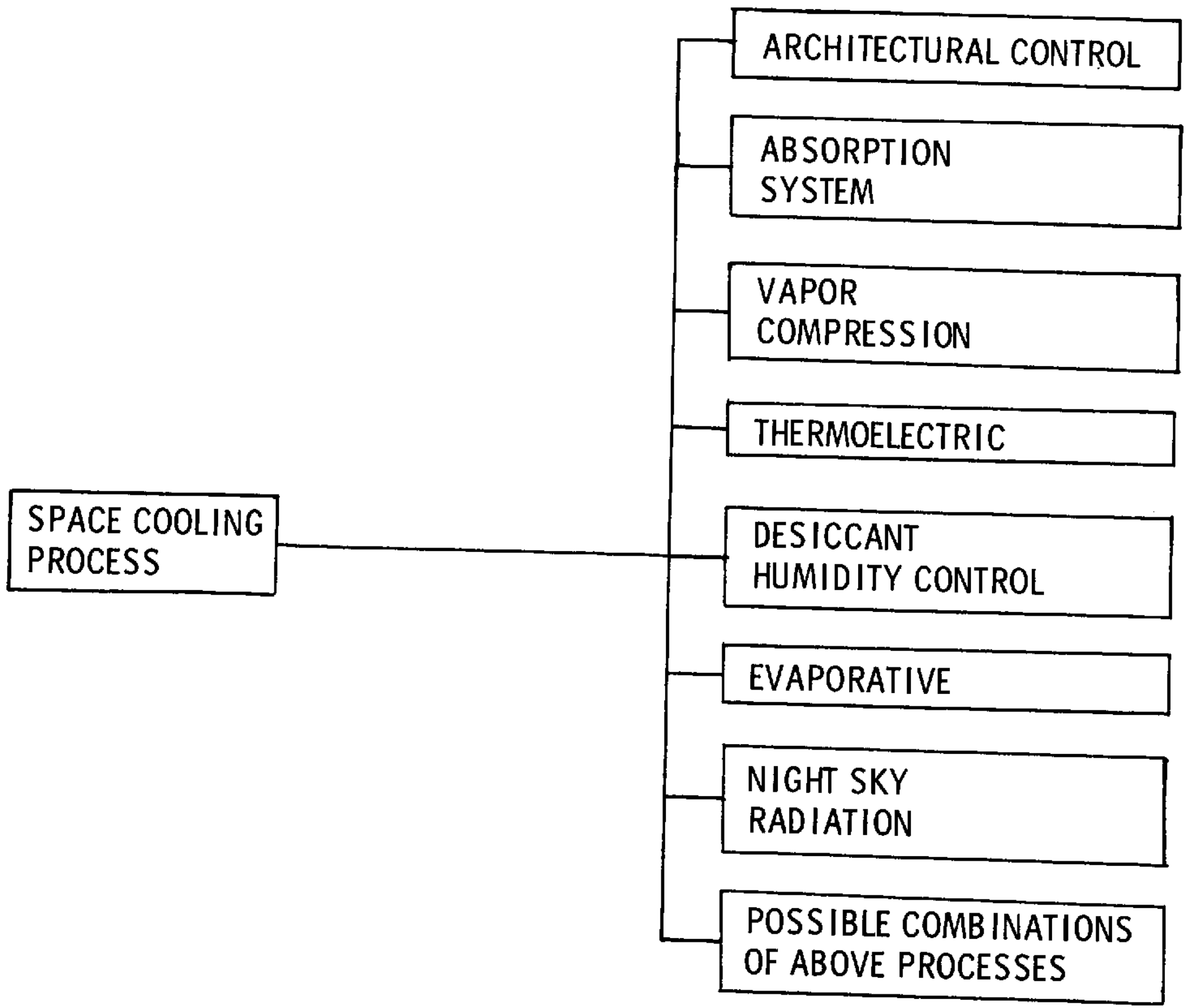


Figure 5-4. ALTERNATIVES FOR THE SPACE COOLING PROCESS REQUIREMENT

The major components are a reciprocating vapor compressor, an evaporator, a condenser, and an expansion valve as illustrated in simplified form in Figure 5-5a. The most commonly used working fluid is Freon-22. The reciprocating compressor is usually electrically driven. However, an interesting approach employing a solar driven Rankine cycle engine directly coupled to the compressor shaft has recently been reported[5-2]. In some applications, for example water chillers, the reciprocating compressor is replaced by a steam jet ejector device for compressing the refrigerant. Russian workers have investigated a freon ejector solar cooler intended for use as an air conditioner [5-3].

Absorption systems are less familiar to the general public since their main applications have been industrially oriented involving large capacity machines. These systems are heat actuated, depending on the use of two substances which are dissolved in each other and then separated. They are the refrigerant (for example, ammonia) and the absorbant (for example, water). A critical review of literature on the absorption cooling process has been published by the Institute of Gas Technology [5-4]. A continuous absorption cycle is illustrated in simplified form in Figure 5-5b. The dissolved refrigerant is boiled off from the absorbant in the generator by heat applied from the energy source. The refrigerant is then condensed giving up heat to the ambient air or a coolant such as water. After the refrigerant liquid flows through the expansion valve which drops the temperature and pressure, it is evaporated by picking up heat from the space to be cooled. The vaporized refrigerant is then reabsorbed in the liquid absorbant and pumped back to the generator. The system is similar to the vapor compression system, except that the reciprocating compressor is replaced by a generator, absorber, and pump.

Other variations on this process are the open regeneration system [5-5], the intermittant absorption cycle [5-6,7], and the three fluid absorption system [5-8]. The intermittant cycle has been proposed primarily for the production of ice from solar energy for food preservation. The three fluid system process is most commonly known to the public as a gas-fired air-conditioner. An additional variation on absorption systems is the possible replacement of the liquid absorbant with a solid.

The thermoelectric cooling system is based on the Peltier effect in which an electric current flowing across the junctions between two dissimilar materials (metals or semi-conductors) causes one junction to cool while the other becomes hotter. It is commonly employed only in small scale, specialized cooling applications.

Evaporative cooling is a process which is feasible with low humidity air in which the air is contacted with water droplets which then evaporate. It has been commonly employed in dry climates such as the Southwestern U. S.

Desicant humidity control involves the use of a hygroscopic material in either solid (such as silicon gel) or liquid (such as

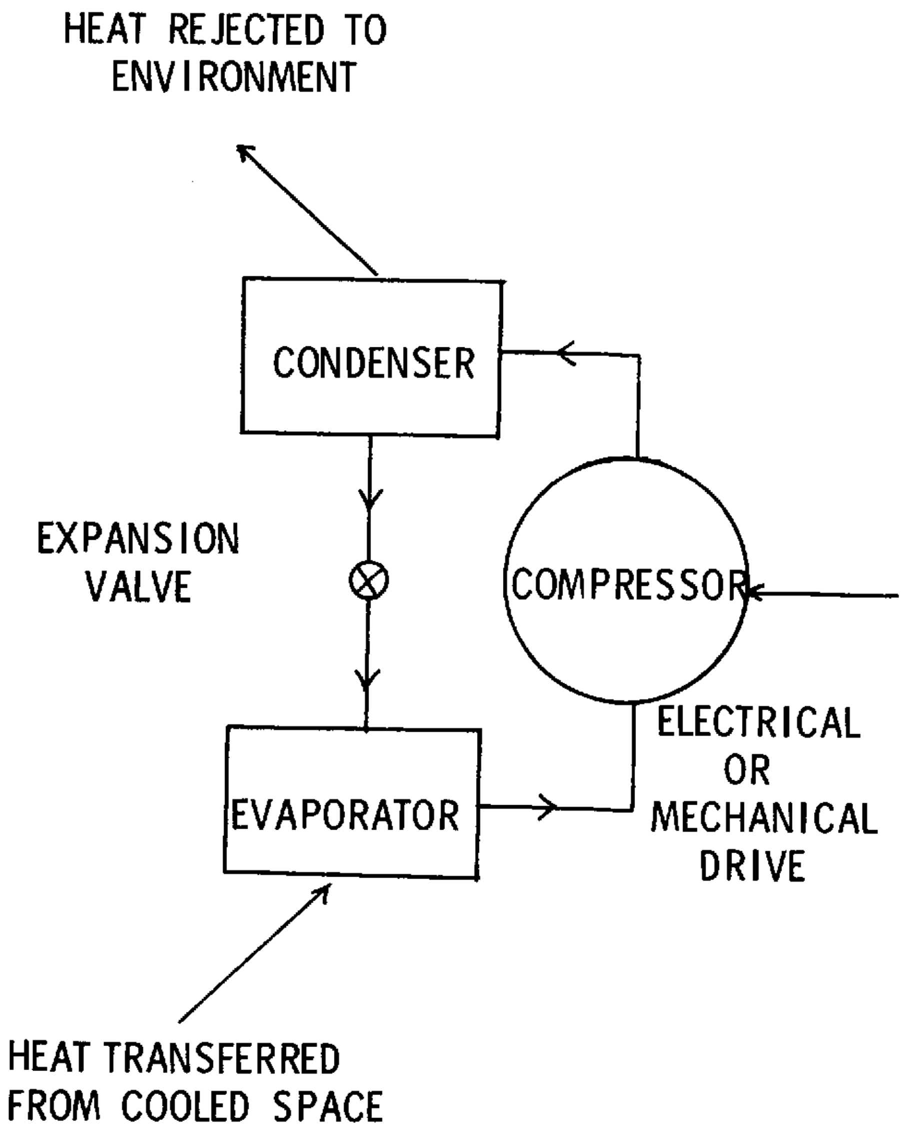


FIG. 5-5a. VAPOR COMPRESSION CYCLE

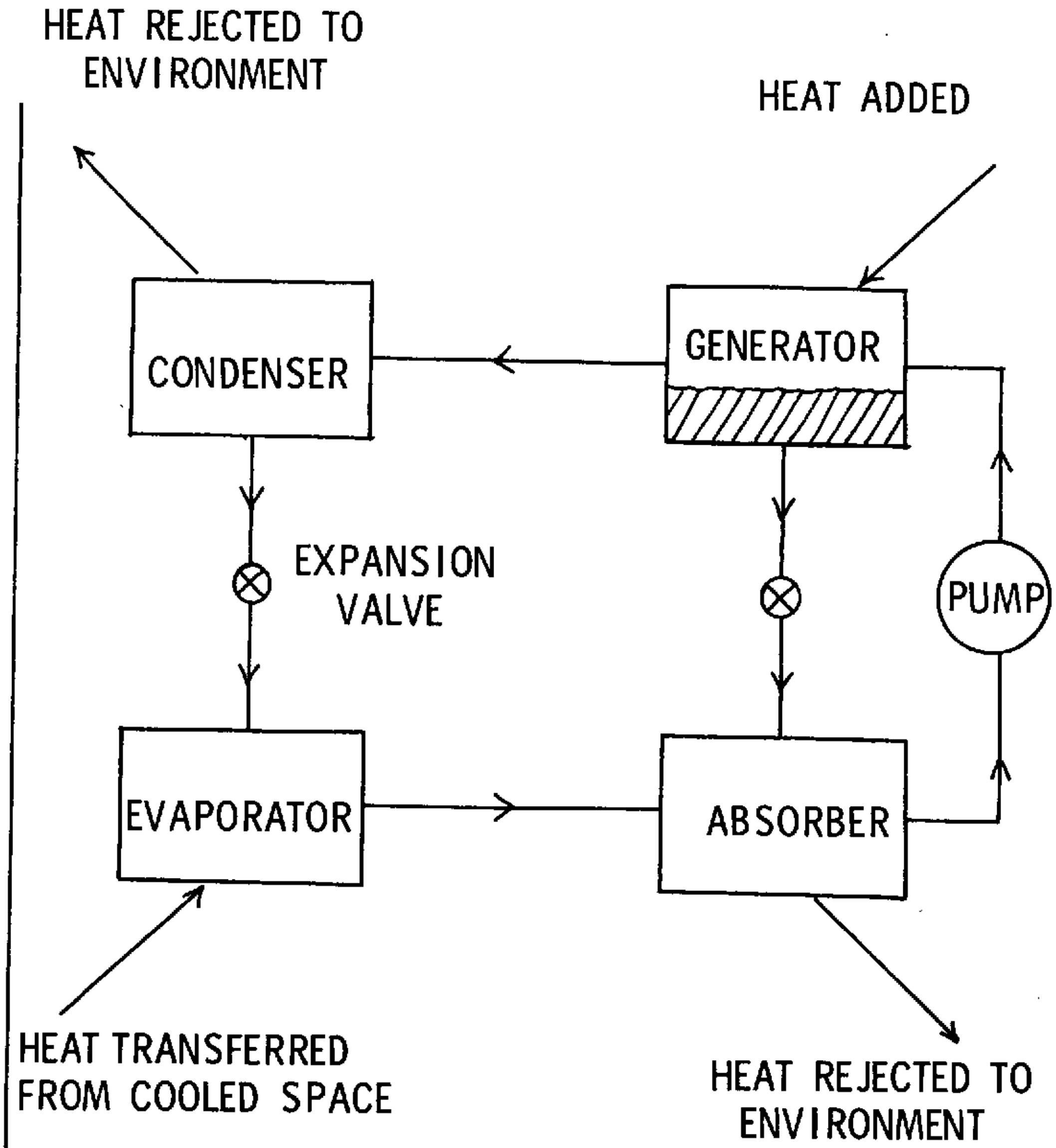


FIG. 5-5b. VAPOR ABSORPTION CYCLE

triethylene glycol) form which will remove most of the moisture from the air with which it is intimately contacted. Regeneration of the desiccant requires application of heat. Cooling of air can also be accomplished by combining this type of system with evaporative cooling. Several papers discussing the use of this technique with solar regeneration have been published [5-9, 10, 11]. Systems using triethylene glycol are in industrial and commercial use in relatively large sizes.

Cooling by night-sky radiation is also possible. In dry climates with low sky temperatures and clear atmospheres it is possible to radiate 25 to 50 Btu/hr/ft^2 from a surface at ambient temperature [5-12]. Air or water can be circulated past a large surface exposed to the night sky and cooled in this way.

Of these techniques, one of the most promising applications of solar energy to space cooling in the U. S. is the continuous absorption system. Some experimentation on the coupling of these systems with solar collectors has been performed [5-8, 13, 14, 15]. Flat plate collectors are the most convenient to use for these applications, but difficulty has been encountered in matching the relatively low temperature achieved by the collectors with the generator temperature required for smooth system operation [5-8, 13, 14]. Efficiency and smoothness of operation can be improved if heat rejection is by once through water cooling or a cooling tower. However, for residential application such heat rejection techniques may not be feasible, so that air cooling would have to be employed. One of the systems referenced above [5-14] was installed in a building which was constructed and tested in Brisbane, Australia. A number of difficulties in the operation of the system were encountered. Japanese workers have investigated the use of a parabolic cylinder concentrating collector coupled with an absorption cooling system [5-15].

Much of the past investigation has been performed by strong proponents of solar energy. There has, therefore, been a tendency on the part of some to overemphasize the favorable aspects of a particular development while omitting or at least not fully stressing the difficulties involved. Lack of sufficient funding has also hindered some of the previous investigations.

What is needed is an approach where promising conceptual system designs appropriate to particular geographical regions are selected for development. This should be followed by detailed design and testing of individual components of these systems. Finally, the complete system should be tested with solar input and under actual or simulated load conditions. Instrumentation should be complete enough so that performance of each component as it functions in the total system can be assessed. In this way the problem areas can be realistically identified and documented so that the state-of-the-art can be advanced.

According to Lof [5-16], "research and development needs in residential solar cooling are system design studies, cooling unit design, testing of combined solar heating and cooling assemblies, economic evaluations, component development and improvement, and manufacturing (industrial) engineering development." He also points out that "major deterrents to commercial entry into the manufacture and sale of solar heating systems are insufficient design information, high capital (initial) costs of the units, and the uncertainty of a profitable market." While the last remark was made in reference to solar heating systems, the same points apply even more strongly to solar cooling systems and to combined systems. As a specific illustration, it appears that to date no major manufacturer of absorption cooling equipment has spent any significant effort on research and development toward absorption cooling units with input from solar collectors and/or storage facilities and their integration with supplementary energy sources.

5-2 SPACE HEATING WITH SOLAR ENERGY

Approximately 25 experimental solar heated structures have been built in various parts of the world. Various combinations of collector types, heat storage techniques, heat distribution techniques, and auxiliary energy supplies have been used.

Alternative space heating processes are indicated in Figure 5.6. The first alternative (architectural control) is to be distinguished from those remaining, each of which involve mechanical control systems. A useful way of comparing these two basically different types of control systems is presented in the following table:

Characteristics of Two Systems

Architectural Control Systems	Mechanical Control Systems
° Basically fixed in nature	° Usually has moving parts
° Little maintenance required	° Regular maintenance required
° Reliability easily achieved	° Reliability an important constraint
° Low operating energy consumption	° High operating energy consumption
° "Passive" control achieved shading devices, natural landscaping, building orientation, thick walls, natural ventilation	° "Active" control necessary: pumps, fans, working fluids, distribution systems, storage systems, valves, monitors, electromechanical controls

The effect of landscaping design and architectural design including use of overhangs and shading devices on the use of energy to heat and cool buildings is shown graphically in Fig. 5.7. If the building has areas of glass exposed to direct summer sun, the capacity of the air conditioning system must be increased and operating costs are higher for summer cooling. If this glass is shaded, either by architectural devices or by proper location of trees and shrubbery, then the operating

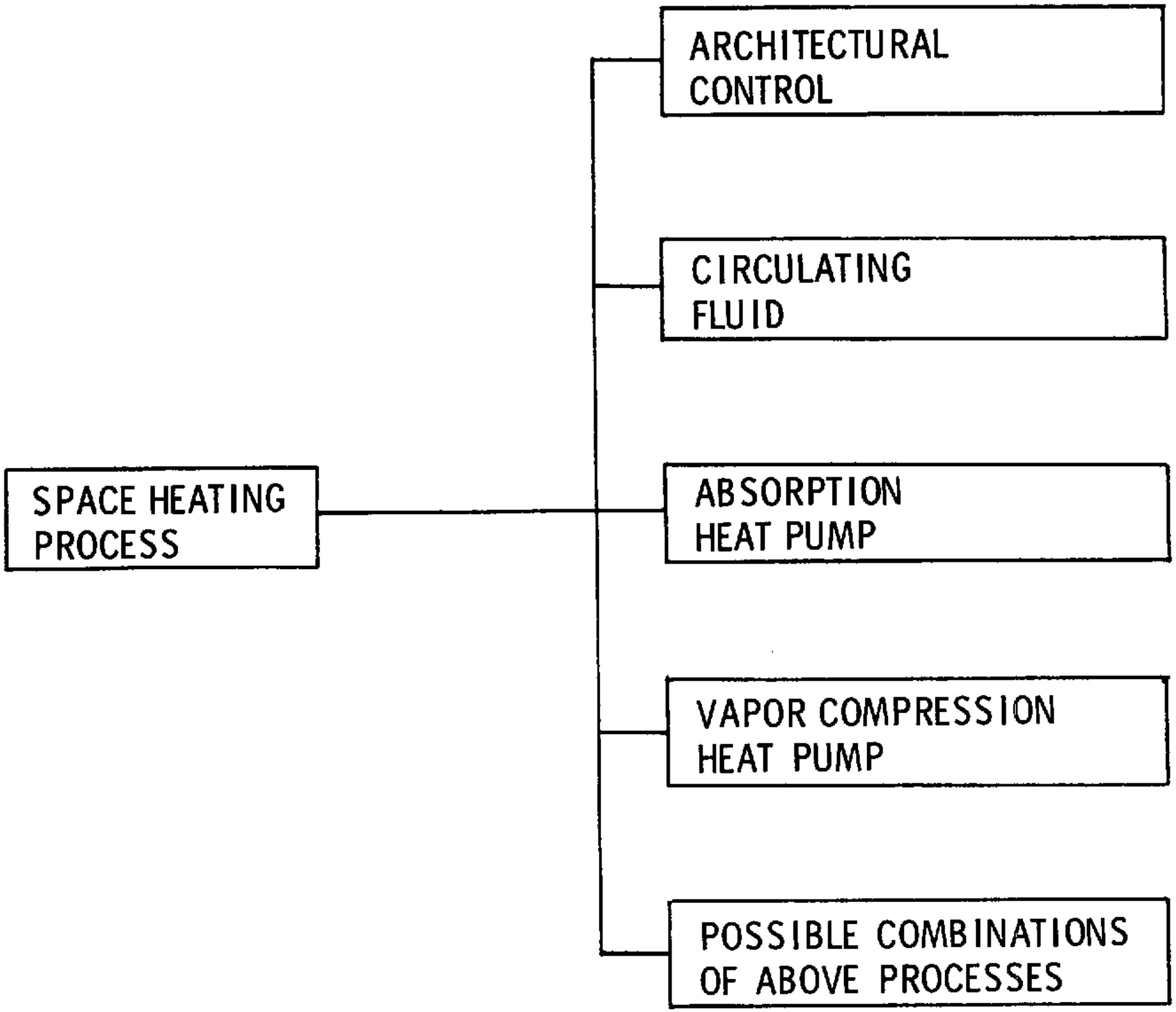
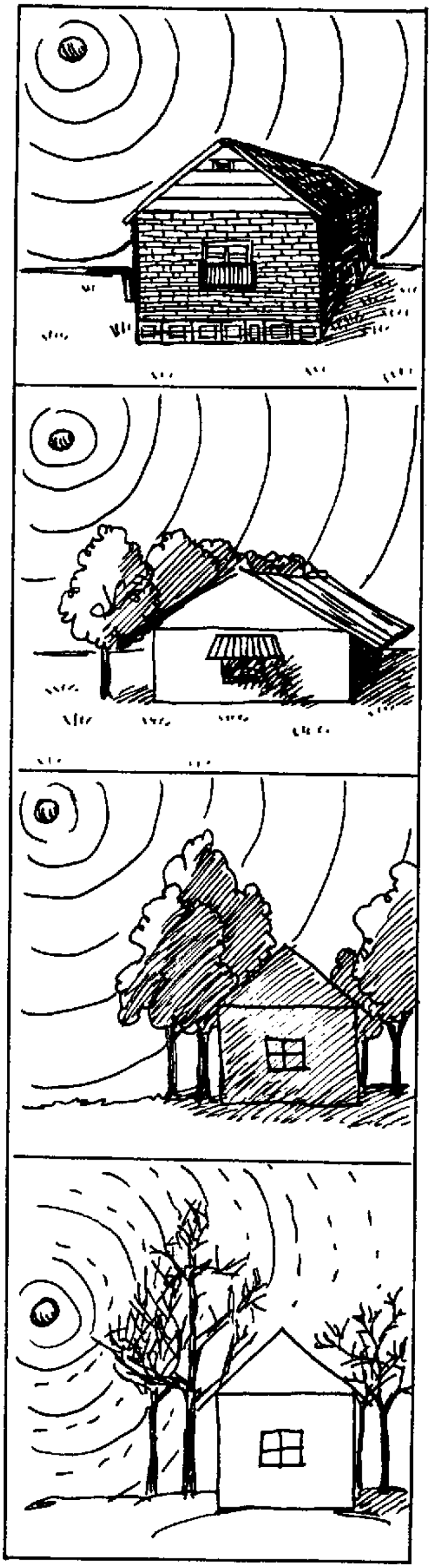


Figure 5-6. ALTERNATIVES FOR THE SPACE HEATING PROCESS REQUIREMENT



House designed with no roof overhang or exterior window shading has higher summer operating costs.

Passive control of insolation: requires less energy for cool living. May require more heating in winter.

Wise placement of deciduous tree shades house in the summer, reduces operating costs.

Deciduous trees shed leaves in the winter, allow penetration of solar energy into house and reduces operating costs.

Figure 5-7. ARCHITECTURAL AND LANDSCAPING DESIGN AS AN AID IN HEATING AND COOLING BUILDINGS costs and capacity of equipment can be reduced. It is not always clear to what quantifiable extent "good" architectural design is responsible for energy conservation or passive solar utilization, but in a rational cost-benefit analysis of the application of solar energy to heating and cooling the inherent characteristics of both systems and their life-cycle costing must be compared. General reference to the study of architectural control of energy can be found in [5-17, 18, 19]. Two selected specific examples of application are in [5-20,21].

The second alternative (circulating fluid systems) usually involves direct hot air distribution to the heated space or circulation of hot water to radiators or heating panels.

The principle of operation of the vapor compression and vapor absorption heat pumps is the same as for the corresponding cooling cycles as described in the previous section (see Figs. 5.5a, b). The mode of operation, however, must be modified so that the condenser (and absorber in the case of the absorption cycle) transfers heat to the heated space and the evaporator picks up heat from the environment.

Selected characteristics of some completed solar heated buildings are presented in Table 5-1. These buildings all utilize some type of circulating fluid heating process. More detailed summaries of these and other completed solar structures may be found in [5-12, 22]. The performance of these experimental systems has been measured with widely varying degrees of completeness and accuracy. The capabilities of the various designs have been roughly established. As a result there is no uncertainty about the technical possibilities of satisfactory solar space heating systems. The heating systems which have been designed, while workable, are not fully engineered. The best systems will need to be selected, the design of the systems needs to be optimized, and several components of these systems need further development and engineering.

Concepts which utilize the heat pump principle with solar input would ordinarily be used only in a combined system where both space heating and cooling is desired, as discussed in the section 5-4.

5-3. WATER HEATING WITH SOLAR ENERGY

Solar water heaters are commercially manufactured in Australia, Israel, Japan, USSR, and the United States. The use of solar water heaters is increasing in Australia, however, it is decreasing at the present time in Japan and the United States.

The technology of solar water heaters is well developed; further product engineering and larger scale manufacturing would result in cost reductions and increased utilization. A complete review of this application solar energy may be found in [5-23].

Table 5-1 SELECTED CHARACTERISTICS OF SOME COMPLETED SOLAR HEATED BUILDINGS

Building Location	Building Type	Date Completed	Collector Type	Transport from Collector	Storage Medium	Supplementary Heat Source	Space Heating Process
Lexington, Mass.	Residence	1958	Flat plate, blackened aluminum, glass covered.	Water	Water	Oil-fired furnace	Warm air circulation
Denver, Colorado	Residence	1958	Flat plate overlapped glass.	Air	Gravel	Gas-fired furnace	Warm air circulation
Albuquerque, New Mexico	Office Building	1956	Flat plate, blackened aluminum, glass covered.	Water	Water	Electrically driven heat pump	Hot water circulation
Princeton, New Jersey	Laboratory	1959	Flat plate, blackened sheet metal glass covered.	Air	Glauber Salt	-	Warm air circulation
State College New Mexico	Residence	1953	Flat plate, blackened steel sheet, glass covered.	Air	Glauber Salt	Gas-fired furnace	Warm air circulation
Dover, Mass.	Residence	1949	Flat plate, blackened sheet metal, glass covered.	Air	Glauber Salt	Added after two heating seasons	Warm air circulation

5-4. COMBINED SYSTEMS FOR HEATING AND COOLING WITH SOLAR ENERGY

The same major components can be used to supply hot water, space heating, and space cooling. Selected characteristics of some completed solar heated and cooled buildings are summarized in Table 5.2. In the strict sense, the cooling processes used in these structures are not solar cooling, but primarily rely on radiation to the cool night sky. The air or water so cooled is used to cool the storage medium. During the day air or water is circulated to the cooled storage medium and then used to cool the interior space of the building. The first three buildings in Table 5.2 are discussed by Lof [5-12], including schematic diagrams of the Tucson, Arizona laboratory system. In the Phoenix test structure [5-24] water stored in shallow ponds or plastic bags on the roof serves for both collection and storage. In winter, moveable insulation is then placed over the water volume during the night so that heat collected and stored during the previous day with the insulation removed is transferred to the interior of the structure. In summer, the operation is reversed so that coolness stored during the night by radiation to the sky causes heat transfer from the interior of the structure to the cooled water during the following day. Cooling techniques using night sky radiation work best in hot, dry climates with relatively large diurnal temperature variations.

Several proposed concepts for integrated systems using heat pumps are outlined in Table 5.3. Three proposals involve the use of vapor absorption cycles [5-15, 25, 26]. One suggests a Rankine engine directly coupled to a vapor compression machine [5-2]. Fig. 5-8 is a preliminary climate control system schematic diagram showing one possible approach for integrating the auxiliary equipment with the solar system equipment [5-25]. The operation of such systems in actual structures with solar energy input remains to be demonstrated. One residence on which testing is in the beginning stages involves a combined thermal and electric system [5-27].

The identification of optimum combined systems is a difficult task because of the large number of possible schemes for arranging and interconnecting the various components. For example, selection of the point at which supplementary energy is added to the system can significantly affect the economy of operation. Some work currently in progress includes investigation of this question [5-28]. A number of combined system schemes are discussed in [5-12].

Since the economic obstacles to solar space heating and cooling are so fundamentally important, it is critical that the design of the solar heating and cooling system be carefully optimized with respect to the cost in order to be as competitive as possible with conventional systems. Because of the large number of design options and design variables, optimization for minimum cost is a very complex problem. Economic aspects of solar heating and cooling in buildings are addressed in the following section.

5-5 ECONOMICS OF WATER HEATING, SPACE HEATING AND SPACE COOLING WITH SOLAR ENERGY

The total cost of solar thermal energy for buildings can be

TABLE 5-2. SELECTED CHARACTERISTICS OF SOME COMPLETED BUILDINGS WITH SOLAR HEATING AND COOLING

Building Type Location, and Date Completed	Collector Type	Transport from Collector	Storage Medium	Supplementary Source	Space Heating Process	Space Cooling Process
Laboratory Tucson, Arizona 1959	Flat Plate green painted copper, no cover plate	Water	Water	Electrically driven heat pump	Hot water circulation	Night sky radiation
Residence Washington, D.C.	Flat Plate blackened, corrugated sheet metal, plastic & glass covered	Water	Water & Rocks	Oil-fired furnace	Hot air circulation	Evaporation, radiation to night sky of flowing water
Residence Amado, Arizona 1955	Flat Plate screen type, loose weave black cloth, glass covered	Air	Rocks	None Provided	Hot air circulation	Evaporation, radiation to night sky of flowing water
Small Test Building Phoenix, Arizona 1967	Water ponds over ceiling	None	Water ponds over ceiling	None	Radiation from ceiling panel	Night sky radiation

5-3. SELECTED CHARACTERISTICS OF SEVERAL PROPOSED CONCEPTS FOR SOLAR HEATING AND COOLING IN BUILDINGS

Building Type & Location, Reference	Collector Type	Transport from Collector	Storage Medium	Supplementary Source	Space Heating and Cooling Processes
Small office Building Lincoln, Massachusetts [5-25]	Flat Plate black absorbing surface, two glass covers	Water	Water	Gas or oil fixed furnace, electric vapor compression cooler	Lithium bromide-water absorption machine combined with circulating water
Residence Primary design for Huntsville, Alabama [5-26]	Flat Plate selective coating on aluminum plate, two Tedlar plastic covers	Water	Water favored at this time	Electrical oil, or gas	Water - ammonia absorption cycle heat pump
Residence Newark, Delaware [5-27] (under construction)	Flat Plate cadmium sulphide solar cells, one glass, one plexiglass cover	Air	Phase Change Salts	Electric, other (?)	Heat pump, possible augmentation by night sky radiation
Residence Feasibility computations for Tokyo, Japan [5-15]	Concentrating type-parabolic cylinder	Santotherm 66	not discussed	not specified	Lithium bromide - water absorption cycle
Heating Cooling System discussed without reference to building types [5-2]	Flat Plate	not specified	not discussed	not discussed	Rankine cycle engine directly coupled to vapor compression heat pump

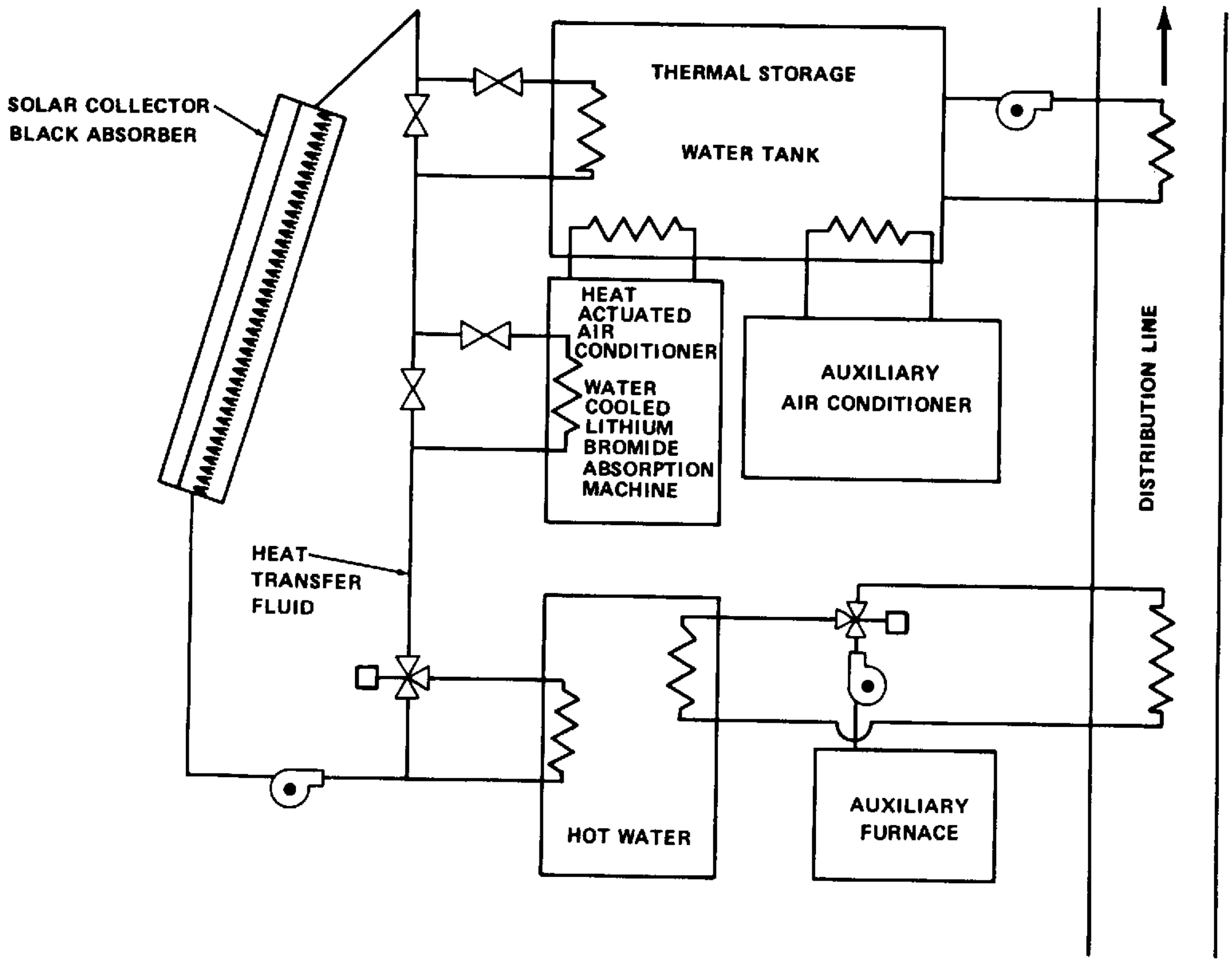


FIG. 5-8. EXAMPLE OF COMBINED SOLAR SPACE HEATING AND COOLING SYSTEM

divided for purposes of discussion rather naturally into the costs of collection (i.e., the collector) and the costs of utilization (i.e., storage, pumps, and controls).

Costs of Collection. A simple calculation can be made which illustrates the fundamental cost problems which arise in the collection of solar energy.

The equivalent cost of the heat delivered by a flat plate collector can be calculated based on the following assumptions:

- The collector can be manufactured for \$2 per square foot.
- The collector lifetime is 20 years.
- The interest rate on capital is 8 percent.
- The long term daily average heat collection is 700 BTU per square foot per day.
- All of the heat which is collected can be utilized.

The capital costs can be amortized over the lifetime of the collector to determine the equivalent cost of heat obtained from the collector.

$$\text{Cost of Heat} = \frac{(\text{Capital Cost})\ (\text{Capital Recovery Factor})}{(\text{Total Heat Collected During Year})}$$

$$= \frac{(\$2)\ (0.102)}{(700 \times 365)} \qquad = \quad \$0.80/10^6 \text{ Btu.}$$

The basic collector costs of $\$2/\text{ft}^2$ is an estimate of costs which may be achievable in mass production. They are optimistic estimates and will require good design and high volume. Attempts to reduce the basic collector costs (e.g., by use of plastics instead of glass) could also result in a reduction in the collector lifetime and therefore may not reduce the net cost of heat.

It is not easy to reduce the costs of the collector. The basic materials are already manufactured in large quantities for other purposes and so the economies of mass production as far as the basic materials are concerned have already been realized. Of course the manufacturer of the collectors themselves has never been on a mass production scale and so economies can be realized there. Another promising concept for cost reduction is to use the collector as part of the roof covering or perhaps even a structural part of the building.

The heat cost obtained represents the costs of collection only. It does not include any of the costs of utilizing this heat. It will be shown in the following section that these costs can easily increase the total cost by a factor of two or more.

It must be reemphasized that this heat cost assumes that all of the heat collected can be utilized. This implies either that long term storage of the heat is possible or that the demand for heat is very uniform over the entire year. This requirement is most nearly met by hot water for domestic use since demands are quite uniform over the year. It is not met for space heating alone or space cooling alone where the amount of heat required may be very seasonal. For example, if solar heat is required for only 4 months during the year the cost of useable heat from the collector will effectively be tripled. This accounts for the desirability of using the solar heat for both heating and cooling since the heat is more fully utilized.

Heat energy is available from coal at a cost of $\$0.50/10^6$ BTU and from oil or gas at a cost of $\$1.80/10^6$ BTU [5-29]. Under these idealized conditions the cost of solar heat is approaching economic competitiveness and will become even more competitive as the costs of the alternate fuels rise.

While somewhat oversimplified this brief analysis outlines the fundamental economic obstacles which must be overcome if solar heating and cooling are to be economically competitive.

Costs of Utilization. The most recent and most thorough studies of total system costs have been performed by Tybout and Lof [5-1, 30]. Using an elaborate computer model they determined the least cost design for a typical solar house in 8 cities in the United States. Their results for heating only are summarized in Table 5-4. Their results for combined heating and cooling are shown in Table 5-5. The comparison of solar heating and cooling costs with alternate fuels is summarized in Table 5-6.

The general broad conclusion which can be reached from the results of this study is that solar heating and cooling is less costly than electric heating and cooling and is approaching competitiveness with gas and oil in some areas of the United States.

An interesting insight into typical system costs can be obtained by examining the total system costs for least cost solar heating designs. These costs are summarized in Table 5-7. Also shown are the total additional system costs per square foot of collector. In all but one of the eight cases the total added cost is close to \$4.50 per square foot of collector. Since the collector cost is $\$2.00/ft^2$ this means that a reasonable estimate might be that the costs of utilization would be about \$2.50 per square foot of collector. Total system costs are approximately 2 to 2.5 times the collector costs.

Table 5-4 LEAST COST SOLAR HEAT
(25,000 BTU/DD House)

Location	Collector Area (ft^2)	Solar Heat (%)	Cost ($/$10^6$ Btu)
Santa Maria California	261	75	1.10
Albuquerque New Mexico	261	60	1.60
Phoenix Arizona	208	72	2.05
Omaha Nebraska	521	47	2.45
Boston Massachusetts	347	40	2.50
Charleston South Carolina	208	55	2.55
Seattle Tacoma Washington	521	45	2.60
Miami Florida	52	70	4.05

Table 5-5 LEAST COST SOLAR HEATING AND COOLING
(25,000 BTU/DD House)

Location	Collector Area (ft^2)	Combined Heating and Cooling (% Solar)	Cost ($\$/10^6$ BTU)
Albuquerque New Mexico	577	63	1.73
Miami Florida	1150	60	2.13
Charleston South Carolina	1150	68	2.47
Phoenix Arizona	1150	33	1.71
Omaha Nebraska	1150	59	2.48
Boston Massachusetts	1150	65	3.07
Santa Maria California	289	52	2.45
Seattle-Tacoma Washington	577	43	3.79

Table 5-6 COMPARISON OF SOLAR HEATING AND COOLING COSTS WITH ALTERNATE FUELS ($\$/10^6$ Btu)

Location	Conventional Fuel			Solar Energy		
	Gas	Oil	Electricity	Heating	Cooling	Combined
Albuquerque New Mexico	0.89	2.07	4.62	2.08	3.29	1.73
Miami Florida	2.81	1.73	4.90	-	2.26	2.14
Charleston South Carolina	0.96	1.55	4.22	3.34	3.49	2.46
Phoenix Arizona	0.79	1.60	4.25	2.87	2.05	1.70
Omaha Nebraska	1.05	1.32	3.24	2.93	5.41	2.49
Boston Massachusetts	1.73	1.76	5.25	3.02	8.72	3.08
Santa Maria California	1.42	1.62	4.36	1.58	1.46	2.46
Seattle-Tacoma Washington	1.83	2.00	2.31	3.14	1.95	3.78

Table 5-7 TOTAL SYSTEM COSTS - LEAST COST SOLAR HEAT
(25,000 Btu/DD House)

Location	Collector Area (ft^2)	Extra Cost of Solar Heating System ($)	Unit Cost of Collector Area ($/$ft^2$)
Santa Maria California	261	1145	4.40
Albuquerque New Mexico	261	1145	4.40
Phoenix Arizona	208	905	4.35
Omaha Nebraska	521	2045	3.90
Boston Massachusetts	347	1430	4.10
Charleston South Carolina	208	990	4.75
Seattle-Tacoma Washington	521	2175	4.20
Miami Florida	52	535	10.03

References

5-1. Tybout, R. A. and Löf, G. O. G., "Solar House Heating", Natural Resources Journal, April 10, 1970, pp. 268-326.

5-2. Teagam, W. P. and Sargent, S. L., "A Solar Powered Combined Heating/ Cooling System with the Air Conditioning Unit Driven by an Organic Rankine - Cycle Engine", Paper EH 94, International Solar Energy Conf., July 1973, Paris, 10 pp.

5-3. KaKabaev, A. and Davletov, A., "A Freon Ejector Solar Cooler", Geliotekhnika, 2, #5, 1966, pp. 42-48.

5-4. Ellington, R. T., Kunst, G. and Peck, R. E., "The Absorption Cooling Process, A Critical Review of Literature", Institute of Gas Technology Research Bulletin, No. 14, Chicago, August, 1957.

5-5. KaKabaev, A. and Khandurdyev, A., "Absorption Solar Refrigeration Unit with Open Regeneration of Solutions", Geliotekhnika, Vol. 5, No. 4, pp. 28-32, 1969.

5-6. Eisemstadt, M., Flanigan, F. M. and Farber, E. A., "Tests Prove Feasibility of Solar Air Conditioning", Heating, Piping, Air Conditioning, Vol. 32, No. 11, Nov. 1960, pp. 120-126.

5-7. Swartman, R. K. and Ha, V. H., "Performance of a Solar Refrigerat System Using Ammonia - Sodium Thiocyanate", Paper 72-WA/Sol-3, ASME Winter Annual Meeting, November 1972, New York.

5-8. Farber, E. A., "The Direct Use of Solar Energy to Operate Refrigeration and Air Conditioning Systems", Revista des Colegio de Ingeneros, Arquitectos Y Agrimensores de Puerto Rico, 15, #3, 1965, pp. 59-64.

5-9. Dannies, J. H., "Solar Air Conditioning and Solar Refrigeration", Solar Energy, 3(1) : 34-39, Jan. 1959.

5-10. Akopdzhanyan, E. S., "Solar Air Conditioning with Solid Absorbents", Geliotekhnika, 3, #6, pp. 81-85, 1967.

5-11. Mullick, S. C. and Gupta, M. C., "A Simple Method for Desorption of Water by Solar Heating of the Absorbent Solution Used for Dehumidification of Room Air", Paper EH 100, International Solar Energy Congress, Paris, July 1973, 12 pp.

5-12. Löf, G. O. G., "The Heating and Cooling of Buildings with Solar Energy", Chapter in Introduction to the Utilization of Solar Energy, McGraw-Hill, New York, 1963, pp. 239-294.

5-13. Duffie, J. A., Chung, R. and Löf, G. O. G., "A Study of a Solar Air Conditioning", Mech. Engng., August 1963, pp. 32-35.

5-14. Sheridan, N. R., "Performance of the Brisbane Solar House", Solar Energy, Vol. 13, 1972, pp. 395 401.

5-15. Kimura, K., Vdagawa, M. and Ohmura, G., "Exploring in House Cooling with Solar Energy - study on the Horizontal Parabolic Cylinder Type of Collector", Paper EH 95. International Solar Energy Conf., July 1973, 10 pp., Paris.

5-16. Löf, G. O. G., "Hearings Before the Subcommittee on Science, Research and Development on the Committee on Science and Astronautics", House of Representatives, 92nd Congress, Second Session, May 1972 .

5-17. Fitch, J. M., American Building Two, The Environmental Forces That Shape It, Houghton Mifflin, 1972.

5-18. Givoni, B., Man, Climate and Architecture, American Elsevier, 1969.

5-19. Olgyay, V., Design With Climate, Princeton University Press, 1963.

5-20. Boaz, J. N., ed., Architectural Graphic Standards, 6th edition, John Wiley and Sons, Inc., New York, 1970, p. 67ff.

5-21. Dubin, F., "Energy for Architects", Architecture Plus, July 1973, p. 38ff.

5-22. Löf, G. O. G., General Report, "Use of Solar Energy for Space Heating", E/CONF. 35/GR/18(S), U.N. Conference of New Sources of Energy, August 1961.

5-23. Löf, G. O. G. and Close, D. J., "Solar Water Heaters", Chapter VI in Low Temperature Engineering Application of Solar Energy, R. C. Jordan (ed.), ASHRAE, New York, 1967, pp. 61-78.

5-24. Hay, H. R. and Yellot, J. I., "A Naturally Air Conditioned Building", Mechanical Engineering, January 1970, pp. 19-25.

5-25. "Solar Heated and Cooled Office Building for the Massachusetts Audubon Society - Initial Planning and Design", final report to Massachusetts Audubon Society, Arthur D. Little, Inc. And Cambridge Seven Associates, June 1973.

5-26. O'Neill, M. J., McDanal, A. J. and Sims, W. H., "The Development of a Residential Heating and Cooling System using NASA-derived Technology", LMSC - HREC 0306275, Lockheed Missiles and Space Company, Huntsville, Alabama, Nov. 1972.

5-27. Boer, K. W., "A Combined Solar Thermal and Electrical House System", Paper EH/08, International Solar Energy Conference, July 1973, Paris, 11 pp.

5-28. Beckman, W. A. and Duffie, J. A., "Modeling of Solar Heating and Air Conditioning", Solar Energy Research Information Meeting of NSF - RANN Grantees, Sponsored by NSF-RANN, NSF-GI-37124, University of Pennsylvania, March 1973, pp. 90-95.

5-29. Hottel, H. C. and Howard, J. B., New Energy Technology: Some Facts and Assessments, MIT Press 1971.

CHAPTER 6. SOLAR POWER GENERATION AND DISTRIBUTION

Power generation using solar energy could go a long way in helping to meet future energy demands. Solar energy can be successfully converted into thermal energy, electrical energy, and chemical energy. A great deal of research and development remains to be done on these systems and the distribution of their energy in order to make such systems practical.

6-1 POWER GENERATION

The generation of power is one of the eventual uses of solar energy collection. Many systems have been proposed and some already built. These vary from the central power station in the gigawatt scale to fractional kilowatt machines.

Löf and Karaki [6-1] estimated that the cost of electricity from solar energy might be as low as 3.75 cents/kWh if in mass production the flat plate collectors can be made for $2.00/ft^2. Selcak and Ward [6-2] have made calculations using a computer and presented minimum costs for different types of collectors. Oman and Bishop [6-3] have studied the generation of electricity by the use of concentrating collectors and found that a minimum cost was obtained (75¢/kWh) when a 9.80 meter diameter paraboloid was used with a Stirling Engine. In isolated regions, where power is not available from a large generating system, Girardier and Masson [6-4] found that the cost of power from the "sun" was cheaper than the cost of power obtainable from a diesel plant for shaft Hp under 8 Hp. For the U.S., where electric power, in most areas, is available at fractions of 1¢/kWh at the generating station and about 1¢ to 3¢/kWh to the consumer, it seems impractical to build solar generating plants except for research purposes in order to be ready when their need comes. All these costs for power are for daytime generation without storage. According to Löf [6-1] storage will increase cost of generation by 25 percent.

Löf and Karaki [6-1] analyzed the alternative of concentrators vs. flat plate collectors and of small installations vs. large installations. Their analysis shows that there is little economic advantage in going to the large central station concept because approximately 95 percent of the cost of the system is for the collector by itself. The problems associated with the gigantic size of gigawatt solar central stations, due to insulation and pumping plus the losses through an energy distribution system, overcome any advantage obtained by using a large and highly efficient turbine. The real cost of these large systems has not been properly assessed in the literature. From their analysis it is also seen that flat plate collectors, while yielding lower Carnot efficiencies, cost much less and are less sensitive to cloud cover than concentrators; thus, even though the collecting area might be bigger, the important parameter, cost/kWh, might be lower. An important factor that deserves study is the energy and materials investment associated with the production of both concentrating and flat plate collectors. This might be a significant parameter from a conservation point of view.

Power generation might be more attractive as a substitute to air conditioning during the summer in those parts of the country where space cooling is not of great significance. This is because the air conditioning implies an extra cost for an added comfort while the generation of electricity constitutes "liquid savings" on the equipment.

Power Generation - Thermal. Solar central power stations will necessarily require extremely large collector areas due to the dilute nature of solar energy. These big stations (see figure 6-1) might be used to power electric generators or to supply process steam in an industrial area. Due to economics, the collection temperature of solar energy cannot be as high as the temperatures obtainable from conventional sources of fuel like fossils and nuclear.

An efficiency idealization, the Carnot efficiency $(T_H - T_L)/T_H$, where T_H is the high inlet temperature and T_L is the low output temperature, both in degrees Kelvin (Kelvin = Centigrade + 273),should be in mind at all times. A modern coal burning electrical power station can have an efficiency of 42 percent which deteriorates with increasing operating time. An obvious rule of thumb is, "T_H should be very high and T_L should be very low for high Carnot efficiency." Most solar energy proponents have not given attention to heat rejection.

Because losses occur at every turn in solar energy conversion, only a fraction of the Carnot efficiency can be attained in practice. A nominal expected efficiency of 20 percent could be a bench mark for a thermal, solar energy station.

If power is transmitted in the form of electricity, more losses occur on conversion and conduction. The reduction of conduction losses by means of super conductive materials under a cryogenic environment is being studied [6-5].

Insofar as serious central power generation is concerned, the idea of solar central power generating stations started with C. G. Abbot, of the Smithsonian Institution (U.S. Patent No. 2, 247, 830 dated July 1, 1941) who is the originator of a thermal collector mounted in an evacuated pyrex tube located at the focus of a reflecting parabolic cylinder for solar energy conversion. This idea is common to many succeeding proposals for solar energy powered central stations.

A general characteristic of collectors with concentrating ratios higher than a few times is that they must track the sun; that is, they are heliostats. Gulf General Atomic (1972) has been working on these and has devised a fixed reflector with a movable collector configuration in order to reduce the effort to track the sun.

Many variants have been proposed for the collection and conversion of solar energy. Three of these proposals are presented as examples:

- The Meinel proposal
- The Minnesota-Honeywell proposal
- The Hildebrandt proposal

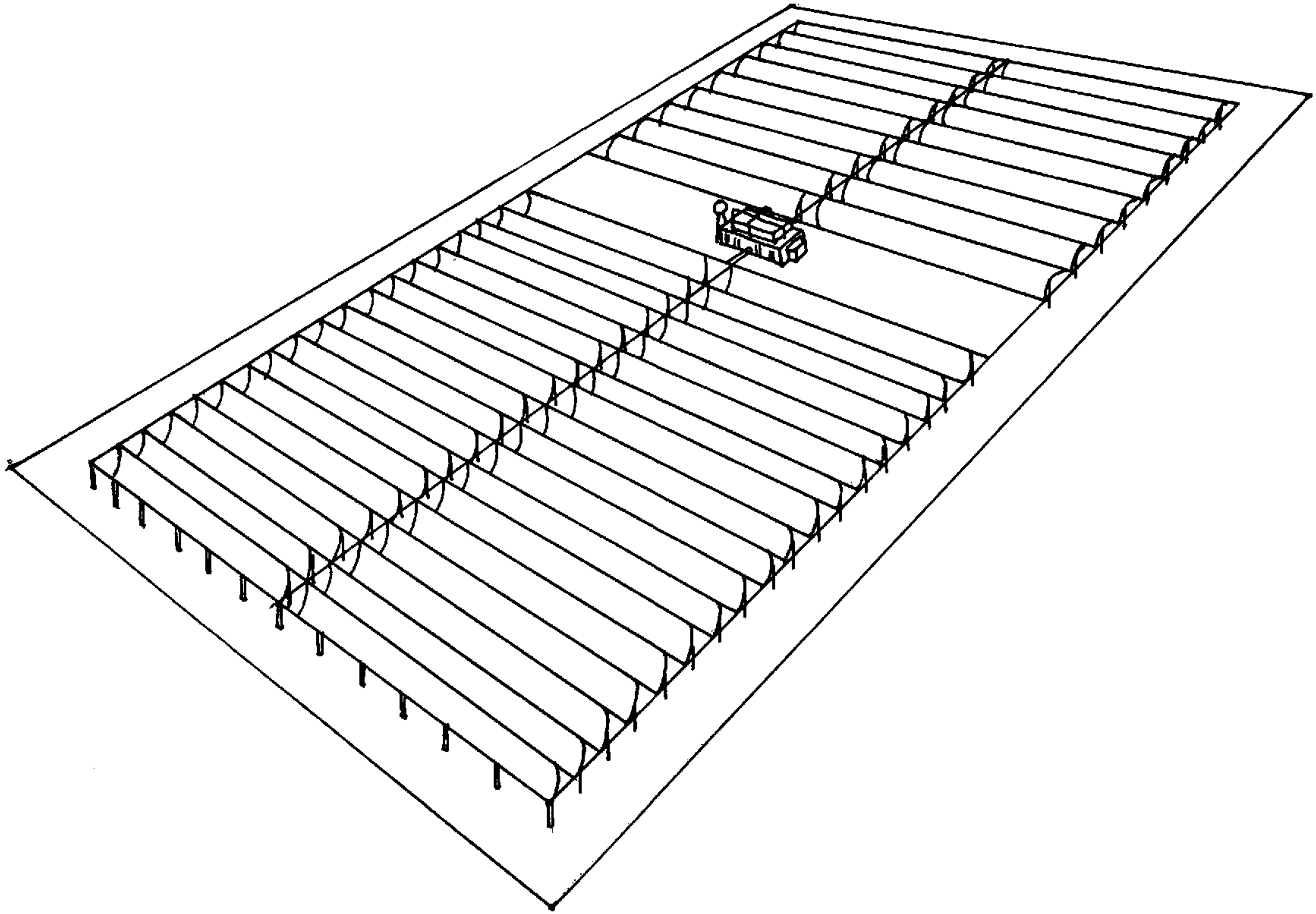


Figure 6-1. SOLAR FARM

<u>The Meinel Proposal</u>. The Meinels [6-6, 6-7, 6-8] proposed the following combination for a central power station.

- A seven mile by seven mile square farm of solar concentrating collectors.
- Each concentrator is a linear Fresnel lens which focuses rays into an Abbot collector.
- The thermal tube of each Abbot collector has special optical coatings.
- Liquid sodium is pumped through the thermal tube.
- The heated liquid sodium is pumped into a heat exchanger-heat storage tank whose medium is molten sodium chloride.
- Steam exits from the storage tank and drives a conventional turbogenerator.

An important feature of the Meinel proposal is the optical coating of the thermal tube. The gist of their experiments is:

- Silicon and germanium coatings have the highest efficiency in converting solar radiation to thermal energy but are limited to 350° C temperature.
- Molybdenum coatings has lower efficiency than the silicon coatings but can attain temperatures as high as 750° C.
- The lifetime of these coatings has not been determined.

A modular cylindrical parabolic reflector with an Abbot collector is in existence at the University of Arizona as a test and demonstration model.

<u>Minnesota-Honeywell Proposal</u>. The constituent elements of the University of Minnesota-Honeywell Company proposal [6-9] are:

- A cylindrical parabolic reflector with an Abbot collector.
- A thermal tube consisting of a gravity assisted heat pipe.
- Molybdenum and aluminum oxide coating; their coating pre-existed the Meinel coating.
- A heat exchanger as receiver for the thermal energy.
- A water-steam storage tank (one hour storage).
- Conventional high and low pressure turbines.

The heat pipe walls are stainless steel (Fe, Cr, Ni) and the heat transfer fluid is water.

Some of the early results from experimental observations are presented:

- Stainless steel has shown a large thermal inpedance which is undesirable.
- A 40° C temperature drop has been the lowest observed in the heat pipe-exchanger system.
- This temperature drop is increased by subsequent hydrogen formation in the heat pipe as a result of corrosion.
- Aluminum oxide and chromium diffuse into each other and form a ruby compound which degrades their heat collecting efficiency.
- Coating lifetime is not considered a problem if the temperature is kept below 400° C.

Besides the heat pipe, another special feature of this proposal is a water-steam storage device. During periods of high insolation, steam is bled prior to the high pressure turbine and introduced at the bottom of a water tank. The intimate steam and water contact produces a highly efficient heat exchanger. During low insolation periods, the pressure is reduced in the storage tank and the vapor is passed from the top of the tank into the low-pressure turbine. This system then provides a "constant" power input to the mechanical system.

The Hildebrandt Proposal. Hildebrandt, Haas, Jenkins and Colaco [6-10] proposed utilizing magnetohydrodynamic (MHD) generation for large scale electrical power generating plants. The main characteristics of their proposal include:

- A closed cycle MHD generator requires helium gas seeded with cesium vapor for electrical conduction.
- Thermal energy converts the helium gas to high velocity.
- Subsequent interaction with a strong magnetic field produces direct current (DC) electrical power.
- DC to AC converters supply transmission lines for distribution.
- Storage is accomplished with electrolytic-dialytic cells which dissociate water into hydrogen and oxygen.
- Fuel cells convert H_2 and O_2 back to DC electricity.

Magnetohydrodynamic (MHD) generators are based on the same electro-magnetic induction utilized in a conventional generator [6-11]. The moving conducting wire of a conventional generator is replaced with a moving stream of gas seeded with metallic ions.

MHD generators are lightweight although bulky in volume. They are well suited for topping units and quick-start generators for emergency situations.

The chief advantage of the MHD generator for solar utilization is its light weight enabling mounting atop a tower which facilitates the concentration of solar radiation from a mosaic of mirrors distributed at ground level.

Power Generation using Photovoltaics. Photovoltaics (solar cells) have many possible applications where there's a need to generate electricity [6-12, 6-13]. The operation of photovoltaics was described in 4-3 where it is also mentioned that their costs must come down considerably before they can be considered competitive for electrical generation on a wide scale.

Photovoltaics can be used as a source of electricity in the house. Boer [6-13] is experimenting with CdS cells where they will be built into the roof of a house and then used to supply part of the electrical energy used in running the various electrical lights, appliances, motors, etc.

Photovoltaics can be used for large scale power generation. Basically they could be classified as terrestrial power plants and space power plants, although, Cherry [6-14] proposes a "solar rug" where a solar array and transmission system "floats" 50,000 feet above the surface of the planet. The main purpose of the "Solar Rug" concept is to supply electrical energy to supplement the peak daytime power demands.

A large terrestrial central power station could be constructed using photovoltaics (solar cells) [6-15 - 6-20]. The output of the power plant could be either electricity or it could be hydrogen generated by electrolysis. The general form of the power plant might be solar cell arrays mounted on ground based support mechanisms that track the sun. The outputs of the arrays would feed either the conversion and distribution system of the plant or feed an energy storage device.

The main problem with a terrestrial based power plant that uses solar cells is the same as with the previously mentioned satellite system, the costs of the solar cells. This then leads to design requirements that minimize the costs of the cells versus the power output. One obvious result is that these plants would be better located in areas of maximum solar insolation (desolate sunny areas) [6-19]. The land system has a significant problem in that large storage capabilities are necessary to overcome the intermittency of solar radiation on the surface of the earth. There are various sources of projected costs for these types of systems [6-19, 6-20]; however, they all allow for significant reductions in the costs of manufacturing of solar cells under mass production. Ralph [6-19] suggests a cost of $1.00/watt which implies a cost reduction on an order of 3 to 4 magnitudes.

Extensive research should be done in the areas of photovoltaics, in reducing costs, increasing efficiency, and in the plant design itself, including the problem of storage.

Probably the most ambitious project to utilize photovoltaic cells is the satellite solar power station concept (see Figure 6-2.) [6-21 - 6-23]. The basic premise of this concept is that the satellite would be placed in synchronous orbit above the Earth which would allow it to collect solar energy on an almost continous basis (blackouts would occur when the satellite is in the Earth's shadow but this happens for very short periods and only a few days in a year). This scheme would eliminate the problems of storage common to Earth-bound systems. The collected energy of the station would be beamed to the Earth using microwaves.

Much of the technology involved in the construction of such satellite power station exists at this time; however, there are significant problems with costs and mass production as well as unforeseen technical problems in transporting and controlling the satellite that must be solved before it can be considered technically and economically feasible. The solar energy to electrical energy conversion is to be accomplished by using photovoltaic cells. It is stated that the cost of solar cell production must be reduced to about $375 per kw [6-16]. This is a reduction of about 500:1 over current costs. The microwave portion must meet the design requirements and be able to be mass produced at a cost of about $133 per kw. Likewise, the ground receiving antenna and rectifier (Rectenna) must meet the necessary specifications as well as be able to be mass produced at a cost of about $100 per kw. Finally, a space shuttle must be developed such that the cost of transporting and assembling the satellite is in the neighborhood of $506 per kw. Thus, if all unforeseen technical problems are manageable and all of the preceding comes true, then the satellite power station concept may become feasible.

The actual development of the satellite power station must wait until the aforementioned costs are realized and the space shuttle program is well underway. The space shuttle will need to make an estimated 500 flights in order to transport the station into space and a maintenance rocket will be required at least once a year.

The desirability of constructing the satellite power station is very complicated and many questions must be answered before a decision can be reached. A detailed study must be done on the merits of constructing a large central solar power station (photovoltaic and thermal) on Earth rather than in space. It may be possible that the system on Earth may be cheaper in the long run since a reduction of 500:1 in the costs of solar cells would also make them more attractive for use on Earth.

6-2 ENERGY DISTRIBUTION

The problem of energy distribution for solar energy systems is the same as experienced by current energy systems with the same output (e.g., electrical, gas, etc.). Thus, this problem is being actively researched by many people. For instance, cryogenic cables [6-5] are being investigated in order to reduce transmission losses in electrical distribution networks.

The various forms of chemical energy, as a result of conversions in solar energy systems, were discussed in section 3-9. Energy in the chemical form can be distributed in many ways. Hydrogen, as a liquid, can

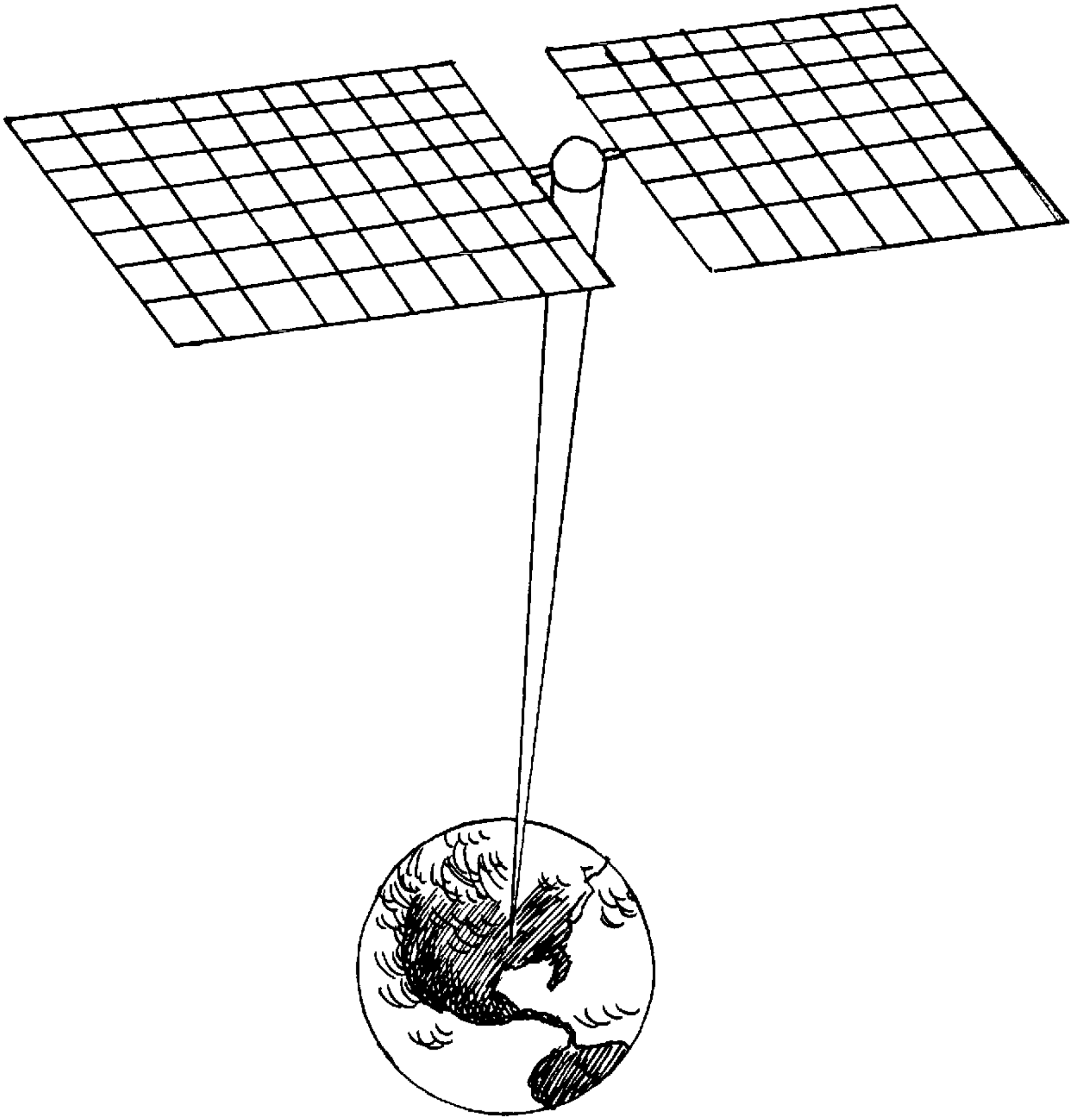


Figure 6-2. SOLAR SATELLITE POWER STATION (SSPS)

be transported as liquid ammonia in tanks, or, as a metal hydride, in containers (see Section 4-2).

Other chemical energy in the forms mentioned above (e.g., methane and methanol) can be transported in similar ways.

Another possibility for long-distance transmission might be to use satellites. Ehricke [6-2, 6-6] has proposed a system that could transmit energy using microwaves and a satellite in synchronous orbit (stationary with respect to a point on Earth). The basic operation of the system is to first transmit energy, via microwaves, from an earthbound power generation system (solar power plant, nuclear power plant, etc.) to the satellite where the energy is passively reflected to an earth receiving station where the microwaves are converted into the desired energy form. The objective of this concept is to transmit energy from a power plant to a distant usage area with as little loss of energy as possible. Thus, large electrical generating facilities could be built in remote areas rather than near the usage area which is the current practice. This means that solar power plants could be built in the desert where they are most efficient and nuclear facilities could be built far from populated areas. Another advantage might be that energy could be bought from and sold to other countries.

The feasibility of such a system depends on several important factors. Three of these would be the development of a space shuttle, technological advances in the research and development of the components, and the results of cost and energy conservation tradeoff with competitive Earth systems.

REFERENCES

6-1. Löf, G. V. G., and Karaki, S., A Rational Method for Evaluating Solar Power Generation Concepts, Solar Energy Soc. Conf. in Paris, paper E-143, 1973.

6-2. Selcuk, M. K. and Ward, G. T., Terrestrial Solar Power Production I. Optimization of the System Employing Heat Engines Under Steady State Conditions, II. Optimization of the System Employing Heat Engines Under Conditions of Varying Radiant Input, Intl. Sol. E. Soc. Conf., Melbourne, Australia, 1970, papers 7/32 and 7/33.

6-3. Oman, H. and Bishop, J., Feasibility of Solar Power to Seattle, Washington, Intl. Solar Energy Soc. Conf., Paris, 1973, paper E 3.

6-4. Girardier, J. P. and Masson, H., Utilization of Solar Energy for Lifting Water, Intl. Sol. E. Soc. Conf., Melbourne Australia, 1970, paper 6/116.

6-5. -----The 1970 National Power Survey, Federal Power Commission, Part IV, Superintendent of Documents, U.S. Government Printing Office Washington, D.C. 20402, pp IV-2-69 to IV-2-74.

6-6. Meinel, A. B., and Meinel, M. P., "Solar Energy: Option or Illusion" AIAA 9th Annual Technical Meeting, Washington, D.C., AIAA paper No. 73-48, January 1973, pp. 1-5.

6-7. Meinel, A. B., "Photochemical Conversion of Solar Energy for Large Scale Electrical Power Production", Optical Science Center, University of Arizona, pp. 1-10.

6-8. Meinel, A. B., "Progress in Photothermal Power Conversion" Subcommittee on Environments, Committee for Interior and Insular Affairs, House of Representatives, Washington, D.C. June 13, 1973, pp 1-19.

6-9. -----"Research Applied to Solar-Thermal Power Systems", Report NSF/RANN/SE/GJ-34871/PR/7214, University of Minnesota and Honeywell Incorporated, December 1972.

6-10. Hildebrandt, A. F., "Large Scale Concentrators and Conversion of Solar Energy" EOS, Vol. 53 No. 7 (July 1972) pp. 684-692.

6-11. -----The 1970 National Power Survey, Federal Power Commission, Part IV, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, pp IV-1-86 to IV-1-88.

6-12. Daniels, Farrington, Direct Use of the Sun's Energy, Yale University Press, New Haven and London, 1964, Chapter 16.

6-13. Boer, K. W., "A Combined Solar Thermal and Electrical House System", International Congress "The Sun in the Service of Mankind", Paris, France, July 1973, paper E-108.

6-14. Cherry, W. R., "A Concept for Generating Commercial Electrical Power From Sunlight", Record of the 8th IEEE Photovoltaic Specialists Conference, Aug. 1970.

6-15. Ibid

6-16. Cherry, W. R., "Military Considerations for a Photovoltaic Solar Energy Converter," Transactions of the Conference on the Use of Solar Energy, the Scientific Basis, Oct. 31-Nov. 1 Tuscon, Arizona, 1955.

6-17. Ralph, E. L., "A Plan to Utilize Solar Energy as an Electric Power Source", 8th IEEE Photovoltaic Specialists Conference, Aug. 1970.

6-18. Ralph, E. L., "Large Scale Solar Electric Power Generation", Solar Energy Society Paper, May 10, 1971.

6-19. Ralph, E. L., "Solar Energy R&D Policy Assessment", Heliotek, Division of Textron, Inc., Sylmar, California, March 1972, Research Paper #135, pp 21-26.

6-20. Cherry, W. R., "The Generation of Pollution-Free Electrical Power From Solar Energy", Journal of Engineering for Power, ASME Transactions, April, 1972, pp 78-82.

6-21. Arthur D. Little Inc., "Satellite Solar Power Station Study", NASA, Lewis Research Center, Cleveland, Ohio, Contract # NAS3-16804.

6-22. Brown, William C., "Satellite Power Stations: A New Source of Energy?", IEEE Spectrum, Vol. 10, No. 3, March 1973, pp. 38-47.

6-23. Glaser, Peter, "The Use of the Space Shuttle to Support Large Space Power Generation Systems," Presented at the Meeting of the Astronautical Society, December 26-31, 1972, Washington, D.C.

6-24. Daniels, F., Direct Use of The Sun's Energy, Yale University Press, New Haven and London, 1964, Chapter 16.

6-25. Daniels, F., Direct Use of the Sun's Energy, Yale University Press, New Haven and London, 1964, Chapter 16, p. 344.

6-26. Ehricke, K. A., "Regional and Global Energy Transfer Via Passive Power Relay Satellites, Tenth Annual Space Conference, Cocoa Beach, Fla., April 11-13, 1973, SD73-SH-0117.

PART III. STRATEGIES FOR, AND THE IMPACT OF, SOLAR ENERGY UTILIZATION

This part of TERRASTAR presents the framework of a strategy for the eventual acceptance of solar energy by the American people. A national energy policy is presented to create a balanced total energy supply and consumption situation which includes solar energy as a competitive energy resource. The potential of solar energy is presented to indicate the magnitude of the solar energy contribution to the energy market. The impacts of implementing solar energy into American society are presented to indicate some of the barriers to the acceptance of solar energy utilization.

The latter portion of this part considers the concept of solar heating and cooling in buildings for a further in-depth study. The market potential on a national and regional basis is presented as a required input to the strategy for the acceptance of the heating and cooling of buildings.

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CHAPTER 7. NATIONAL ENERGY POLICY

Until about 1970, few people recognized or acknowledged that the United States was on the verge on an energy crisis. In 1971, the President of the United States sent to Congress the first energy policy message ever submitted by a United States president. The results of this message were mainly to increase the federal funding of R&D programs in energy and to make available more federally owned energy reserves. Considering the rapidly deteriorating energy situation, time has shown that government actions were too little -too late. It was not until the winters of 1971 and 1972, when natural gas and fuel oil were scarce, and the summer of 1973 when gasoline was in short supply in certain areas, that the general public became truly aware of the existence of an energy problem. Now that everyone in the U.S. is aware of the energy problem, a National Energy Policy formulated by the federal government has gained broad-based support.

7-1. BACKGROUND

The President, in his message to Congress on April 18, 1973, outlined his National Energy Policy which included:

1. Increased domestic production of all types of energy
2. Many governmental moves to conserve energy
3. Energy needs should be met at the lowest cost consistent with security and environmental needs
4. Reduction of regulatory-administrative impediments to the construction of energy producing facilities (refineries, nuclear plants)
5. Improve international relations in trade
6. Expand R&D and implementation efforts in all energy areas
7. Coordinate all Federal energy efforts in one office of the Executive branch

Several bills have been introduced into the 93rd Congress which propose solutions to portions of the energy problem: Some bills (e.g. H. R. 44) propose that "a study of national fuels and policy" be established. A bill for the "establishment of a corporation for the development of new energy sources, and for other purposes" (S. 454) has been submitted. The most comphrehensive bill appears to be S. 1283 which has elements of all other bills mentioned above incorporated into it.

The National Petroleum Council has proposed a set of "Major U.S. Energy Policies." The essence of these policies is as follows:

1. Assure adequate supplies of secure sources of energy
2. Preserve the environment in the production and use of energy
3. Promote efficiency and conservation in all energy operations and uses
4. Recognize that in all three of the above objectives appropriate consideration must be given to the impact of energy costs in economic welfare and progress

Obviously, the details of this policy are heavily petroleum oriented.

Philip Sporn, a well known and knowledgeable public utility industrialist, outlined points that should be considered in the formulation of a "national energy policy" in a recent "Conference on Research in the Electric Power Industry". Mr. Sporn's bias was toward the rapid development of nuclear power.

The Ford Foundation in their Energy Policy Project is now in the process of making one of the most comprehensive studies of energy policy problems and options ever undertaken. The results of this study will not be published until 1974. All of these organizations and individuals have recommended that there be a National Energy Policy and some have outlined such a policy in more or less detailed fashion. However, it has been 2 years since the President's first energy message to Congress and we still do not have a well defined, comprehensive, integrated, long range national energy policy. Following is an attempt at suggesting a National Energy Policy.

7-2. APPROACH TO THE FORMULATION OF A NATIONAL ENERGY POLICY

A National Energy Policy, to be effective, must concern itself with the 3 major areas of the energy problem:

1. Supply of energy
2. Demand for energy (or consumption, which is the gross input of energy required to satisfy demand)
3. Conservation of energy

Conservation, although effecting demand, is discussed separately because of its importance.

Most of the previously mentioned proposals for looking at the national energy problem or for establishing a National Energy Policy have put much of their emphasis on supply and conservation and have paid only lip service to demand reduction. All three of these areas will be discussed in greater detail later in this report.

In Chapter 1 of this report, three possible future energy scenarios were presented. Two of the scenarios established reasonable upper and lower bounds on future consumption and the third scenario presented a more rational mid-course projection of consumption. Scenario 3 was proposed as a national plan for the consumption and supply of energy; conservation, although not obvious in the figure displaying the scenario, is part of the plan.

The rationale for using Scenario 3 as the basis for a National Energy Policy was discussed in Chapter 1 but will be reiterated and explained here in terms of consumption, supply, and conservation.

7-3. CONSUMPTION

The control of consumption (demand), other than by conservation, has not been stressed by government to date. In fact, President Nixon, although stating that "we must explore means to limit future growth in energy demand," then stated in his energy message that "there should be no need for a nation which has always been rich in energy to have to turn to energy rationing." The National Petroleum Council, in their policy statement, states that, "forced reductions in energy consumption are undesirable and should be employed only on an emergency basis." Their report states further that, "the growth in per capita energy consumption during the past quarter of a century has created new jobs, expanded productivity, increased living standards, recreational and intellectual pursuits. Wise policies can provide the basis for continuance of these desirable objectives."

This reluctance to "tamper" with demand, this tendency to equate progress in most areas to growth in per capita energy consumption, and the self-given charge of most power companies in the past of expanding capacity to meet "demand" is part of the cause of our energy problem today. The Brookhaven and Department of Interior projections (Appendix C) appear to be typical of the recent approach to projecting energy needs, i.e. project consumption on the basis of exponential growth (" A Trend is Destiny") and expand the supply to meet this projection - independent of whether it is economically, socially or environmentally wise to do so.

The consumption projection presented in Scenario 3 is believed to be a rational plan for the growth in energy consumption. To allow Energy consumption to follow the exponential curve is tantamount to national suicide! A National Energy Policy must provide for a reasonable control of energy consumption. This policy must include more than just simple conservation means for reducing the rate of growth in consumption.

To attain the level of consumption recommended in Scenario 3, three things must be done

1. Population growth must be controlled
2. Per capita consumption must be regulated
3. Conservation must be used in all areas

Population growth is already coming under control. The 1972 U.S. population was slightly under that projected by the Bureau of Census, Series E Curves. At this rate by the mid-21st century, the U.S. should reach zero population growth (ZPG).

To control per capita consumption, the Federal Government must look at GNP, industrial growth, and increased standard of living as things that should be planned, not just left to happen. With this type of philosophy, a total systems model could be developed by the Federal Government to assist in planning all aspects of the economy, not just energy consumption. All the variables in this complex problem and their interactions must be considered to the fullest degree possible.

To demonstrate that the rate of growth of per capita consumption can be reduced without "destroying" the economy, the per capita consumption for 1971 - 1972 was approximately the same as the previous year due to fuel shortages and as also indicated in Fig. 1-3 for the period 1920-1940, yet our GNP and industrial output increased in all of these time periods. Adjustments would have to be made and conservation used to continue this stabilized per capita consumption rate, but it does raise some questions as to the need for controlled per capita consumption growth to maintain prosperity.

7-4. SUPPLY

The quantity of energy required from each source to supply the consumption projected in the national energy plan (Scenario 3) is discussed in detail in Chapter 1. Only the more important supply considerations will be reiterated and expanded here.

The supply considerations of the national energy plan presented herein are designed to improve our national energy picture and to minimize societal, economic and environmental disruptions. This is accomplished mainly by:

1. Minimizing our reliance on imports as soon as possible
2. Eliminating the need for any crash R&D or crash implementation programs in any of the supply areas
3. Preserving our domestic oil and gas reserves for future non-fuel uses

The particular allocation of supply that was used was determined from a systems analysis of the technological, political, societal, economic and environmental aspects of each of the energy sources and their interactions.

Minimizing reliance on imports contributes to national security, reduces the international trade deficit, tends to strengthen the economic position of domestic suppliers of energy and does not require an extremely expensive program to build deepwater ports for supertankers. Only one or two ports and a few supertankers need to be built to handle future import needs. This modest program can save billions of dollars over that required by exponential growth in energy consumption and its resulting reliance on Middle East imports.

7-5. RESEARCH AND DEVELOPMENT FUNDING

Even though the proposed national energy plan precludes the need for a large increase in funds for energy R&D, a moderate increase in R&D funding is required in all of the energy supply areas for the following reasons:

1. Too much reliance is being put on nuclear energy to solve the energy problem in the near future. The technical feasibility and environmental acceptance of the breeder reactor may require more time than anticipated
2. Even if the technical and waste disposal problems of the breeder are solved, it still may not be desirable from an economic, societal and, particularly, safety point of view to institute a crash nuclear building program before the year 2020
3. In the very long-run solar energy may be the only dependable source of energy, especially if fusion reactors are not perfected

7-6. NON-FUEL USES

The use of oil and, to some degree, gas for non-fuel purposes (plastics, pharmaceuticals, synthetic rubber, asphalt, etc.) is rapidly increasing. These products are important as there are not presently available substitute sources from which these products can be made;

thus, it is essential that our domestic oil and gas reserves be conserved for this purpose. Obviously it is not possible to cease the use of domestic oil and gas supplies immediately for fuel purposes. By tapering-off their use to 10 quads each by year 2020, a substantial supply for non-fuel uses is maintained. Hopefully, this will provide enough time to find new reserves and to develop techniques for using coal to manufacture these petrochemical products.

7-7. CONSERVATION

As a large consumer of energy the United States must be concerned that this energy be produced efficiently and used wisely. The terms "belt-tightening" and "leak-plugging" are used by the National Bureau of Standards as the two methods that must be used to moderate energy demand.

Efficiency of Energy Utilization. The topic "efficiency of energy utilization" is often discussed under the heading, "conservation of energy". The latter terminology has a disadvantage in that it does not really focus on the major issue. In the thermodynamic sense, there is no energy crisis. If a crisis exists, it is an entropy crisis. After a given quantity of energy is used for a certain purpose, that energy still exists. The point is that it then often exists in a form that is less useful. This being the case, we should devote much attention to the "productivity" associated with the utilization of energy.

The flow chart of the overall energy system depicted in Figure 7-1 is taken from a recent report which addresses this question from a fundamental viewpoint. This report states that the "utilization aspect of the energy flow pattern has received the least attention of all the elements in energy technology". It points out further that traditionally, the measures of energy utilization in an energy-using system have been how much energy the system uses and the costs associated with this energy. At this level of description no explicit account is taken of (1) the "quality or grade" of energy, (2) the "match-up" between supply and demand, (3) the "cascading or reuse" of energy and (4) the "productivity" of this energy.

Recent publications indicate that a much needed emphasis is finally being directed toward the area of energy utilization. This is reflected in two recently issued reports, one prepared by the Department of Commerce and one by the Office of Emergency Preparedness. A study conducted by Oak Ridge National Laboratory for the NSF-RANN Program examined in some detail the economics of thermal insulation in residential construction.

The three major areas offering possibilities for increased efficiency of energy utilization at the point of consumption are buildings, industrial processes and transportation. The report prepared by the National Bureau of Standards emphasizes the buildings area. However, several important general remarks regarding "leak-plugging" for industrial processes are included in the following statements:

> "As a general rule, individual items of industrial plant equipment, or indeed entire plants, which represent large long-term capital investment, are designed to use energy on a cost-effective basis. In some instances, this means that energy losses have been minimized, but this is not necessarily the case.

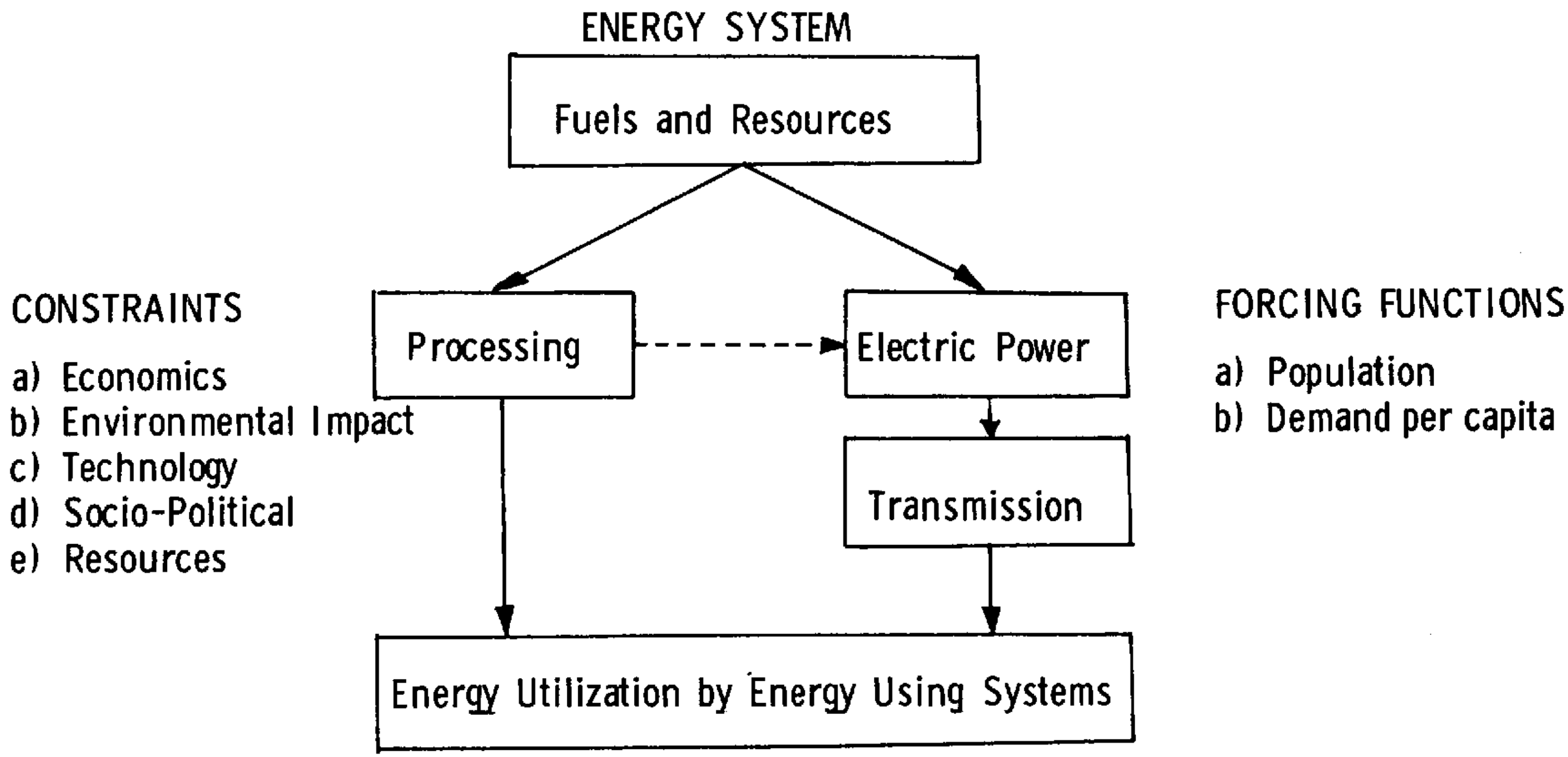

Figure 7-I. FLOW CHART FOR AN OVERALL ENERGY SYSTEM

> Because of the low costs of energy in the past, it has been often more economically effective to permit a leak of energy than to plug it.
>
> "The sometimes conflicting estimates produced by knowledgeable persons indicate that energy conservation through improvement of efficiency of industrial processes is the terra incognita of the energy conservation field."

The major uses for energy in buildings are space heating and cooling (comfort conditioning) and water heating. Economic considerations for comfort conditioning equipment in buildings are usually governed by initial costs. As a result, when combined with the low cost of energy, high energy consumption has often been designed into buildings and equipment in order to reduce initial costs. Some specific areas for consideration in "leak-plugging" related to comfort conditioning are listed below in Table 7-1. It has been stated by Dubin [7-1] that a significant reduction in energy usage is possible.

TABLE 7-1.

SPECIFIC AREAS OF CONSIDERATION RELATED TO ENERGY UTILIZATION FOR COMFORT CONDITIONING IN BUILDINGS

- Insulation (walls, ceilings)
- Prevent Excessive Ventilation
- Air Infiltration Rates
- Window Areas (size, location, type)
- Roof Overhangs
- Exterior Surface Finishes
- Building Orientation
- Landscaping (trees, ground texture)
- Underground Construction
- Usage of Illumination
- Techniques and Criteria for Sizing Equipment
- Efficiency of Equipment
- Maintenance of Equipment

Hot water heating accounts for about 4 percent of the total national energy consumption. Once the hot water is used, the energy it contains is usually wasted as it goes down the drain. Consideration should be given to recovering some of this low grade energy by using heat exchangers for purposes such as preheating of the inlet water to the hot water heater. However, according to NBS, such techniques may be in conflict with existing local plumbing codes.

In considering such measures, use of energy in the economy as a whole should be taken into account. It is useful, therefore, to determine the energy investment in the materials and products, such as insulation and heat exchangers, utilized for such purposes. This energy investment should be compared with the expected energy savings over the life of the structure. According to NBS, the basic data from which such comparisons can be made are not now available and should be developed.

It is significant that many of the same considerations involved in improving the efficiency of present energy utilization in buildings are also major considerations in the efficient utilization of solar energy for such purposes. A prime example of this relationship is the emphasis on increased initial costs relative to fuel costs.

Social Awareness. The first step in effecting a move toward the conservation of energy is making everyone energy conscious, i.e., making everyone aware that energy is consumed anytime anything is produced, processed or transported. The next step is in making everyone realize any individual saving, no matter how small, becomes significant when that saving is made by the entire population.

A specific example of social awareness can be offered in which two city-owned public utility companies (supplying natural gas and electricity) had their gas supply cut 30 percent. Over a relatively short time, by appealing through the mass media, each company effected a firm 12 percent reduction in the amount of energy demanded by their customers.

Education via mass media, bumper stickers, pins, etc., is one way of informing the public that they must conserve energy. However, this education, in all probability, will not become completely effective until the shortage of fossil fuels is transferred to the consumer via increasing costs of natural gas, gasoline, fuel oil, etc.

Brochures on energy conservation practices have been prepared by many corporations and utilities such as Montgomery Ward, Dupont, Honeywell, Consumer Power (Michigan), Concern, Inc., Owens-Corning Fiberglass and The Electric Energy Association. Television has been utilized by the petroleum companies on gasoline conservation and by Alcoa on the small amount of energy required for recycling as compared to production from raw materials.

A thorough analysis of energy conservation with all of its ramifications is presented in Reference 7-2, which was prepared for the U. S. Senate Committee on Interior and Insular Affairs.

In conclusion, the office of Emergency Preparedness Report [7-3] estimates that the potential for energy conservation may be as great as 16 percent of the total energy consumption by 1980. This is equivalent to two-thirds (2/3) of the projected oil imports in 1980. It is therefore imperative that the National Energy Policy stress conservation so that the potential energy savings may be realized.

7-8. SUMMARY OF ELEMENTS OF THE NATIONAL ENERGY POLICY

Following is a summary of the main elements of a national energy policy:

1. In accordance with Preisdent Nixon's energy statements, all of the Federally controlled energy programs should be brought under a cabinet level position in the Executive Branch.

2. Any comprehensive, integrated, long-range national energy policy must consider and control all three areas: consumption, supply and conservation.

3. A national energy policy must not just concern itself with energy problems, but must reflect a totally interactive systems approach in handling the economic, societal, political, environmental and technical impacts associated with the energy problem.

4. Whatever policy is decided upon, it should be long range and have continuity so that not only the government but also industrial concerns can make more realistic long range plans.

5. A more realistic balance must be struck between energy needs and environmental goals. Total impact statements and cost-benefit analyses must be made and objectively evaluated whenever a conflict arises.

6. Imports of oil and gas must be reduced as soon as possible in order to (a) improve the self-sufficiency of our national defenses, (b) reduce the international trade deficit and (c) strengthen the domestic suppliers of fuels.

7. Nuclear power should not be implemented at the accelerated rate contemplated until more of its technical, fabrication and environmental (waste disposal and safety) problems are solved. More money should be spent on R&D in this area.

8. All energy prices should be freed to find their natural level in the market place. This, along with more workable tax incentives, should increase the exploration and production of gas and oil.

9. A moderate increase in Federal R&D funding in all areas of energy supply is necessary. It is recommended that $60 million per year be spent over the next 5 years on solar R&D, as outlined in Chapter 8. Even though 20 Quads of solar power is suggested for implementation by 2020, it is suggested that from an R&D point of view, a goal of 40 Quads should be planned for now. As the year 2020 approaches, new developments in all energy areas can then be considered to determine more clearly the goals for solar energy.

10. Develop off-shore oil at an accelerated rate only when less pollution-prone extraction methods are found.

11. Speed up the development of coal gasification and liquefaction processes. Since more coal will be used in these secondary processes and directly under Scenario 3, it is essential that the environment problems associated with strip-mining be minimized as soon as possible.

12. Recycling efforts for steel, aluminum, paper, cardboard and plastics should be encouraged. The energy requirements for recycling are as low as 10 percent of that required for processing from the raw material.

7-9. LONG-RANGE PLAN

The planning horizon in this study is 47 years - to the year 2020. A realistic plan for controlling consumption and supply during this period has been suggested in Scenario 3, Chapter 1. The next question is "what can be said about what needs to be done about the energy supply after the year 2020?"

If population is held to the Series E Curve, zero population growth (ZPG) will be reached sometime in the mid-twenty first century. At this point the distribution of supply, both relatively and absolutely, will not differ much from the year 2020, as shown in Chapter 1. One of the following realistic scenarios will probably exist at that time:

1. Fusion reaction will be technically, environmentally and economically acceptable.

2. Fusion reaction will not be acceptable, but the breeder reactor will have become very acceptable on all accounts.

3. Nuclear power will still not be environmentally acceptable.

Under the first scenario above, a new policy for expanded, but controlled, growth can be formulated with less emphasis placed on all other forms of energy, except solar which will be developed further.

The second scenario would produce the same effect as the first scenario except that the allowable increase in growth would be slower - solar still being developed further.

In the third scenario above, solar energy would have to be expanded to take more of the load from the fossil fuels so that they would not be completely depleted. In all of these scenarios, solar power would play a significant role. It has to do so when one considers that all other sources of energy are very limited, unless fusion power can be harnessed.

REFERENCES

7-1. Dubin, Fred S., "Energy Conservation Needs New Architecture and Engineering Conservation Measures can Preserve Quality of Life at Least Energy Cost", Public Power, March/April 1972.

7-2. Perry, Harry, "Conservation of Energy", Prepared for U.S. Senate Committee on Interior and Insular Affairs, Serial No. 92, August 18, 1972.

7-3. -----"The Potential of Energy Conservation", Executive Office of the President, Office of Emergency Preparedness, October, 1972.

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CHAPTER 8. SOLAR ENERGY POTENTIAL

In December of 1972, the NSF/NASA Solar Energy Panel published their report [8-11] which assessed the potential of solar energy as a national resource. The state-of-the-art is presented for each of the eleven concepts presented in that report along with recommendations for further research and development in these areas.

The solar experts on this panel suggested an R&D program for each of these concepts in terms of a schedule and cost. The discussion and recommendations for each concept were considered independent of the other concepts. That is, an interactive systems approach was not used to study these concepts and make the recommendations. Hence, no phased implementation or R&D plan was suggested for integrating the R&D effort of all these concepts to produce an optimal impact on the energy problem. In fact, no priority scheme was even proposed to suggest which concepts could produce the greatest impact at the lowest cost in the shortest time.

Table 8-1 and Figure 8-1 show the proposed breakdown of R&D funding for each concept, by year, along with the total funding required, assuming that R&D on all eleven concepts start simultaneously. The total R&D budget would be $3.52 billion over a 15-year period. As can be seen, the first five years, during which time most of the concepts are going through their feasibility phase, the R&D budget is fairly low - increasing from $56 million to $91 million/year in the fifth year.

Presented in Table 8-2 and Figure 8-2 are the estimated energy contributions by period for each of the solar concepts, assuming that the R&D funding for each project was started in 1973. (A linear fit between data points was made in Figure 8-2 for convenience - in reality the growth probably would be exponential.) The totals, thus presented, assume that the effects of each concept are additive, which may not necessarily be true. If all solar concepts proved feasible and were implemented, which is extremely optimistic, the panel estimated that 137 Quads of energy could be supplied by the year 2020. These figures were arrived at considering only the technical feasibility and not the political, economic, social, and environmental feasibility and impacts.

Solar Power Development

To obtain 137 Quads of energy from solar devices by the year 2020 would require a major national commitment starting now. From a total systems point of view (considering consumption and all sources of energy) two questions arise:

Table 8-1.
NSF/NASA SOLAR ENERGY PANEL PROPOSED R&D FUNDING SCHEDULE

PROPOSED R&D FUNDING BY YEAR (MILLION DOLLARS)

Solar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
A. Thermal Energy for Buildings Development Demonstration	9.5	9.5	9.5	9.5	9.5	9.5 4.8	9.5 4.8	9.5 4.8	4.8	4.8						100 76 24
X. Photosynthetic Prod. of Organic Material and Hydrogen Research Development Pilot Plant	4.75	4.75 4.6	4.75 4.6	4.75 4.6	4.6	4.6 3.6	3.6	3.6	3.6	3.6						60 19 23 18
B. Combustion of Organic Materials Feasibility Study Component Development Pilot Plant Demonstration Plant	.66	.66	.66	4.	4.	4.	4. 12.	4. 12.	12.	12.	12. 11.2	11.2	11.2	11.2	11.2	138 2 20 60 56
C.* Bioconversion to Methane System or Laboratory Studies Pilot Plant Demonstration Plant	1.8	1.8	1.8	1.8	1.8	3.83	3.83	3.83	3.83	3.83	3.83 5.8	5.8	5.8	5.8	5.8	61 9 23 29
D.* Pyrolysis to Liquid Fuels System or Laboratory Studies Pilot Plant Demonstration Plant	.4	.4	.4	.4	.4	2.	2.	2.	2.	2.	2. 7.	7.	7.	7.	7.	49 2 12 35
E.* Chemical Reduction to Liquid Fuels System or Laboratory Studies Pilot Plant Demonstration Plant	.6	.6	.6	.6	.6	3.	3.	3.	3.	3.	3. 8.2	8.2	8.2	8.2	8.2	62 3 18 41
F. Thermal Electric Conversion Feasibility and Comp. Devel. Pilot Plant Demonstration Plant	4.28	4.28	4.28	4.28 14.3	4.28 14.3	4.28 14.3	4.28 14.3	14.3 125.	14.3 125.	14.3 125.	125.	125.	125.	125.	125.	1130 30 100 1000
G. Photovoltaic on Buildings Feasibility Study Technology Development System Definition Prototype Testing	.33 5.68 -	.33 5.68	.33 5.68	5.68 1.	5.68 1.	5.68 1.	5.68 1.	5.68 1.	5.68	5.68	5.68	5.68	5.68	5.68	5.68	91 1 85 - 5
H. Photovoltaic Ground Station Feasibility Study Technology Development System Definition Prototype Testing	.29 5.68	.29 5.68	.29 5.68	.29 5.68	.29 5.68	.29 5.68	.29 5.68 7.78	5.68 1.33 7.78	5.68 1.33 7.78	5.68 1.33 7.78	5.68 7.78	5.68 7.78	5.68 7.78	5.68 7.78	5.68 7.78	161 2 85 4 70
I. Photovoltaic Space Station Feasibility Study Technology Development System Definition Prototype Testing	1. 9.33	1. 9.33	1. 9.33	9.33	9.33 7.5	9.33 7.5	9.33 7.5	9.33 7.5	9.33 7.5	9.33 7.5	9.33 68.	9.33 68.	9.33 68.	9.33 68.	9.33 68.	528 3 140 45 340
J. Wind Energy Conversion Feasibility Study Component Development Pilot Plant Demonstration Plant	1.33 9.6	1.33 9.6	1.33 9.6	9.6 4.	9.6 4.	9.6 4.	9.6 4.	9.6 4. 98.	9.6 98.	9.6 98.	98.	98.				610 4 96 20 490
K. Ocean Thermal Gradient Feasibility Study Component Development Pilot Plant Demonstration Plant	.66	.66	.66	8.6	8.6	8.6	8.6 11.	8.6 11.	11.	11.	11. 86.	86.	86.	86.	86.	530 2 43 55 430
TOTAL	55.89	60.49	60.49	88.41	91.16	105.59	131.77	351.53	324.43	324.43	469.50	437.67	339.67	339.67	339.67	3520

* Estimated schedule, since no clear schedule was given.

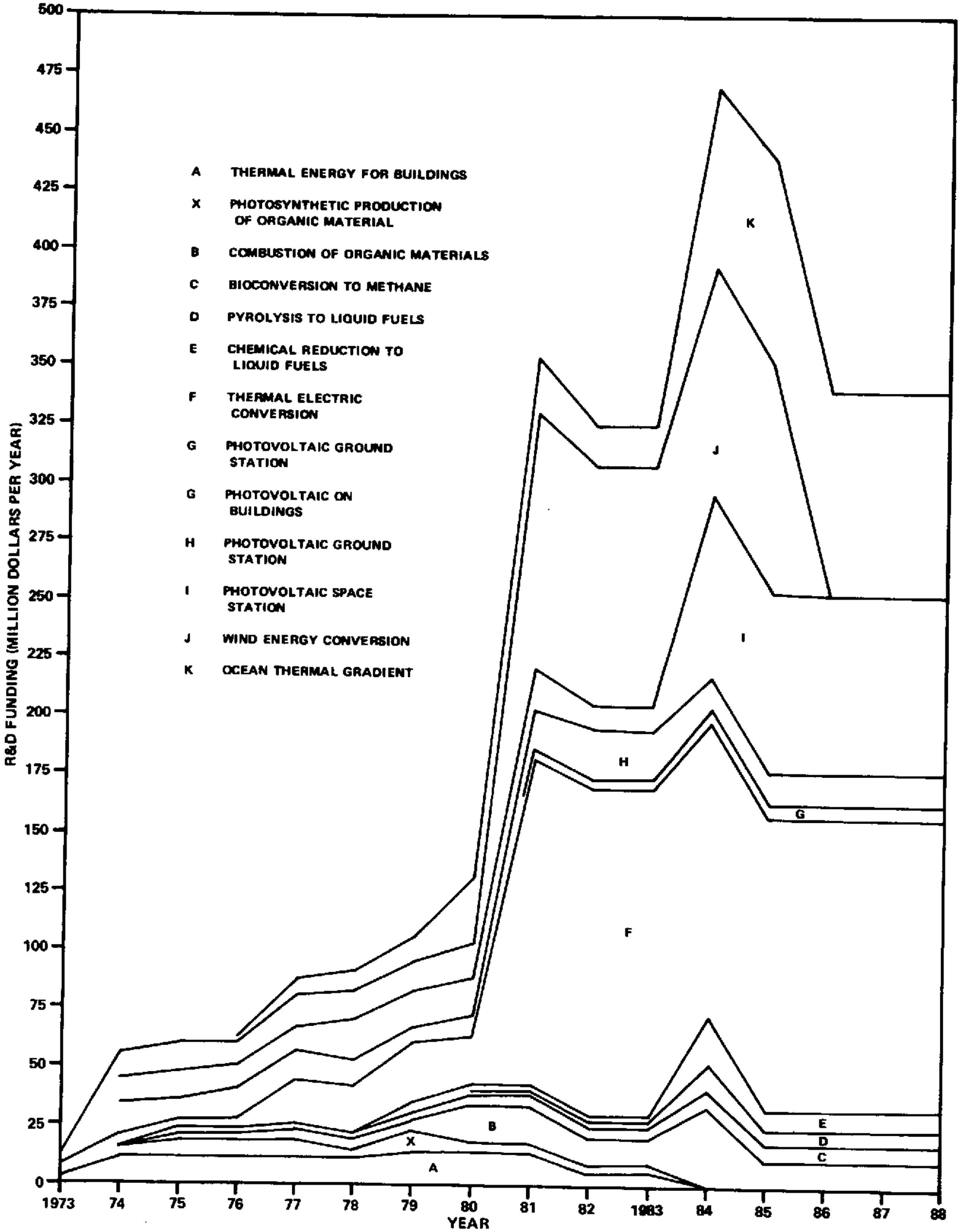

Figure 8-1 R&D FUNDING FOR SOLAR ENERGY
NSF/NASA REPORT

TABLE 8-2. NSF/NASA SOLAR ENERGY APPLICATIONS PROJECTIONS[1]

System	Energy Produced[2] (10^{15} Btu) 1985	2000	2020
Thermal Energy for Buildings	.17	2.1	10.5
Conversion of Organics to Fuel or Energy			
Combustion of Organic Matter	-	.76	16.0
Bioconversion to Methane	.27	3.1	12.3
Pyrolysis to Liquid Fuels	-	.63	8.0
Chemical Reduction to Liquid Fuels	-	.63	8.0
Electric Power Generation			
Thermal Conversion	-	.76	8.0
Photovoltaic			
Systems on Buildings	-	.75	10.5
Ground Stations	-	.76	16.0
Space Stations	-	.76	16.0
Wind Energy Conversion	-	.76	16.0
Ocean Thermal Difference	-	.76	16.0
Total[3]	.44	11.77	137.30

1. NSF/NASA Solar Energy Panel Report, Dec. 1972.

2. Assuming the R&D effort in all systems proposed in the report are started now and all are successful.

3. Assumes that the energy effect of all these systems is additive.

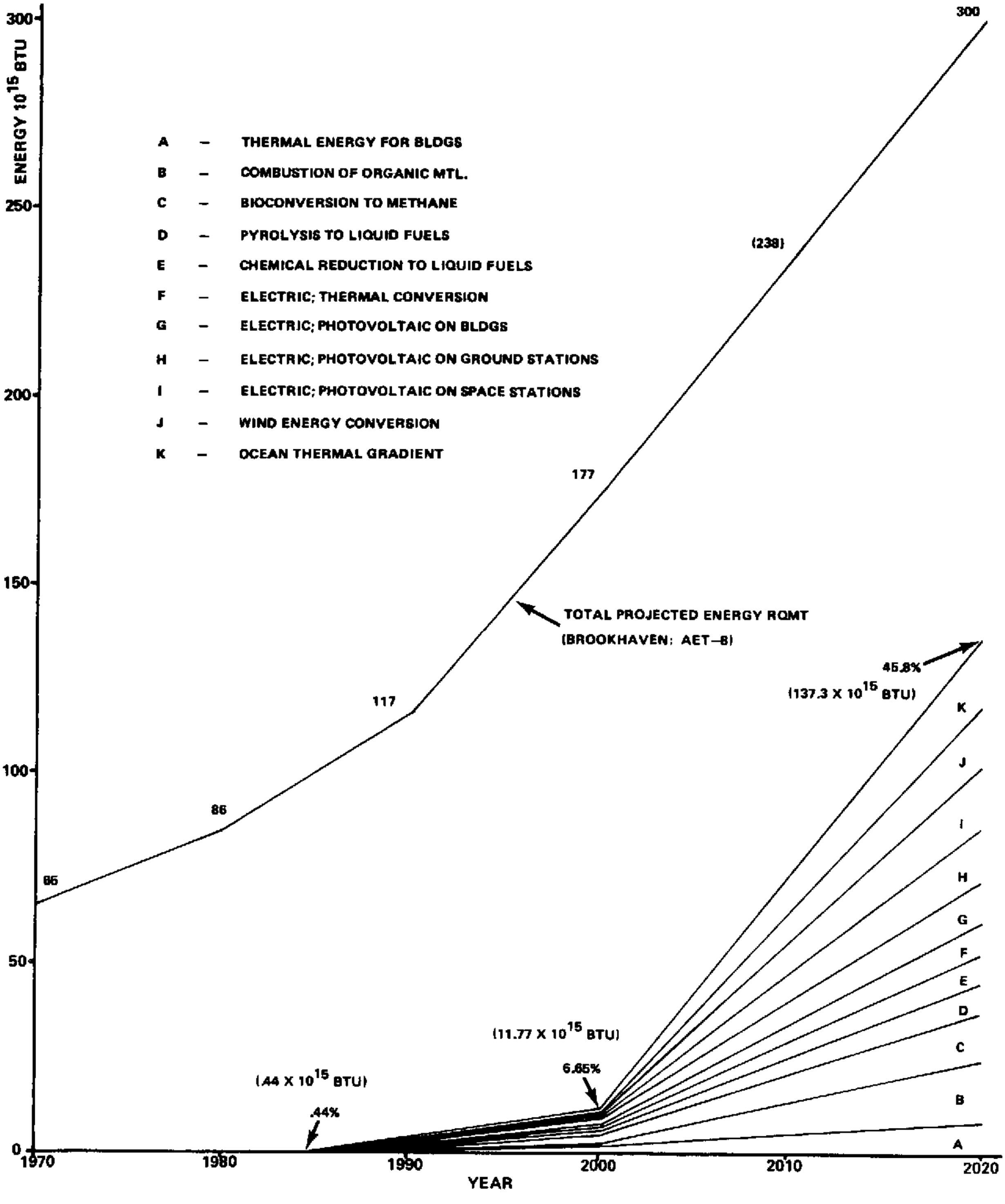

FIGURE 8-2. TOTAL PROJECTED DEMAND VS. SOLAR ENERGY CONTRIBUTION PER NSF/NASA SOLAR ENERGY PANEL REPORT (ASSUMING ALL PROJECTS START NOW, ARE SUCCESSFUL AND ADDITIVE)

1) What are the impacts of this large solar commitment on the political, economic, social, and environmental aspects of the U. S.?

2) Is this much solar energy desired or required, even if the detrimental impacts of generating it are small?

The impacts of attempting to obtain 137 Quads of solar energy by the year 2020 would be as follows:

- The R&D funding of solar energy over the next 15 years would be at least $3.52 billion or an average of $235 million per year, which is 20 times the present funding rate (it should be pointed out that the greatest portion of the R&D money is in demonstration projects which come toward the end of the concepts development). Without making a supply of new R&D funds available, other energy R&D programs would have to be cut back drastically.

- The amount of natural resources required to build what is required here is significant. (In Chapter 5, the amount of material required to supply just the solar devices for home heating and cooling is shown to be great.

- The basic metals, glass, and fabrication industries would have to increase their capacities considerably to produce what is required over a 47 year period.

Table 8-3 supports the last two impacts just presented as can be seen, the number of energy plants required and the land area required to produce the projected 137 Quads of energy by 2020 is overwhelming and would preclude all concepts being implemented. This limitation would therefore drop the potential considerably below the 137 Quads level.

The second question above is best answered by considering the "National Energy Policy" in Chapter 7. Using proper consumption planning and taking a systems approach to supply, it appears that only about 20 Quads of solar energy need be supplied by the year 2020. This amount of energy obviously will be much easier to attain than 137 Quads. How much solar energy will actually be required or desired will be mainly a function of our ability to control consumption and whether the breeder reactor is technically, economically and environmentally viable.

Because of the uncertainty of the energy consumption/supply situation in 2020 a goal of having the capability of producing more than 20 Quads from solar devices should be established. In Chapter 7, this goal was set at 40 Quads. To attain this goal as painlessly as possible by 2020, those solar concepts which show the most promise should be funded earlier and to a larger extent than those which show

TABLE 8-3 ESTIMATED IMPACT OF SOLAR CONCEPTS[1]

	1985	2000	2020
Thermal Energy for Buildings			
No. of new homes with thermal collectors (% of total starts)	$.22 \times 10^6$(10%)	1.16×10^6(50%)	2.28×10^6(85%)
Photosynthetic Production of Organic Material			
Easily collectible organic wastes (10^7 tons/yr.)[2]	5-7	5-8	6-9
Land and water plant forms (10^7 tons/yr.)[3]		20-35	215-360
Combustion of organic matter			
No. of 1 G. W. (Gigawatt) electric power stations (steam)	-	19	390
Bioconversion to methane			
No. of 1000 ton/day conversion plants	61	692	2770
Pyrolysis to liquid fuels			
No. of 2000 ton/day conversion plants	-	72	900
Chemical Reduction to liquid fuels			
No. of 1000 ton/day conversion plants	-	143	1800
Electric Thermal Conversion			
Land area required (square miles)	-	185	2000
Photovoltaic Building Systems			
No. of new homes with solar collectors[4]	-	1.16×10^6	2.28×10^6
Photovoltaic ground stations			
Land area required (square miles)	-	300	3000
Photovoltaic space stations			
No. of 10 G.W. space stations	-	2	39
Wind Energy Conversion			
No. of 100 mw (Megawatt) wind generators	-	185	3900
Ocean Thermal Difference			
No. of 400 mw ocean stations	-	46	975

1. Derived from information contained in the NSF/NASA Solar Energy Panel Report.

2. The present, readily available 4-6 x 10^7 tons/year of human and animal organic wastes are assumed to grow linearly with population (series E).

3. This is the amount of material that would have to be grown (over and above that provided by organic wastes) to supply the next four processes with enough input energy to produce their projected output.

4. It is implied in the NSF/NASA report that houses with thermal collectors from year 2000 will also have photovoltaic panels.

less promise. Unfortunately, most of these concepts have not been developed enough to determine a proper priority system for phasing the R&D effort to get the optimal impact. (The only concept that presently has "commercial readiness," according to the NSF/NASA report, is the heating of buildings, and this is not yet economically competitive with fossil fuels.)

The Federal Government should therefore give initial R&D funding to each of the 11 concepts (plus the attendant photosynthesis concept). Each of these projects should be funded to take them at least through the feasibility stage, as shown in Figure 8-1. This would require $300 million over a five-year period. At the end of this time, a decision could be made more intelligently as to the priority and subsequent funding to be given each concept. Once this point is reached, then a phased R&D and implementation plan can be developed.

The energy displacement potential of solar energy therefore lies between a maximum of 137 Quads for all eleven solar energy concepts and a probable low bound of 20 Quads which is a very conservative estimate. This low bound figure of 20 Quads appears to be deceptively small but when it is put into the perspective that it is over 10% of the total energy requirement of scenario 3 by the year 2020 it takes on much greater significance.

It is realized by the authors that many factors other than technical feasibility will influence the acceptance of solar energy by the American people. It will be these other factors which will greatly determine the "realistic potential" of solar energy in the decades to come.

References

8-1. Donovan, P., and Woodward, W., co-chairmen, An Assessment of Solar Energy as a National Energy Resource, NSF/NASA Solar Energy Panel, Department of Mechanical Engineering, University of Maryland, December 1972.

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9-1

CHAPTER 9. IMPACTS OF SOLAR ENERGY UTILIZATION

9-1 INTRODUCTION

Recent history serves well to emphasize the necessity of considering a priori the societal ramifications of any technological innovation, breakthrough or notable advancement. Examples of recent technological achievements and their accompanying adverse societal aspects are: the advent of electronic digital computation and its accompanying "invasion of privacy" aspect and the development of oral contraceptives and the associated "juvenile moral influence". A long list accounting the history of the "technology explosion" and related societal consequences could be developed. Devastating effects or consequences of technological accomplishments are depicted by authors such as Toffler [9-1], Kahn [9-2], and Schwartz [9-3], among a host. They foretell of a future society victimized by the ravishment of technology. On a much lower dynamic scale, it can also be pointed out that, in many cases, the benefits of technological advancement to mankind have not been maximized, moreover certain existing undesirable conditions have been exacerbated.

As a result of first-hand observations of societal disruptions and of a growing denouncement of "technology for the sake of technology", a keener sensitivity has been developed; an awareness of the importance of attempting to assess the impact of a new or extended technology on society currently exits. It is recognized that projected societal impacts can supply a valuable feedback into a primarily technological system development model, and consequently play an important role in providing a trade-off in the optimum design of the end product. There would be a substantial prophylatic value in doing no more than identifying the difficulties, or pointing out the inherent associated problems, but identification of problem areas alone falls short of providing the maximum possible societal benefits.

With the widespread realization of the import of technology assessment has come the logical initial development of a methodology of technology assessment. A sound approach which has been employed in the development of a methodology is one which uses retrospective analysis of recent technological innovations and accompanying societal impacts [9-4, 9-5]. In these references space exploration and computer-communications networks, among other technologies, are explored extensively relative to their unanticipated side effects.

Conceivably, there should exist a quantitative means of relating the different societal impact areas (political, environmental, psychological, social) to each other, as well as to the technology. This would imply the applicability of a systems approach, with transfer functions and weighting factors, resulting in a mathematical model which could incorporate a direct trade-off among conflicting design considerations. However, there are no quantitative transfer functions relating the various impact areas, or, if they exist, the methodology of technology assessment is not sufficiently developed at this point to mathematically quantify impact area interractions.

There are methods of sampling and analysis (opinion surveys: Appendix D , the Delphi method, pairing techniques, etc.) which yield numerical values relative to certain aspects of societal acceptance of a new and radically different product or process; but, there exists an infinitely large number of considerations which should constitute parameters in a systems model of societal impact which would have any pretense of completeness, and which therefore would have an acceptable measure of reliability. Therefore, it is a presently accepted fact that the formulation of such a mathematical model is unrealistic and that efforts to develop such a model are impractical.

In line with the state-of-the-art in technology assessment, the major focus is then placed on identifying probable/possible specific impacts (through such techniques as opinion surveys, brainstorming, scenarios, etc.) which may fall within one or all of the designated impact areas, as the interrelationships graphically illustrated in Figure 9-1. Resulting specific impacts, which may be common to a number of the designated impact areas, thus provide interactive relationships between impact areas. An attempt is then made to determine the magnitude of these impacts, somewhere along the scale: large to small; or perhaps only to the extent: large or small.

The development of scenarios holds the promise of being a major contribution to technological planning. The effectiveness of this technique lies in demanding consideration of the best course of technological activity in view of a range of future possibilities [9-6]. Two popular methods of scenario development are: 1) to extend trends, determine thresholds at which social conditions will halt or alter these trends, and consider the resulting scenario, and 2) consider five environments (technical, social, economic, political and ecological) as related to competitive conditions and internal organizational developments; extreme and more probable events in each area are then selected from current literature and speculations of knowledgeable people.

When the foregoing identification and assessment processes are extended to the point of "acceptable" completion, trade-offs are made and the results are formulated into policy statements. The assessment of a technology can encompass one or more of the following results:

1) Identification of unexpected desirable/undesirable consequences

2) Identification of regulatory or other control measures

3) Identification of feasible corrective measures to minimize negative effects

4) Modification of the technology in order to reduce disbenefits or to increase benefits

5) Encouragement of the development of a technology into new areas to exploit anticipated benefits

6) Prevention of the technology from developing

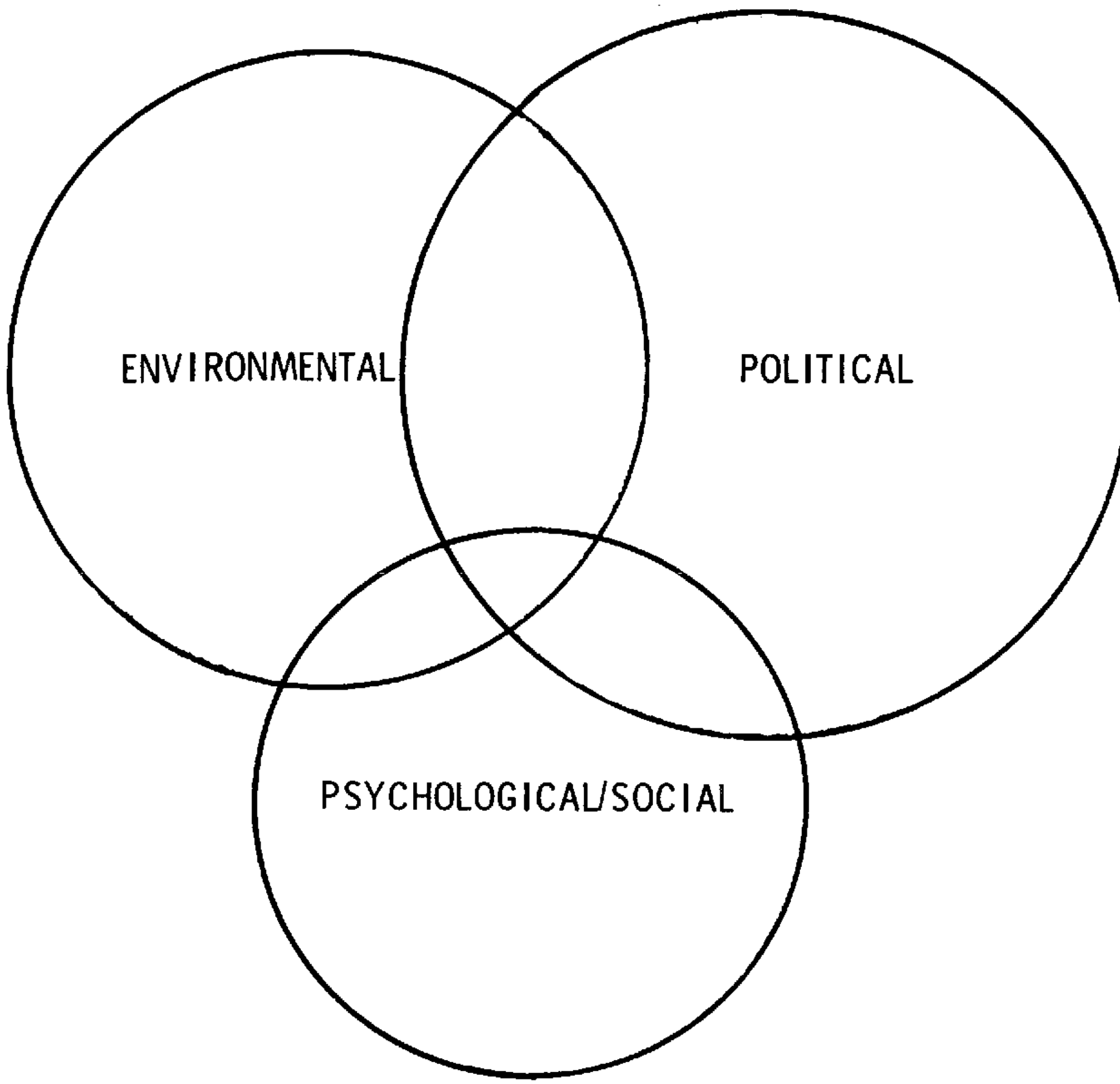

Figure 9-1 MODEL OF IMPACT INTERACTIONS

In order to test the impact "evaluation criteria", a number of examples of the application of the technology can be assessed. From this testing of the impact analysis, new considerations may appear. Thus, the impact analysis is logically concluded only after a number of iterations.

The foregoing brief discussion of technology assessment is a necessary introduction to a consideration of the impacts of the implementation of solar energy. In the following sections, solar energy will be considered as a candidate for assessment in the political, environmental and psychological/social areas based upon the effects of its implementation upon:

1) Industry
2) Government Structure
3) Balance of Trade
4) Lifestyles
5) Resources
6) Land Use
7) Health & Safety
8) Housing Policy
9) Maintenance & Labor
10) National Security
11) Architecture & Design

9-2 POLITICAL

The implementation of solar energy into American society will most certainly impinge upon the nation's political structure. In fact, it may well be in the general area of "politics" where future solar energy utilization will have the most drastic impacts and consequences. A brief examination of the functional interrelationships between the American political structure and the energy business system will properly orient this section.

Industry. Many Americans operate under the fallacious assumption that public policy is initiated by the American political structure (i.e., the President, the Congress, governors, state legislators, etc.). Actually, political actors are more "reflectors" of social change, rather than initiators of it [9-7]. They respond to the demands and interests of private groups and individuals in their public policy determination decisions [9-8]. This is not to say that politicians are not important actors in the public policy process, because they certainly are. It is to say, however, that elected political officials fill intermediate links while administrators (bureaucrats) fill final links in the policy process. Much of the philosophy and substance of policy decisions is formulated well before bills ever reach the floor of the legislature or the desk of the executive.

So, public policy initiation often begins with the policy demands and requests of citizen interest groups and individual citizens. But linkages among the policy desires of public constituencies and political decision-makers' behavior are, at best, uncertain. Warren E. Miller and Donald K. Stokes, for example, have found that only in the issue area of civil rights does a significant relationship exist between constituency opinions and congressional voting behavior [9-9]. On an economic welfare scale, the ralationship was weak, and on the question of American foreign involvement, it was virtually non-existent. Moreover, the representational relationship is further complicated as the structure of belief systems among the mass public is diffuse and does not conform to an unidimensional scale [9-10].

Thus, the question arises: "if not mass public beliefs, then what?" In other words, if political actors do not (or perhaps more appropriately, cannot) base their decision-making behavior upon public attitudes and demands because of, among other things, their lack of simple structure, then how can they ever hope to fulfill the requisites of representativeness? This introduces the political vote of vested interest groups.

Vested interest groups, because of their heavy monetary support, close proximity to political decision-makers, and general level of acceptance by decision-makers, provide significant inputs for the policy making process. While interest groups do not always desire identical policy goals for the same issue area, they do offer the politician a less complex picture of the viable alternatives within the area. Moreover, their claims of representativeness of citizen desires do not fall upon deafness in the chambers of government.

In the energy area, interest groups can be sub-divided into several major types:

1. Government owned utility companies (e.g., Tennessee Valley Authority)

2. Investor-owned utility companies (e.g., Consolidated Edison, Houston Light and Power Company)

3. Petroleum product companies (e.g., Standard Oil of New Jersey, Texaco, El Paso Natural Gas)

4. Coal producers (e.g. Consolidated Coal Company)

5. Energy producing equipment suppliers (e.g., Westinghouse, General Electric)

6. Owners of energy producing land areas

7. Government conservation agencies and groups (e.g., Environmental Protection Agency)

8. Private conservation groups (e.g., Sierra Club)

Additionally, several of these organizations are among the major financial enterprises in America. According to a 1964 survey of the 500 largest industrial corporations in the United States, for example [9-11],

1. Of the 10 corporations with the largest total assets, 7 are petroleum product companies.

2. Of the 20 corporations with the largest total assets, 7 are petroleum product companies, 2 are utility companies, and 1 is an energy producing equipment supplier.

3. Of the 50 corporations with the largest total assets, 12 are petroleum product companies, 8 are utility companies, and 3 are energy producing equipment suppliers

4. Of the 100 corporations with the largest total assets, 18 are petroleum product companies, 17 are utility companies, and 4 are energy producing equipment suppliers.

Finally, the five largest corporations (American Telephone and Telegraph, Standard Oil of New Jersey, General Motors, Ford Motors, and United States Steel) lay claim to greater than 12 percent of all assets in the United States. While all five of these industrial giants are certainly involved in the energy picture as either major producers or consumers, the future of three of the five (Standard Oil of New Jersey, General Motors, and Ford Motors) are directly related to the status of petroleum products in America. Recent investigations have concluded that these three corporations have combined revenues which are greater than the combined revenues of the fifty American States, and the revenues of General Motors alone during the mid-1960s were 50 times greater than those of Nevada, eight times greater than those of New York, and nearly 1/5 times those of the Federal Government [9-12].

Hence, any new energy technological application (e.g., solar energy) will have to consider the dispositions of these vested interests toward that application. A phasing in/out process should come to an early appreciation of the extent of political influence which the major energy related interests can mobolize. An attempt, for example, to develop a phasing-in scheme which would phase-out or severely limit the operations of these interests is almost certain to fail politically.

Government Structure. The unique brand of American federalism makes political and administrative decision-making a complex, intricate and often frustrating process. According to the popular notion of the American federal structure, political decision-making is visualized as a two-layer arrangement between Washington, D.C., and the fifty state capitals. A more realistic and practical view, however, has been proposed by Morton Grodzins. Grodzins' "marble cake" theory argues:

> "An accurate image is the rainbow or marble cake, characterized by an inseparable mingling of differently colored ingredients, the colors appearing in vertical and diagonal strands and unexpected wherts. As colors are mixed in the marble cake, so functions are mixed in the American federal system" [9-13].

Thus, the "new federalism" of the twentieth century is essentially a cooperative effort between the national government and the states, as it normally involves "voluntary compliance" [9-14] and administrative responsibilities by the state governments, rather than mandatory acceptance.

American government and politics, however, practically involves an additional level of consideration -- the local level (i.e., counties, municipalities, etc.). But counties and cities have no constitutional status within the American federal system. They are subordinate both constitutionally and legally to the state in which they are located. Yet greater than 70 percent of all Americans reside in urban areas in the 1970s, and most desire some degree of control over the political and administrative decisions which affect their daily activities. This is the paradox of American federalism. Governmental power is at least once (state government), and usually twice (national government), removed from the masses of people who, according to democratic theory, govern.

Hence, any scheme which is realistically geared toward the implementation of new energy sources and technology (e.g., solar energy) into American society should consider the unique interrelationships of the American federal structure. It is not enough, for example, to argue that a solar energy policy must (1) be passed in bill form by the Congress, (2) be signed into law by the President, and (3) be determined as constitutional by the Supreme Court should it become involved in a legal dispute. A solar energy policy will also require administrative inputs from national, state, and local bureaucrats. It will involve political inputs from both state and local political officials.

To a great extent, the nature and direction of state and local administrative and political inputs into the implementation of a solar energy policy will be determined by the economic base of the sub-national area. Especially in those areas where coal production (see Figure 9-2), petroleum product production (see Figure 9-3), and natural gas production (see Figure 9-4) are heavy, one should not expect an immediate and strongly positive acceptance of any plan for wide-spread solar energy implementation by the state and local political forces. Only until solar energy can be shown to complement these energy (fossil fuel) related economies are the political actors likely to endorse and actively support its implementation and utilization to any considerable degree.

This should not be taken as a statement that solar energy is a politically unwise and inexpedient concern throughout the American States, however. To the contrary, as Figure 9-5 demonstrates, almost one-half (24) of the states have no significant amounts of fossil fuel production within their boundaries. These political units are heavily dependent upon the twenty-six fossil fuel producing states and upon foreign imports to satisfy the energy needs of their citizens and their industries. The political market for new energy sources within these states should be quite receptive.

Many of these states are within the best areas in the United States for solar resources. The South Atlantic Coastal States of North Carolina, South Carolina, Georgia, and Florida and the Western States of Arizona and Nevada, for examples, are in the non-fossil fuel producing category.

Finally, even among some of the twenty-six producing states, potential political receptivity of solar energy might be expected. As Figure 9-5 illustrates, only four states (Texas, Louisiana, California, and West Virginia) had over $1,000,000,000 worth of fossil fuel production in 1971 and only five more (Oklahoma, Kentucky, Pennsylvania, Wyoming, and New Mexico) had over $500,000,000 worth. In the remaining seventeen states, fossil fuel production contributes a much smaller share of the state's economy. It is in these areas where a well planned scheme of complementary solar energy utilization may be politically acceptable.

But in the long run, the energy problem involves serious national considerations. So, much of the motivation behind the development of new energy resources and technology must come from the national level of government. Already in 1973, for example, an Energy Policy Committee headed by former Governor John A. Love of Colorado, has been created by President Richard M. Nixon. The committee has been delegated cabinet level status and is oriented in theory toward offering alternative solutions to the "national energy crisis."

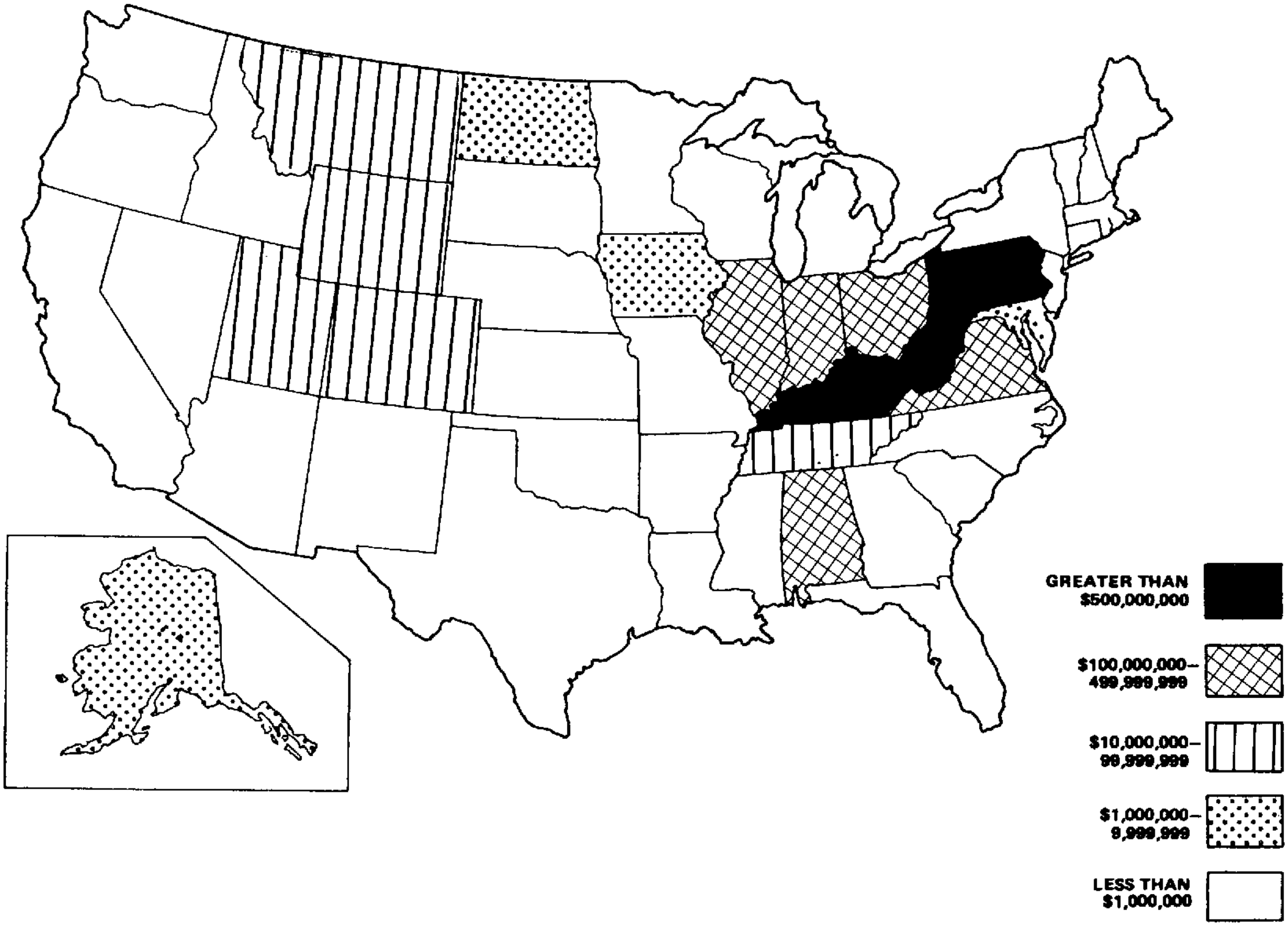

Figure 9-2 COAL PRODUCTION IN DOLLAR AMOUNT IN THE UNITED STATES BY STATE, 1971

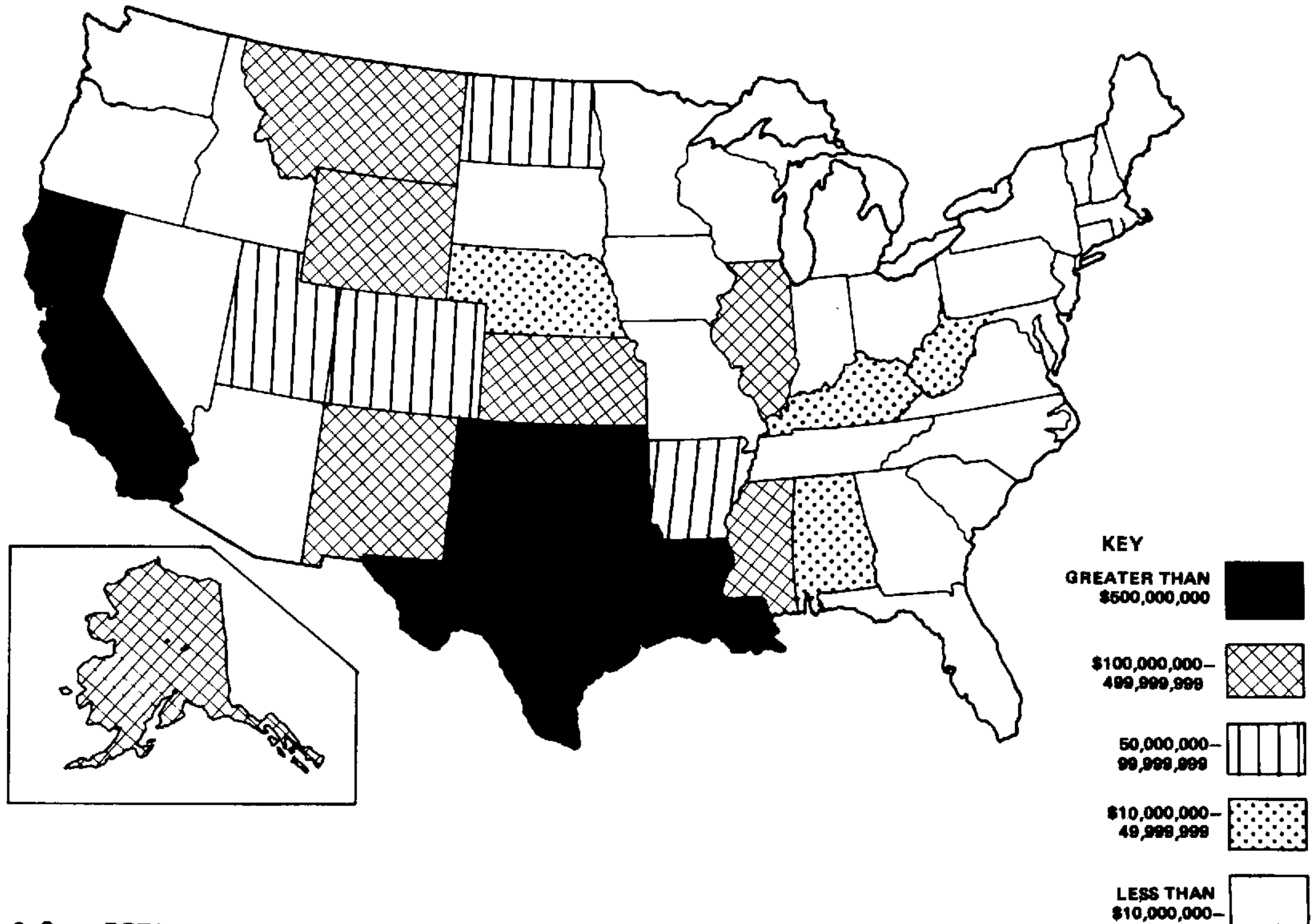

Figure 9-3. PETROLEUM PRODUCTION IN DOLLAR AMOUNT IN THE UNITED STATES BY STATE, 1971

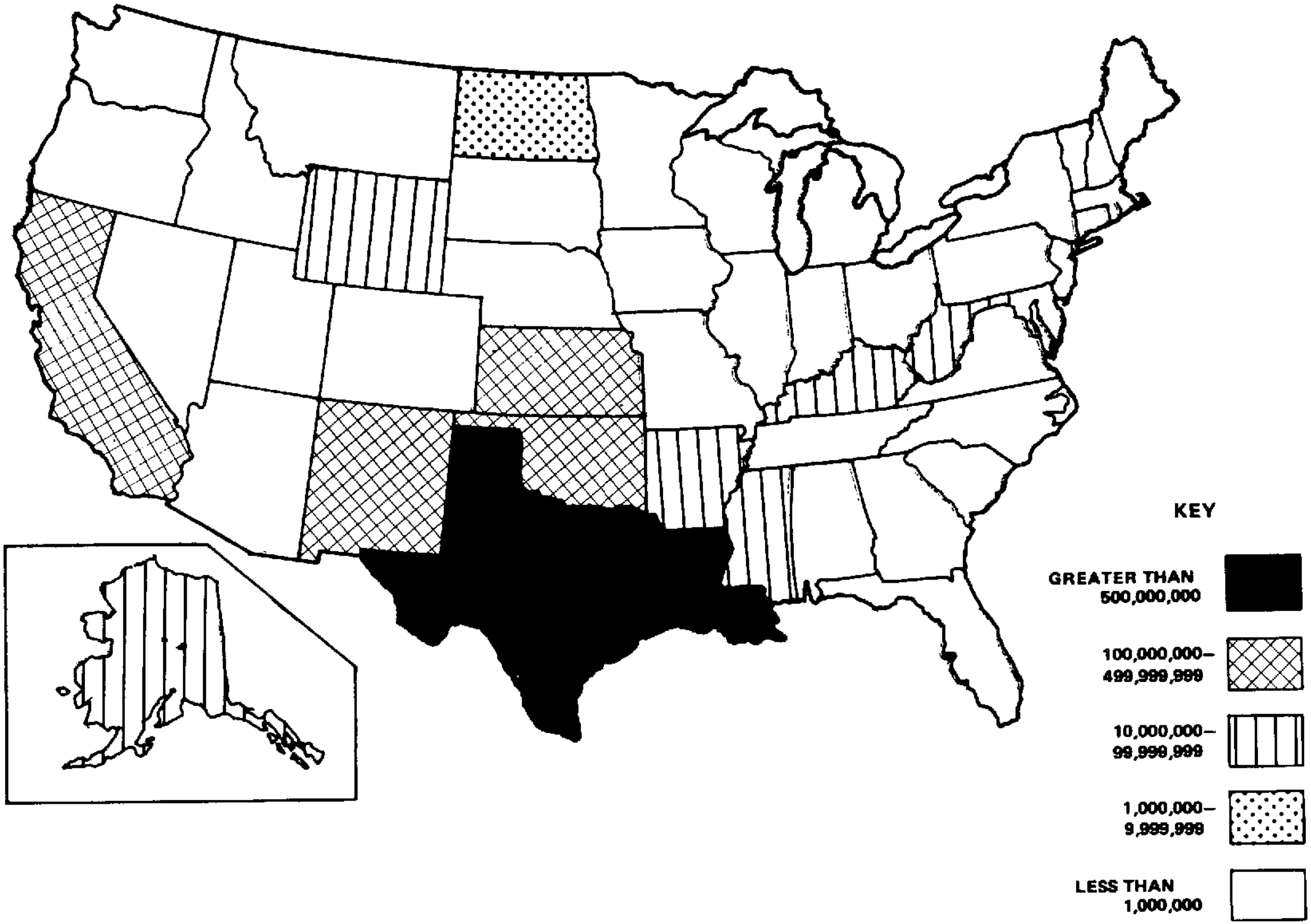

Figure 9-4. NATURAL GAS PRODUCTION IN DOLLAR AMOUNT IN THE UNITED STATES BY STATE, 1971

TOTAL FOSSIL FUEL (PETROLEUM, NATURAL GAS, & COAL)
PRODUCTION IN DOLLAR AMOUNT IN THE UNITED STATES BY STATE, 1971

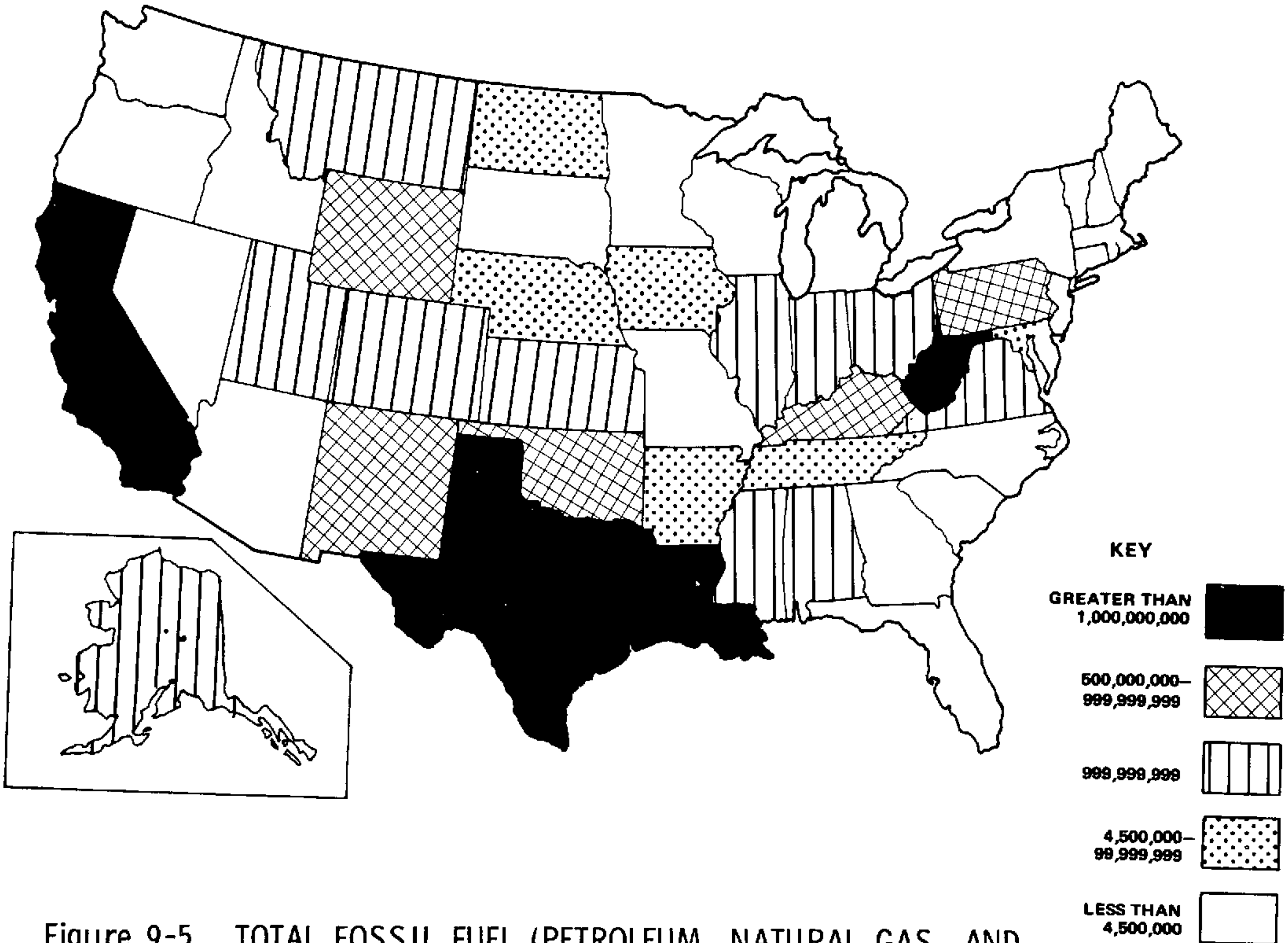

Figure 9-5. TOTAL FOSSIL FUEL (PETROLEUM, NATURAL GAS, AND COAL) PRODUCTION IN DOLLAR AMOUNT IN THE UNITED STATES BY STATE, 1971

In Congress, numerous resolutions and bills have recently been introduced which refer directly to the establishment of a national energy policy. House Resolution (H.R.) 1894, for example, proposes the establishment of a Commission on Fuels and Energy which would have the authority "to recommend programs and policies intended to insure, through maximum use of indigenous resources, that the United States requirements for low-cost energy be met, and to reconcile environmental quality requirements with future energy needs." [9-15]. Perhaps the most sweeping bill on the energy matter to be introduced into the Congress to date, however, is S.70 which calls for the establishment of a Council on Energy Policy. That, among other things, could have the authority to "coordinate all energy activities." [9-16]

Individual congressmen have also been quite vocal lately in their discussions of the national energy problem. During early July, 1973, a representative of the Auburn Design Group wrote to all United States Representatives, Appendix D . The letter requested that the congressman express his opinions on the national "energy crisis" and on the possibility of solar energy being utilized to help solve the crisis. Because of the time limitations of the Auburn Design Program, only 25 Senators and 29 Representatives had responded to the letter by the termination of the program. While the data is restricted because of low response (25.0 percent for Senators and 12.8 percent for Representatives), it is helpful in that it identifies potential response trends on the questions of the energy crisis and solar energy utilization among national political figures.

As Table 9-1 illustrates, one-fourth (25.0 percent) of all congressmen responding to the inquiry had a very favorable attitude toward the potential for solar energy applications. Representative John N. "Happy" Camp of Oklahoma, for example, wrote that "solar energy is one of the more viable alternatives in terms of a major power source." Senator Lowell Weiker, Jr., of Connecticut substantiated this opinion with his comment that "solar energy . . . (is) probably the cheapest and most efficient means of providing new energy sources." Finally, Senator Hubert H. Humphrey of Minnesota felt "convinced that the current level of investment in solar energy research and development is totally inadequate."

Almost one/half (47.7 percent) of the congressmen saw solar energy as a possible but long-term alternative to the energy crisis. Representative Romano L. Mazzoli of Kentucky probably best illustrates this feeling with the response,"although solar energy may help to provide an adequate energy source in the future, I have not seen any indications that it will be able to significantly alleviate the energy crisis of the present and immediate future." Senator Bill Brock of Tennessee wrote that, "in all probability its (solar energy) widespread use still remains beyond the immediate time."

An additional one-fourth (25.0 percent) of the respondents viewed the energy shortage as a crisis situation, but made no written mention of the potential for solar energy. Finally, one congressman--John G. Dowen of Texas--saw no application for solar energy before the turn of the century. Moreover, Senator Dowen stated that "The current energy crisis will be solved by petroleum."

TABLE 9-1

CONGRESSMENS' RESPONSE ON THE POTENTIAL
FOR SOLAR ENERGY

Response	U.S. Senators		U.S. Representatives		Total	
	No.	Percent	No.	Percent	No.	Percent
Very Favorable	8	32.0	3	15.8	11	25.0
Possible But Long Term	11	44.0	10	52.6	21	47.7
Energy Crisis Bad, But No Mention of Solar Energy	5	20.0	6	31.6	11	25.0
No Potential	1	4.0	0	0.0	1	2.3
	25	100.0	19	100.0	44	100.0

From these responses it appears that political factors at the national level of government are at least beginning to develop an awareness of the energy problems facing the United States. A rather wide spread level of support for solar energy applications among many of these actors in the future seems at least possible.

Balance of Trade. Certainly, one of the major political and economic circumstances involved in the current energy crisis is the balance of trade problem. The United States' portion in the balance of trade picture is worsened by its continual and increasing dependence upon foreign imports of petroleum products.

Political power and economic power are tied closely together. The middle Eastern countries are particularly aware of the relationship. During 1972, for example, "Arab leaders made no fewer than fifteen public threats to use oil as a political weapon against their enemies." [9-17]. In a word, the Arabs have threatened to delete their exports of petroleum to the United States because of the U.S.'s support of Israel.

A thorough implementation of solar energy resources would indeed help to alleviate this long-term situation by reducing the level of American dependence upon Middle Eastern petroleum products. This provides an additional rationale for the utilization of solar energy.

Lifestyles. The political decision-making process ultimately involves the public. Democratic theory is oriented directly toward the public selectors of political office holders and as constituencies to be represented in the public policy making process. Thus, public attitudes and public opinion, both of which are strongly associated with the lifestyles of people [9-18],are crutial considerations for the implementation and application of a new energy technology.

During July, 1973, the Harris Poll conducted a nationwide sample survey of 1,537 households. The survey was designed to ascertain the public's (1) view of the seriousness of the current energy crisis, and (2) evaluations of the probable causes and results of the crisis [9-19]. The poll indicated that a substantial proportion (77 percent) "of the American people take the 'energy crisis' as a 'serious' matter" (Table 9-2). When asked to evaluate the causes and results of the crisis, a large number of responses were offered. These are contained in Table 9-3. In a word, the public expects a sharp rise in the costs of fuel in the future and a growing dependence upon foreign imports. Almost one-half (40 percent) also felt that gasoline might have to be rationed before the end of the summer of 1973. It is also highly significant that 52 percent of the sample saw American "know-how" as "so good" that the U.S. will be able to fulfill its future energy demands" without a lot of trouble." Finally, an additional 49 percent of those interviewed did not believe that the public will be willing to conserve its use of energy,and greater than two in five (43 percent) did not feel that the federal government is competent to solve the current crisis.

As with any potential technological advance, there is apparently a void of public opinion on the specific question of solar energy. Thus, it must be created. The public opinion formation process involves five basic stages: (1) the identification of some problem area by a number of people, (2) the recognition of the problem area as important by these peo-

TABLE 9-2*

HOW SERIOUS IS THE ENERGY CRISIS?

Response	Number in Sample	Percent of Sample
Very serious	722	47
Only somewhat serious	461	30
Not very serious	246	16
Not sure	108	7
Total	1537	100

*Adapted from the Harris Poll of July, 1973.

ple, (3) the discussion of the problem area, (4) the development of alternative solutions and the narrowing of alternatives, and (5) the mobilization of the opinion in order to affect the final policy either through majority vote or by leadership assessment of the public opinion [9-20].

Thus, the creation of favorable public opinion toward solar energy application and utilization would require a number of actions. First, the public must be made aware of the energy problem. Second, politicians, the mass media, social and economic agencies, etc. must make the public aware of the significance and extent of the energy problem. Third, there should be a full disclosure of the various factors involved in energy production, supply, and consumption. Fourth, the various alternatives toward solving the problem (Alaskan pipeline, nuclear breeder, coal liquification, SSPS, Meinel central power plant, etc.) must be presented to the public. Fifth, the advantages and disadvantages of each alternative must be thoroughly presented. Sixth, should a variety of solar energy be the "best" approach, it should be identified as such. Seventh, the public must elect political officials who are aware of the alternative, and after elected, those officials must implement the alternative as public policy.

TABLE 9-3 *

THE PUBLIC'S EVALUATION OF THE ENERGY CRISIS

Response	Agree %	Disagree %	Not Sure %
Reasons why crisis is serious			
Cost of gasoline, heating, air conditioning going to rise sharply	75	13	12
U.S. running out of oil and natural gas and will have to depend on imports	51	36	13
Might have to ration gas before end of summer	49	33	18
Soon there will be a lot of brown-outs and power failures	39	43	18
Reasons why crisis is not serious			
U.S. will find enough energy to meet our needs	52	33	15
Most people will be willing to use less air conditioning, less heating and drive cars less	39	49	12
Federal government will not allow crisis to take place	35	43	22
Fuel and electricity have always been cheap in U.S. and will remain so	25	64	11

* Adapted from the Harris Poll of July,1973.

9-3 ENVIRONMENTAL

As man's standard of living rises so do his demands for energy. When these demands are coupled with an increasing population, the exponential increase in energy demand can outstrip energy availability. This is shown in Chapters 1 and 2 to be a possibility.

Unfortunately, in converting natural resources to the energy forms that are demanded, inherent wastes of energy and material result in ever pressing pollution problems. These problems make imperitive the evaluation of the environmental impacts of any program that significantly disturbs the face of the earth, before the program is implemented.

Resources. All endeavors require an investment of resources. Space exploration, Columbus' voyage, elevated modes of living, food production, etc. have been, or are being, allocated a portion of the resources of earth and man. The benefits derived in the future from such projects must be carefully weighed against their costs. Resulting societal benefits may not be entirely material in nature, but may appeal only to the aesthetic value of man. Inevitably, most projects attain a state where the return is insufficient to justify further consumption of resources.

Solar energy utilization does not appear to be of this character. In regard to man's existence on earth, solar energy is an inexhaustible supply of energy. Materials and other resources committed to the application of solar energy for the use of man are not dedicated to short-lived processes, such as oil and natural gas production.

It should be noted that the use of any fuel necessarily requires the production of associated suitable hardware. The development of such hardware often has been relatively slow, responding to increasing new and additional fuel demands or needs. Often scant attention has been given to secondary consequences of this dedication of materials and resources. For example, the evolution of a mobile society has spawned corporations devoted solely to the production of the automobile and its associated components. The rubber, asphalt, steel, et al, industries all orchestrate for this one mode of transportation. Societal impacts of these industries: pollution, energy consumption, jobs, etc., should be accrued to the automobile. Similar coordination of industrial efforts and their associated impacts will probably be necessary to utilize solar energy.

Solar heating and cooling may require investments of rather large amounts of copper, aluminum, transport fluids, storage materials and housing insulation. Material commitment to central solar collection facilities and satellite stations probably will also be quite large. Such commitments need to be made now if future generations are to have some probability of a comfortable lifestyle. Finite fossil fuels must not be depleted before such a commitment is made to use an inexhaustible energy resource - the sun.

This aspect should prevail in any plan of action or energy management scheme. Energy problems should be resolved with the primary intent (possibly the only intent) of insuring the continuation of man on earth. Needless and irresponsible consumption of resources can only lead to future crisis situations.

Land Use. Due to the low intensity of power in solar energy methods of collection and storage land use is naturally of major concern. Both items have a substantial effect on the utilization of solar energy. In an economic sense, these two factors may be the greatest barrier to the short-term use of solar energy. As the cost of collectors and storage systems is decreased by mass production techniques, further consideration must be given to their integration into society on a physical basis.

The three solar systems commonly proposed are: heating and cooling, central solar collection facilities and satellite collection with subsequent transmittal to central stations. These proposals can be categorized on the basis of the point of interception and collection of the solar insolation. Heating and cooling applications as applied to individual dwelling units are by nature dispersed over a wide area. The question of land use disruptions is not as pressing in heating and cooling applications if skyscraper condominiums are not considered. Central solar collection facilities (thermal or photovoltaic) and satellite collection and transmission requires the dedication of blocks of land areas for each installation.

The importance of land utilization is becoming more critical every day. Significant disruptions already have occurred in this decade due to the structuring of our transportation requirements around individual units -- the automobile and its requirement of highway systems. The world has only eight billion arable acres of land with an associated eight billion acres of potential grazing land [9-21]. Approximately three and one half billion are presently under cultivation. This restriction of land for food production places an upper limit on world population. The maximum population which can be supported has been estimated to be approximately eight billion (2.5 times the 1971 population [9-21]. As the population increases toward this limit, more of the energy resources must be applied to meeting the caloric requirements (food) of man. Man does not live by bread alone, but he does not live without it either. Perhaps, it is in this light that long range projects should be considered.

The aim of most proposed central solar collection facilities is the production of electrical power. At the present time, the facilities which convert energy via steam-turbine generators (thermal systems) appear to be the most likely initial step. This primarily is due to the difficulties and cost in the mass production of photovoltaic units. Electrical energy requirements have been estimated to be 1880 gigawatts in the year 2000. If this were met solely by central solar collection thermal facilities, approximately 4.5×10^7 acres would be required for the collector installations based on 37 square miles for a 10 gigawatt plant [9-22]. Earth receivers for microwave transmission from a solar satellite are estimated to require 17.33 square miles each [9-23]. In order to supply the same projected demand in the year 2000, a total of 2.1×10^6 acres will be required. In addition, this figure does not include the land commitment to produce the energy and materials for the 2×10^5 shuttle launches [9-24] which would be necessary to build the required 188 10-gigawatt satellite stations. Based on the efficiences of collection and transmission and the proposed satellite collector area, earth photovoltaic installations would necessitate using 2.2×10^7 acres to meet the year 2000 projected demand. An 89 percent reduction in from-space-to-earth insolation was assumed [9-25].

Other factors also must be considered if electrical power generation from solar energy is to be successful. New transmission lines will have to be built if the collector facilities are in locations of the greatest insolation. These areas, the Southwestern United States, are considerably displaced from some major population concentrations, e.g., the Northeast Corridor.

Unless a cheap innovative means of power transmission is developed, electrical generation from solar energy may be less than desired. Shifts of industry and population to regions of greatest insolation, to minimize transmission losses, may likewise prove not to be acceptable. The converse alternative, locating the facilities close to population centers, will require the reallocation of more valuable land and may reduce the capacity of the facility due to decreased insolation. Decreases of insolation may occur not only from variations of geographic locations on the globe, but also from variations in pollutant levels.

In the future, the balance between societal desires and needs will become more crucial than today's problems. A proper allotment of the limited resources of earth will become increasingly more important. This issue will concern all resources, land, manpower, energy, etc.

Health and Safety. Generally, solar and nuclear energy are accepted to be the only high potential long-range energy resources. The entire future of nuclear energy appears to be immersed in a quagmire of serious problems, any one of which may limit the existence of man. The overriding issue is the release of radioactivity, either on a phased schedule or by some catastophic event. The problem of phased releases boils down to the question of - is low-level radioactivity generally harmful to man? This question can be phrased from another position - is low-level radioactivity generally beneficial to man? The answer to this issue is not entirely clear at this time, especially in regard to long-range genetic effects. Historically, man's use of intensive energy sources has been accompanied by adverse side effects, e.g., concentrated explosives, nuclear warheads. In light of these issues, a solar oriented society should be pursued as opposed to the concept of a society based on nuclear power.

In general there appear to be few serious health and safety problems associated with the use of solar energy in comparison to alternate energy resources. However, it is the intent of this section to indicate possible areas of concern.

Two primary problem areas exist in solar heating and cooling in buildings: utilized material effects and degree of concentration effects. If glass is a major material necessary to the utilization of solar energy, reflection and breakage factors can not be discounted. If entire building walls are glassed for heat collection, open areas must be provided to gain access to the insolation. Correspondingly, such open areas could possibly prove to be a hinderance to pedestrian and automobile traffic.

Long duration exposure to the reflected rays of the sun could also lead to damage of the optic nerve. In addition, the possibility of physical burns exists when concentrating collectors are utilized. Since concentrating collectors inherently require less space than flat plate collectors, the protection or isolation of these devices should prove to be no greater a problem than the isolation of present day electrical power devices.

In all probability, central solar collection stations can be sited to minimize the probability of injuries. On the other hand, additional problems may be incurred with the installation of large solar collection facilities. Local changes in the microclimate of the stations may occur. Affects on the local wildlife and other ecosystems also are possible.

The use of microwaves for transmission of power, either from a space satellite or ground stations introduces additional problems. Although the projected power density of such energy beams is not considered to be sufficient for immediate damage, long term exposure effects should be investigated. Interference with standard communication systems may become a serious problem, especially in critical applications such as heart pacemaker devices.

In summary, some health and safety problems probably will occur with the implementation of solar energy devices. These problems do not appear to be insurmountable when viewed in contrast to those associated with today's conventional fuels. The health hazards resulting from oil, natural gas and nuclear energies have been recognized and are quite pressing. Solar energy has none of the particulate, carbon dioxide or radioactive waste storage problems of our current energy resources.

9-4 PSYCHOLOGICAL/SOCIAL

In the United States there is a tremendous social awakening; certain low income and deprived groups are desirous of improving their living conditions. The lifestyle of these groups is of a quality far below that which would be expected to be commensurate with the present stage of development of this nation. Elevation of the standard of living of a relatively large segment of society concurrent with a decrease in per capita energy consumption (or at least of zero increase in per capita consumption) appears to be paradoxical. Strong forces are at work to improve the standard of living of minority groups, and the accomplishments of social reform are many, demonstrating that strong social forces must be dealt a hand. Thus a very sensitive and complex social-psychological situation exists.

It could be suggested that the pursuit of an improved lifestyle is probably one of the major factors causing a tremendous drain on U.S. energy reserves. The per capita consumption of energy has increased exponentially over the past thirty years; however, conservative projections suggest a short term continued increase in energy consumption with an eventual leveling off (See Chapter 1). Since a desire to improve the individual's circumstances exists, there is an insufficient amount of fossil fuels to adequately provide the necessary energy supply to do this over a long period of time. Consequently, new or innovative technologies must be developed which will help alleviate the problems associated with the availabiltiy of energy resources and the insufficiency of energy which is needed for future consumption.

Lifestyles. Solar energy could help alleviate a long range energy crisis and probably simultaneously ameloriate the living conditions of man. There are probably some societal disruptions associated with phased implementation of this innovative technology; however, there exists a "real energy need", i.e., an energy need which will help mitigate the inevitable energy crisis and simultaneously permit social development. Solar energy appears to be a potential energy source which can be employed to satisfactorily close the future gap between available energy and energy consumption. Once humanity is sufficiently and properly educated concerning this aspect of solar energy then there will be a minimization of the difficulty of its implementation. In the past an apparent energy abundance has markedly changed people's lifestyles; and, since there has evolved an acquisition of a relatively comfortable lifestyle then there would result minimum societal disruptions if there is not a radical lowering of lifestyle. Radical changes precipitated by new technological developments strengthen the barriers hindering their acceptance and adoption. Solar heating and cooling of buildings is not necessarily a radical innovation and probably has more positive societal impacts than negative. The reaction of people to innovations depends to a degree on a status quo of the individual's living conditions. Indications are that solar heating and cooling of buildings is a feasible technological development which will permit individuals to maintain their present lifestyle and also aid in supplying sufficient amounts of energy for predicted future consumption.

A number of reasons exist why heating and cooling of buildings via solar technology has not progressed as rapidly as expected. One possible reason could be the lack of proper public education to the enormous possibilities of solar energy for the heating and cooling of buildings. Societal characteristics have an effect on the rate of phased implementation of solar energy, and there have been cited some cases in which solar collectors were placed on apartment complexes for water heating. However, because of improper communication the innovation was not accepted by the social class involved. Perhaps it is necessary that some exposure to the feasibility of heating and cooling of buildings via solar energy be made visible by an example or other high visibility demonstration of solar energy technology which shows minimum perturbation of societal reluctance to change from familiar ways of living to new and energy conserving ways, therefore, minimizing any radical change in lifestyles.

Health and Safety. There are genuine concerns for a decrease in environmental pollution and for the conservation of energy. The popularity of these two notions makes energy a "social force" [9-26]. Solar energy is virtually inexhaustible and as a fuel it is essentially pollution free, therefore, making it an attractive source of energy. There is a tradeoff between human comfort and the privilege of environmentally clean air. If solar energy is used on a large scale to heat and cool homes the problems of storage will have to be solved; furthermore, any inefficiency in night heating or heating during inclement weather could conceivably result in some discomfort. In addition, people might not accept the concept of the ambient room temperature being a little lower than that to which they are generally accustomed. Indeed this represents a trade-off between familiar and comfortable living conditions and conservation of fossil fuel and possible environmental pollution.

There can conceivably be concern involving utilization of solar energy for air conditioning. If ammonia is used in absorption air conditioning, there may be problems associated with leakage which could create societal fears and opposition to its implementation. In summary, solar energy implementation has more positive aspects than negative concerning personal well being if solar energy is to be utilized.

Housing Policy. It is virtually impossible to definitively evaluate all social and psychological impacts of solar energy implementation; however, some impacts can be treated in a qualitative manner. Furthermore, it is difficult to exhaustively enumerate all the social and psychological consequences of phased solar energy implementation, but there are some outstanding positive and negative societal disruptions resulting from implementing solar energy technology. In the heating and cooling of buildings, because of the economic status of the majority, there would exist financial problems accompanying the added cost of solar equipment. The overall tax assessment of the property would increase; therefore, creating more financial problems for some already low income and deprived people. In addition, there would probably be the fear associated with breakage and the upkeep expense resulting from vandalism. The possibility of vandalism also increases the home insurance rates, again creating financial problems and added expense for home financing.

Maintenance and Labor. There are minor problems of training service personnel to be competent in repair of solar equipment for homes, solar farms, and satellites. Tremendous problems exist in getting to a solar satellite to make necessary maintenance and repair.

National Security. The solar farm and solar satellite concepts represent a more difficult phasing problem of solar energy technology. Beside the environmental problems previously enumerated, there are problems involving vulnerability to immediate annihilation of the central solar stations. This creates a problem of national security which could have rather severe negative psychological consequences associated with it.

Architecture and Design. Any implementation of solar energy should be reasonably compatible with the overall building design. An aesthetically compatible building utilizing solar collectors for heating and cooling could have positive psychological impacts resulting in minimum reluctance to acceptance.

In conclusion, the phased implementation of solar energy in terms of heating and cooling of buildings, the solar farm concepts, and the solar satellite concepts certainly involve an interrelationship between societal impacts and technology. Furthermore, an analysis of societal problems accompanying solar energy technology development requires a shift of focus from physical considerations to social considerations.

9-5 SUMMARY

The future comprises an intricate web of interacting events, some of which are so extreme or bizarre as to be unpredictable or inconceivable through conventional planning [6]. Technology assessment is the term which is applied to a class of policy studies which systematically define, explore and evaluate the full range of political, environmental, psychological/social and other consequences of the introduction of a new technology or the expansion of an extant technology. Through a technology assesment, critical impact fronts and their possible interactions can be identified. A qualitative evaluation of specific impacts enables input to be made into an overall systems design model, and societal impact to play a role in the development of the technology.

An attempt has been made to identify specific impacts and interrelations, if they exist, and to evaluate the realtive magnitudes of the societal impacts of solar energy. The basis for a set of "evaluation criteria" to which example applications of solar energy technology must be subjected is thus developed.

REFERENCES

9-1. Toffler, A., Future Shock, Bantam Books, 1970.

9-2. Kahn, H. and Bruce, Briggs, B., Things to Come - Thinking About the 70's and 80's, MacMillan, New York, 1972.

9-3. Schwartz, E. S., Overskill - The Decline of Technology in Modern Civilization, Ballantine Books (Intext), New York, 1972.

9-4. Bauer, R. A., Second-Order Consequences, MIT Press, Cambridge, 1969.

9-5. "A Technology Assessment Methodology," a seven-volume report prepared by the MITRE Corporation for the Office of Science and Technology, Executive Office of the President, June 1971.

9-6. Bright, J. R., A Brief Introduction to Technology Forecasting-Concepts and Exercises, The Permaquid Press, 2nd Edition, Austin, Texas, 1972.

9-7. Griffin, R. W. and Dyer, G. E., "The South: From Yesterday to Today", in G. E. Dyer and R. W. Griffin (eds.), The New Southern Politics (New York: Intext Educational Publishers, forthcoming, 1974).

9-8. Irish, M. D., and Prothero, J. W., The Politics Of American Democracy, 6th Edition (Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1971), Ch. 1.

9-9. Miller, W. E., and Stokes, D. C., "Constituency Influence in Congress", in Angus Campbell et al., Electrons and the Political Order (New York: John Wiley and Sons, Inc., 1966), pp. 351-372.

9-10. Converse, P. E., "The Structure of Belief Systems in Mass Publics", in David Apter (ed.), Ideology and Discontent (New York: Free Press, 1964), pp. 206-261.

9-11. -----"The 500 Largest Industrial Corporations", The Fortune Directory, August , 1964.

9-12. Dye, T. R., and Zeigler, L. H., The Irony of Democracy: An Uncommon Introduction to American Politics, 2nd Edition (Belmont, Calif.: Wadsworth Publishing Co., Inc., 1972), p. 101.

9-13. Grodzins, M., "The Federal System", Goals for Americans, (New York: Columbia University, The American Assembly, 1960), p. 265.

9-14. Mitau, G. T., State and Local Government: Politics and Process, (New York: Charles Scribner's Sons, 1966), p. 7.

9-15. Saylor, J. P., H.R. 1894, 93rd Congress, 1st Session, Jan. 11, 1973.

9-16. Holtings, Senator E. F., S. 70, 93rd Congress, 1st Session, (For himself, Senator W. G. Magnuson, Senator F. E. Moss, and Senator J. U. Tunney), January 4, 1973.

9-17. Elliott, O., "Over the Mideast Oil Barrel," Newsweek, Vol. LXXXII, No. 4, pp. 59-62.

9-18. Campbell, Angus, et al., The American Voter (New York: John Wiley & Sons), 1960.

9-19. -----"U.S. Energy Crisis Serious, 77% say," Birmingham Post-Herald, July 27, 1973, A8.

9-20. Katz, Daniel, "Attitude Formation and Public Opinion," Annals of the American Academy of Political and Social Scientists, Vol. 367, (September 1966), pp. 150-162.

9-21. Gates, David M., "The Flow of Energy in the Biosphere", Scientific American, Sept. 1971, Vol. 224, No. 3 p. 88-100.

9-22. Hottel, H. C., New Energy Technology, MIT Press 1971.

9-23. Brown, William C., "Satellite Power Stations - A New Source of Energy," IEEE Spectrum, Vol. 10 No. 3, March 1973, pp. 38-47.

9-24. NSF/NASA Solar Energy Panel, Our Assessment of Solar Energy as a National Resource, December 1972.

9-25. -----Handbook of Physics, MacMillan, New York 1961, Section 16, pp. 28-29.

9-26. Miller, R. J. and Duffie, J. A., "Thoughts on Economic-Social Implications of Solar Energy Use", International Solar Energy Society Conference (1970).

CHAPTER 10. MARKET POTENTIAL FOR SOLAR HEATING AND COOLING IN BUILDINGS

Before any new technological innovation is accepted by industry there must be a convincing argument that there is a sufficient market to make it a profitable venture. The market potential on both a national and a regional basis is presented below to indicate the size of the market for the solar heating and cooling in buildings.

10-1. NATIONAL MARKET POTENTIAL

A summary of the amount of energy used for water heating, space heating, and space cooling in residential and commercial buildings in the United States in 1968 [10-1] is shown below in Table 10-1.

Table 10-1. RESIDENTIAL AND COMMERCIAL END USE CONSUMPTION

Sector and End Use	Consumption (1968) in Quads	Annual Rate of Growth (1960-1968)	Percent of National Total
Water Heating			
Residential	1.736	5.2%	2.9
Commercial	0.653	2.3%	1.1
Space Heating			
Residential	6.675	4.1%	11.0
Commercial	4.182	3.8%	6.9
Space Cooling			
Residential	0.427	15.6%	0.7
Commercial	1.113	8.6%	1.8

The total energy used for water heating, space heating, and space cooling in residential and commercial buildings was 14.786 Quads in 1968. Energy for these purposes accounted for 24.4 percent of the total energy use in the United States. The annual rate of growth (1960-1968) was 4.1 percent.

The total energy used in the United States in 1968 was 60.526 Quads. The annual rate of growth in total energy was 4.3 percent

It is difficult to make projections of the potential for use of solar energy in buildings with any degree of confidence. Several factors contribute to this uncertainty:

- Space cooling currently is only a small fraction of the total energy consumption, however, it is by far the most rapidly growing end-use. It is difficult to project the extent and rate at which space cooling will continue to grow.

- Building construction growth patterns are uncertain except in the very short-run. It is also likely that energy availability problems may influence building pattern growth as much or more than building growth influences energy availability.

- Increasing emphasis on energy conservation in buildings, e.g., new insulation requirements, use of total energy systems, etc. may have a very significant effect on the amount of energy which will be used in buildings in the future.

- Inertia in the building industry makes it difficult to predict the rate at which the use of solar energy could be integrated into construction.

Despite all of these difficulties it is of interest to make some speculative projections. The intent of these rough projections is to make preliminary evaluation of the potential impact on energy displacement, business volume, and materials requirements. Two separate gross national projections will be considered. In a later section a projection based on regional considerations will be discussed.

The assumptions upon which the first two projections will be made are as follows:

- Solar energy use on a large scale would begin in 1979. This delay is a result of the complexity of the building industry.

- Solar heating will be used on new construction only since retro-fitting of old buildings will be very difficult and expensive. (For example, heat storage tanks are large, roof orientations may be unsuitable, etc.). This means that solar energy can only displace a portion of the annual increase in energy used for these purposes.

- No more than 50 percent of the new construction will be able to utilize solar heating because of undesirable climate, unsuitable locations, trees, tall buildings, etc. This degree of solar utilization would require a maximum effort to accomplish. It is probably much higher than could be achieved under all but the most extreme measures.

- For those buildings which utilize solar heat, solar equipment will provide 70 percent of the total heat required, the rest will be supplied by a conventional system.

- The projected total energy consumption is taken as the AET-8 Brookhaven value of Figure 1-2. The amount of energy which is used for heating and cooling is assumed to be as indicated in Table 10-2.

Table 10-2. ENERGY FOR HEATING AND COOLING PROJECTED TO 2020

Year	Total Energy Consumption (10^{15} Btu)	Energy for Heating and Cooling	
		Amount (10^{15} Btu)	Percent of Total (%)
1968	60.5	13.25	24.4
.			
.			
.			
1979	84	21.0	25
1980	88	22.0	25
1990	127	31.8	25
2000	175	38.5	22
2010	230	46.0	20
2020	300	54.0	18

This projected energy pattern is an attempt to take several trends into account:

(1) The use of air conditioning will continue to increase at a high rate for perhaps 20 years and then saturate.

(2) The energy required for heating and cooling of buildings will gradually decrease because of improved design.

(3) The population growth rate will be decreasing during this period.

(4) Other energy uses will probably grow more rapidly than heating and cooling.

Two projections will be considered. The first represents a maximum effort of implementation. The second represents a more gradual phased implementation (Table 10-3).

Table 10-3. PERCENT OF NEW CONSTRUCTION UTILIZING SOLAR HEATING AND COOLING

Time Period	Percent of New Construction Utilizing Solar Energy for Heating and Cooling	
	Projection 1	Projection 2
1980 - 1989	50	10
1990 - 1999	50	20
2000 - 2009	50	30
2010 - 2019	50	40

Projection 1

Energy Displacement. Using the assumptions given, the amount of energy which would be displaced by a maximum effort to implement solar heating and cooling is shown in Table 10-4.

Table 10-4. ENERGY DISPLACEMENT - MAXIMUM EFFORT

Year	Cumulative Solar (10^{15} Btu)	Percent of Total (%)
1979	0	0
1980	0.26	0.3
1990	3.78	3.0
2000	6.12	3.5
2010	8.75	3.8
2020	10.78	3.8

During the first few years of this projection the additional amount of energy displaced annually would be approximately 0.3×10^{15} Btu. This represents a very significant amount of energy. It is equivalent to the annual output of 10 very large (1000 Mwe) electric power stations operating at full output 24 hours a day for 365 days a year.

From an overall total energy consumption viewpoint, however, this annual increment of energy displaced is less than 1/3 of 1 percent of the total energy consumption. It can be seen from the projected displacement figures that a very long period of time is required before a significant impact can be made.

Projection 2

The second projection is a more gradual phased implementation of solar heating and cooling. The results of this phasing would amount to approximately half the energy displacement of projection 1 as is shown in Table 10-5.

Energy Displacement.

Table 10-5. ENERGY DISPLACEMENT - GRADUAL PHASING PLAN

Year	Cumulative Solar (10^{15} Btu)	Percent of Total (%)
1979	0	0
1980	0.052	0.06
1990	0.74	0.6
2000	1.68	1.0
2010	3.26	1.4
2020	5.50	1.8

This projection is a more realistic one; however, it still represents a very significant level of effort to implement and the impact on energy displacement is slower than the first projection.

10-2. REGIONAL MARKET POTENTIAL

The determination of national market potential for the solar heating and cooling of buildings was of necessity based upon very gross assumptions. It did not include such things as varying climates, varying competitive energy sources, and varying patterns of population and building growths. In order to remove some of these deficiencies the market potential on a regional basis is determined and the sum of the regional market potentials is given as the national market potential. The analysis given herein is primarily for homes, either single family, multi-family, or mobile. The commercial and industrial potential is not studied in any significant detail.

Two important indicators of market potential are regional population and housing projections. A recent Forest Service report [10-2] documents the growing demands for housing in the United States (Figure 10-1). Using a model relating population growth, age distribution, and vacant and replacement units, to household formations, three series of housing demands are projected to the year 2020. These series (1, 2, and 3) reflect Bureau of the Census population projections based on fertility rates of 2.78, 2.45, and 2.11, respectively. In the long-run population and income factors are the most important determinants in household formations and housing demand.

The regional projections (Figure 10-2) indicate that the South will reflect the largest growth. By 2020 it will comprise 33% of the total population and 37% of the total new construction. Next in size will be the North Central region- 25% of the total population and 24% of the total new construction. The West, with 20% of the total population, will account for 22% of the new construction, while the Northeast, with 22% of the total population, will indicate only 17% of the total new construction.

However, from these projections only "rough" regional estimates may be inferred. These Census regions need to be further refined by climatic characteristics. Regional variations of solar availability as well as heating and cooling requirements will affect the extent of solar heating and cooling application. In view of these limitations, market projections by population and housing were redefined based on solar regions, which were determined from the mean daily solar insolation (Figure 3-7).

Figure 10-3 which indicates the population growth by solar region was arrived at by using Bureau of the Census projections on a state-by-state basis to 1990 [10-3]. The total national Bureau of the Census projected growth between 1990 and 2020 [10-4] was then broken down into solar regions by using the same growth percentages which were projected between 1970 and 1990. Figure 10-4 was then constructed by using a household formation factor similar to that used by the Department of Agriculture [10-2]. The housing starts by region (e.g., South, West, etc.) were then checked against the values shown in Figure 10-4 and found to be in reasonable agreement.

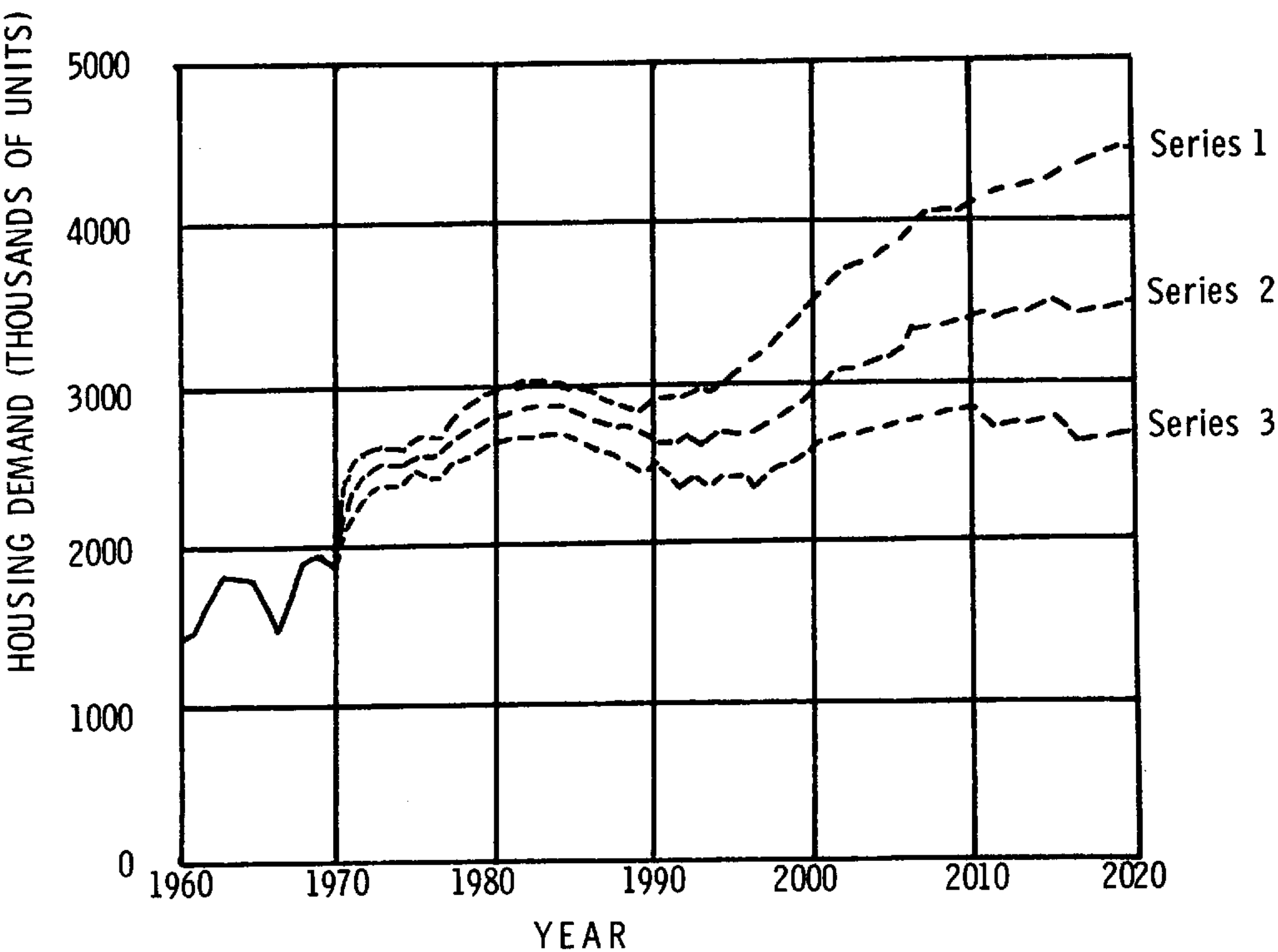

Figure 10-1. TOTAL DEMAND FOR HOUSING 1960-2020

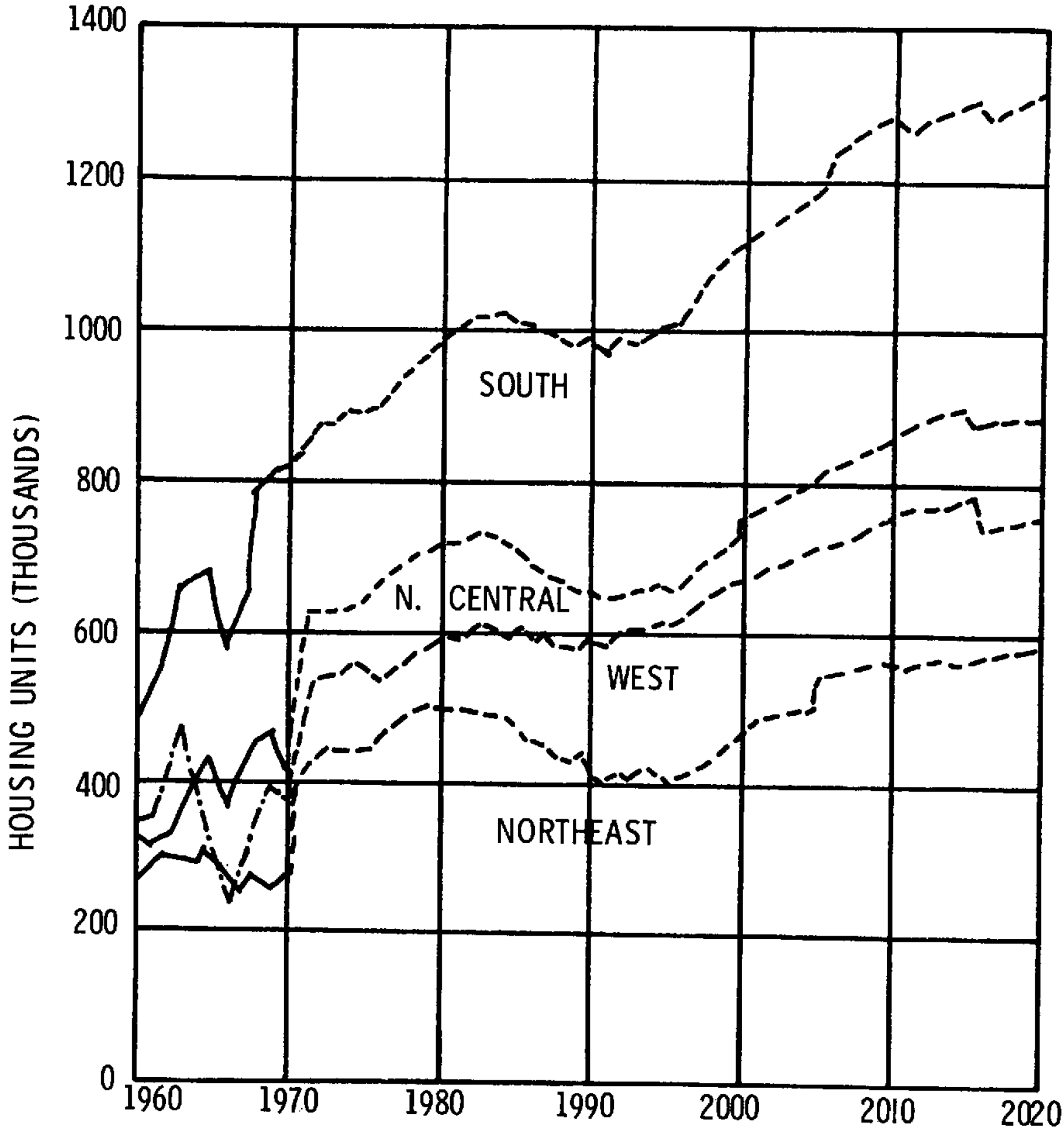

Figure 10-2. TOTAL HOUSING BY REGION 1960 - 2020

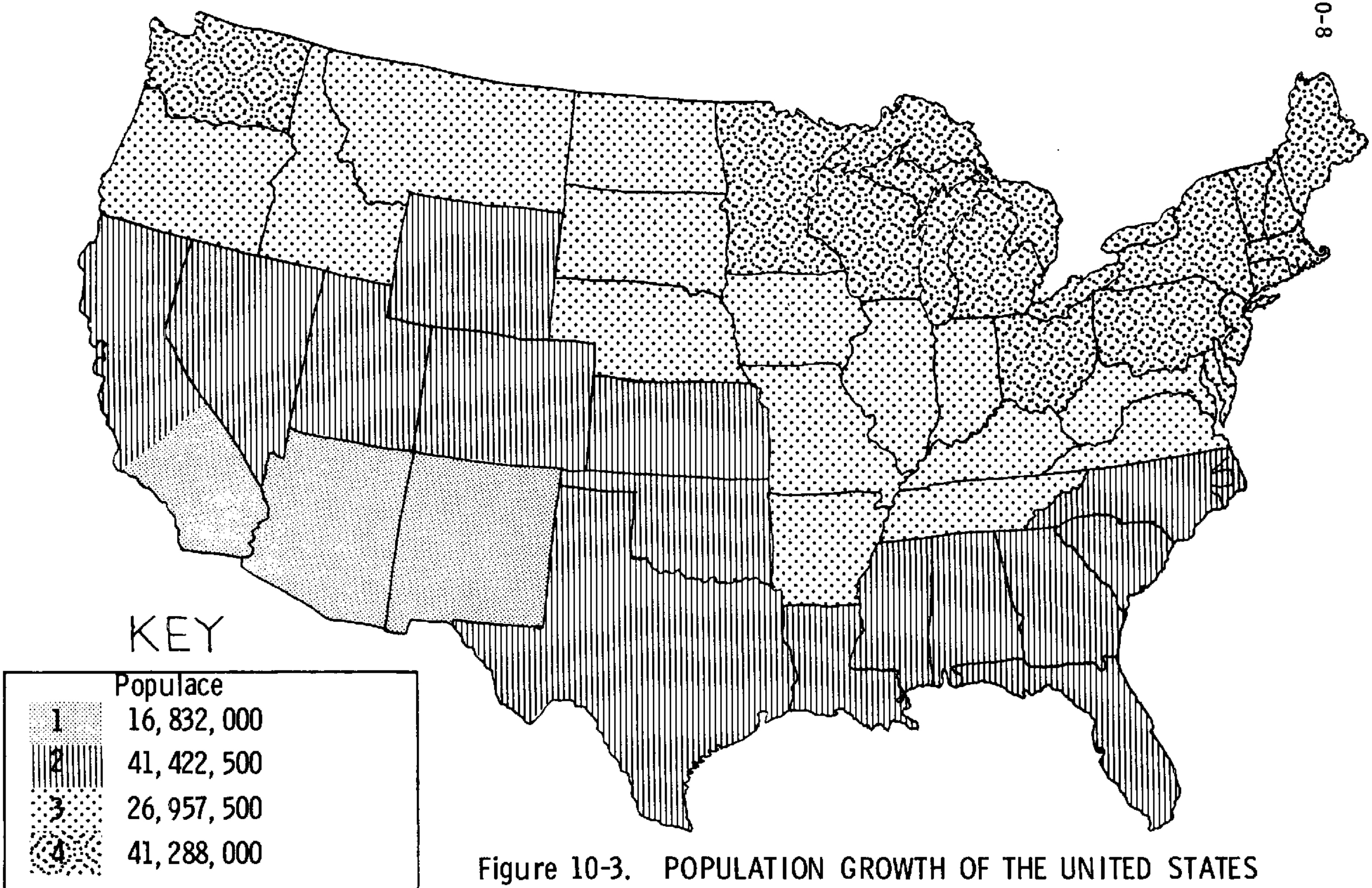

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Figure 10-3. POPULATION GROWTH OF THE UNITED STATES BY SOLAR REGION 1970-2020

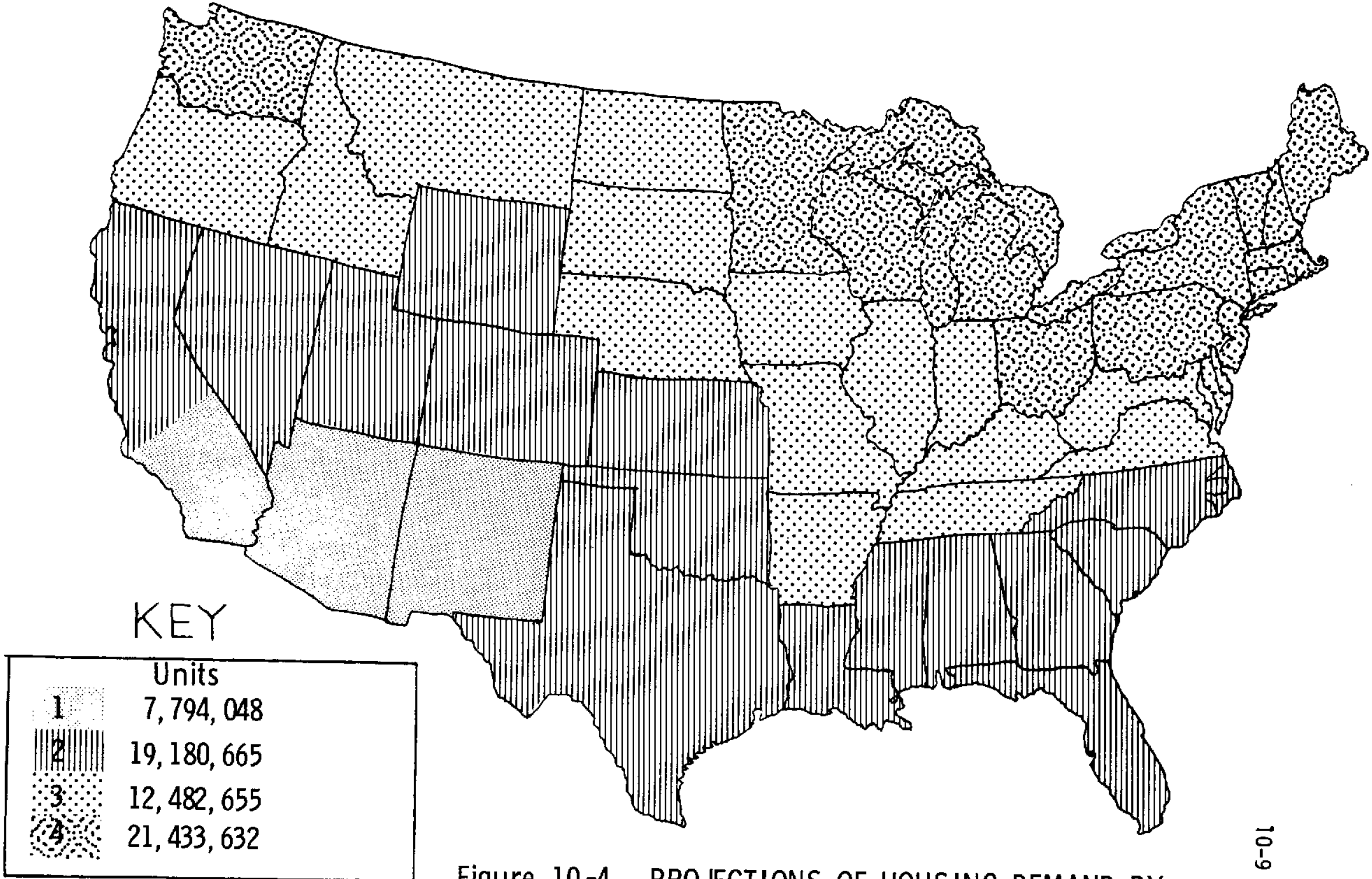

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Figure 10-4. PROJECTIONS OF HOUSING DEMAND BY SOLAR REGION 1970-2020

According to this refinement (Figures 10-3 and 10-4), Region 1, which includes the states of Arizona, New Mexico and Southern California, will represent 13% of the total projected population and new residential construction by 2020. Region 2 will account for 32% of the total. It is important to note that this region includes the fast-growing South (as projected by the Bureau of the Census). Even though Region 4 , which consists of the Northeast, the Great Lakes, and parts of the Northwest, shows the greatest potential in terms of population and housing needs (35% of the total), for climatic reasons it is not as practical for solar energy applications as are Regions 1 and 2.

To determine the potential regional markets for the solar heating and cooling of residential buildings it is necessary to assign a percentage of market capture to each solar region. An approach to a definition of this regional market potential is indicated in Table 10-6.

Table 10-6. REGIONAL MARKET POTENTIAL - HOUSING 1970-2020

	Housing Starts (Figure 10-4)	% Market Capture	Solar Heated and Cooled Housing Units
Solar Region 1	7,794,048	50	3,897,024
Solar Region 2	19,180,665	40	7,672,266
Solar Region 3	12,482,655	20	2,486,531
Solar Region 4	21,433,632	10	2,143,363
Total	60,891,000		16,199,184

The total figure of 16,199,184 units is, of course, very approximate and should only be used as a bench mark number. This approximate analysis indicates a possible 26 percent of the total new housing built in the United States between 1970 and 2020 could be solar heated and cooled. It should be recognized that this analysis has considered only new population moving into the regions either by birth or migration, and does not include any replacement housing for the population currently living in these solar regions. Over a 50-year period most existing housing would probably be replaced, which indicates a vast potential market not accounted for in the previous analysis.

Specific market needs may be inferred from the projections of the housing demand by types of units (Figure 10-5). One-unit (single family) construction will increase its share of the total new construction from 43% in 1971 to 47% by 2020. Multi-unit new construction will continue to rise. Interestingly, mobile homes will rise from 18% of the total in 1971 to 23% by 2020 (with 35% of the total mobile units located in the South).

These sub-markets indicate a further refinement for solar energy application. There is a need for an analysis and specification of requirements for the type of system- heating and cooling process, and for the function of the system- water heating, space heating, space cooling, and the combination of these- generated by solar and auxiliary systems. For

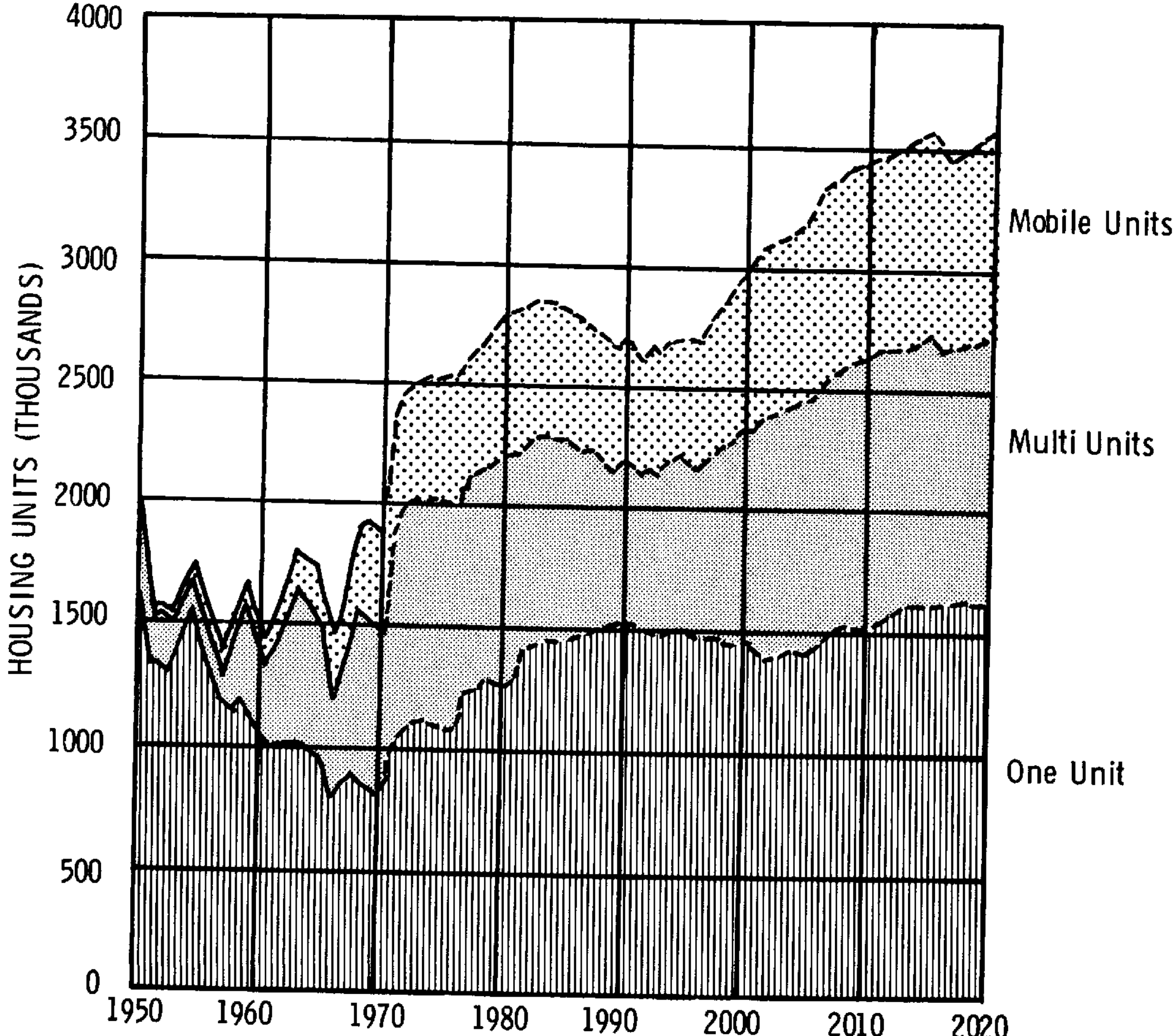

Figure 10-5. HOUSING PRODUCTION BY TYPE OF UNIT

example, multi-unit (single story) construction may prove to be more practical for solar energy application due to the insulation characteristics of common walls. Mobile home construction may also offer a good potential. Mass production characteristics of the mobile home industry may suggest practical/integrated systems.

There is substantial evidence that commercial development is closely connected with population growth. It should therefore be possible to determine the market potential for commercial buildings by using a similar procedure to that described above.

In summary it can be stated that there is indeed a market potential for the solar heating and cooling of buildings. This potential will be even greater if the cost of competitive fuel increases to the levels projected. Assuming a $3000 per dwelling cost for a combined solar heating and cooling installation and applying this to 16,000,000 units over the next 50 years, will yield a $48 billion or approximately $1 billion per year market potential. This does not include possible applications to commercial or industrial facilities nor does it include the replacement housing market. It is thus conceivable that the potential could be as high as $3 - $5 billion per year in the not too distant future.

REFERENCES

10-1. Stanford Research Institute for the Office of Science and Technology, "Patterns of Energy Consumption in the United States", January, 1972, p. 5.

10-2. Marvin, T. C., Projections of Demand for Housing by Type of Unit and Region, U.S. Department of Agriculture, Forest Service, Agriculture Handbook, No. 428, May, 1972.

10-3. U.S. Department of Commerce, Population Estimates and Projections, Series P-25 (477) Washington, D.C., March, 1972.

10-4. U.S. Department of Commerce, Bureau of the Census, Population Estimates and Projections, Series P-25 (493), Washington, D.C., December, 1972.

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CHAPTER 11. STRATEGY FOR SOLAR HEATING AND COOLING IN BUILDINGS

The basic strategy for the introduction of solar heating and cooling in buildings (SH/CB) into the economy is shown in Figure 11-1. The strategy begins with this diagram (Figure 11-1); there are two phases to the strategy. The first phase consists of the steps necessary to determine the types of (solar) equipment that manufacturers would find most promising for market development. The second phase shows the steps from manufacturing to equipment installation. The first phase should be funded primarily by the Federal government and Foundations. The second phase would be the responsibility of private industry.

The TERRASTAR report constitutes the initiation of a feasibility study, and it also presents considerations germane to each of the steps in phases one and two, as is evident by reading the report and the discussion to follow. The strategy presents a framework for identifying barriers to the implementation of SH/CB, opportunities for industry, educational institutions, technical and professional societies, and government to attack and to overcome these barriers and possible sources of funds to surmount the barriers.

The shorthand notation used in each of the circles to denote the steps of the strategy is explained, and discussion of each step is, as follows:

11-1. FEASIBILITY STUDY

The feasibility study was the focal point of the TERRASTAR effort, and it is, in essence, outlined in the Table of Contents of this report. Efforts have been devoted to determining the technical, economic, environmental, sociological, political and strategic feasibility of solar heating and cooling within the whole solar energy picture and within the context of the total energy picture. The output of the feasibility study consists of reccomendations for each step displayed in the strategy.

11-2. R&D (RESEARCH AND DEVELOPMENT)

There are a number of areas of research and development (R&D) pertinent to SH/CB. The R&D referred to in this step is primarily concerned with solar heating and cooling equipment.

There are many articles in the literature on solar heating and cooling, and some of these are discussed elsewhere in this report.

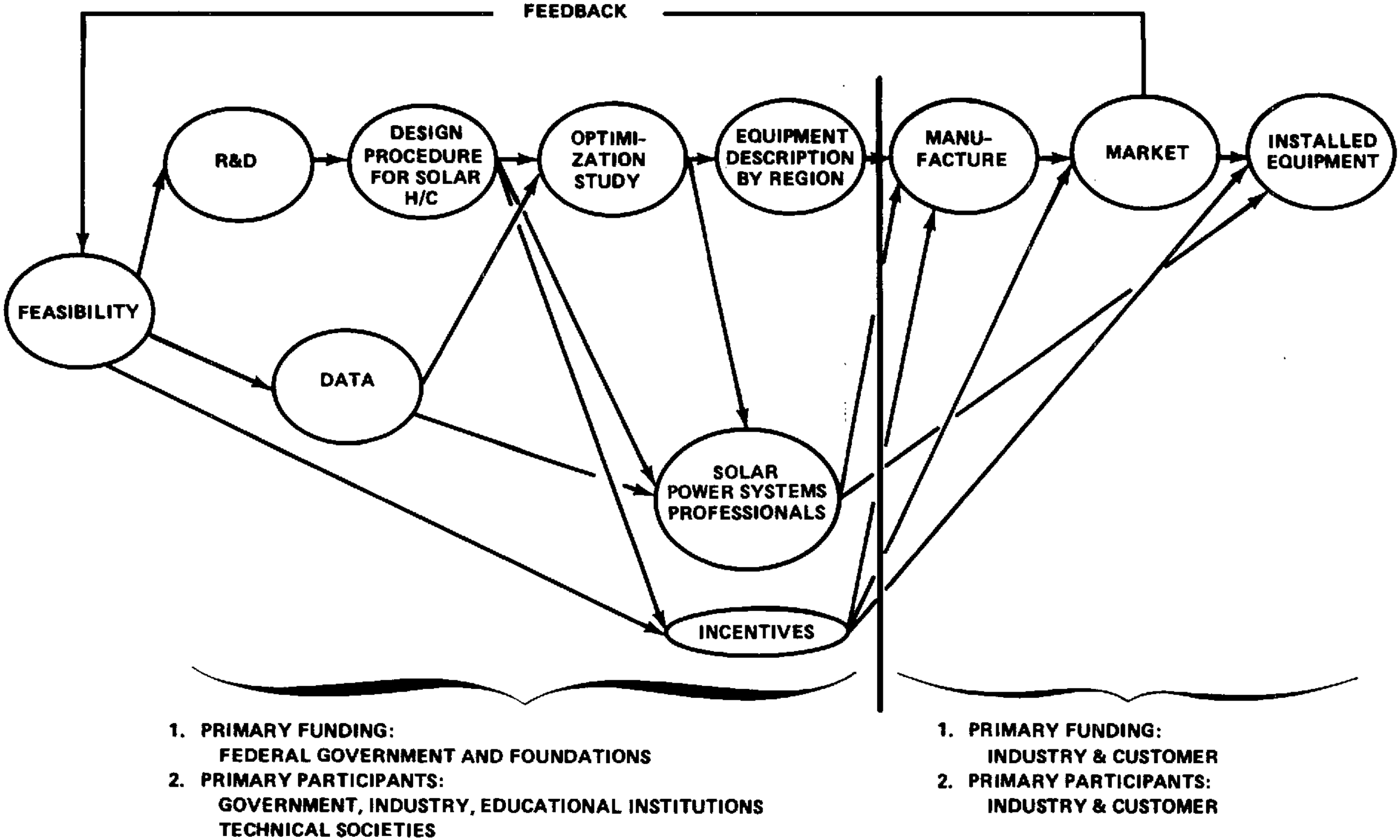


Figure 11-1. STRATEGY FOR THE ACCEPTANCE OF SOLAR HEATING AND COOLING IN BUILDINGS

Experiments have been conducted with solar equipment components, and demonstrations of solar heating and cooling have been made. Solar heating is currently practical, but problems remain to be solved if solar cooling is to become practical. Both solar heating and cooling can profit from further research. R&D to improve the economics of solar heating is necessary to promote acceptance of solar heating, and research on solar cooling is required to prove this concept.

Components and systems for SH/CB were reviewed in Chapters 4 and 5 of this report. The background and current status of this important area of application were discussed. Some excellent pioneering work has been performed. This work will serve as a basis upon which to build the future R&D needed for the advancement of the state-of-the-art. Figure 11-2 depicts the major R&D areas relating to solar heating and cooling equipment and their interactions. Examples of specific areas requiring attention are outlined in the following paragraphs. The order of presentation is not intended to indicate priorities, nor should the listings be regarded as necessarily complete.

Total System R&D

- Identification of new systems concepts
- Workable system identification and simulation
- System optimization and trade-off studies
- Optimum integration of supplementary systems
- Development of retro-fitting techniques
- Control systems development
- Architectural integration studies

Subsystem and Components R&D

- Collectors

  Overall design including new concepts
  Optimization of specific design concepts
  Comparative studies of alternate concepts
  Cover plate mounting and sealing techniques
  Convection suppression techniques
  Selective coatings
  Effects of contaminants on cover plate transmission
  Importance of thermal capacitance effects
  Prevention and/or effects of loss of coolant
  Cost-benefit studies of tracking techniques

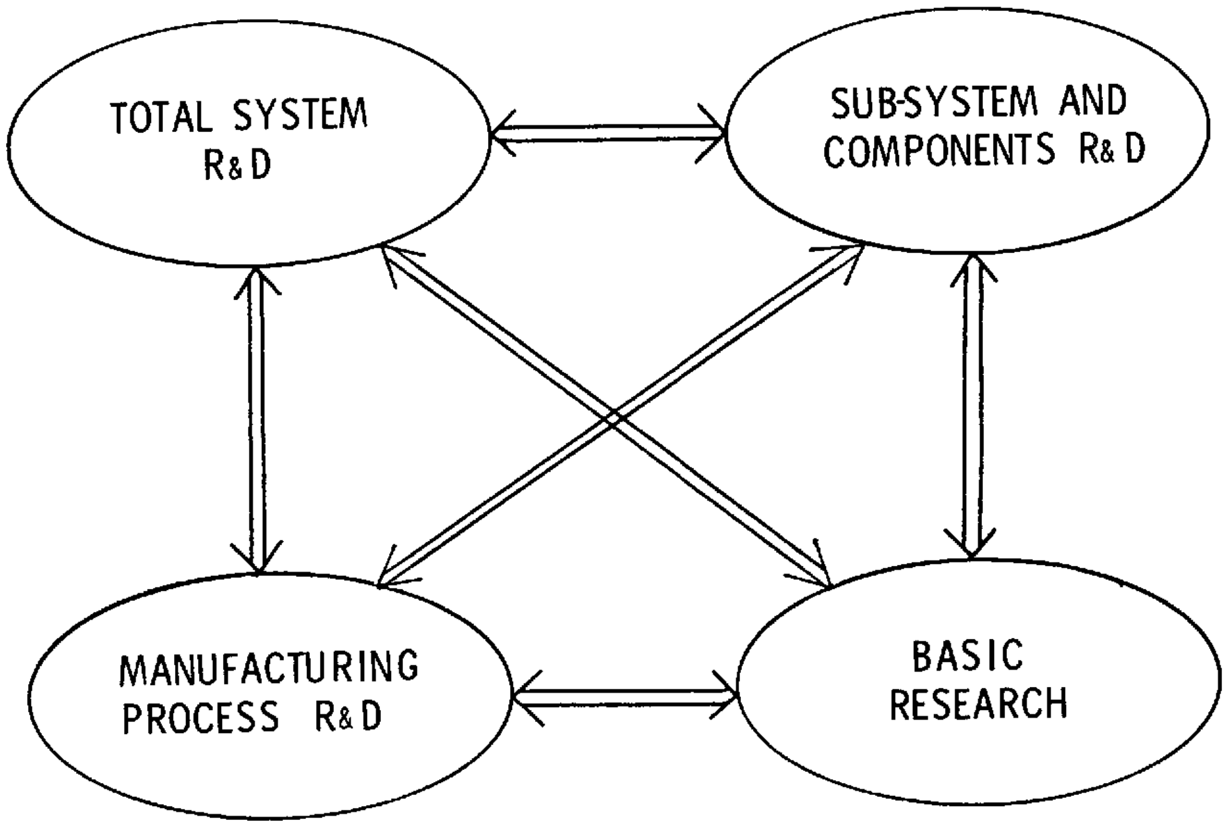


Figure 11-2. MAJOR RESEARCH AND DEVELOPMENT AREAS FOR SOLAR HEATING AND COOLING EQUIPMENT AND THEIR INTERACTIONS

- Storage

  Low-temperature phase change materials
  Improved nucleation of phase change materials such as salt-hydrates
  Crystal settling prevention techniques

- Heat-Actuated Conditioning Systems

  Low input temperature operation
  Variable input temperature and heat rate operation
  Investigation of heat rejection techniques
  Cost-efficiency trade-offs
  System simulation including off-design-point and non-steady operation
  Working fluids (refrigerants, absorbants), including compatibility with respect to corrosion and toxicity
  Component design improvement directed toward increased efficiencies

Manufacturing Process R&D

- Mass production of selective coatings
- Low-cost mass production of cover plates
- Component assembly and quality control

Basic Research

- Anti-reflection coatings
- Selective surface stability
- Dust-repellent surfaces
- New or improved plastic cover materials
- Synthesis of improved phase change storage materials

Of equal importance with the identification of the required R&D are the approaches pursued in its performance. Research and development on subsystems and components should be performed under controlled or laboratory conditions whenever possible. For example, a new collector design should be adequately tested in the laboratory. It is not necessary to incorporate the collector design into a complete structure for performance testing, as has sometimes been done in past work. Properties of components of a subsystem under test should be independently measured, so that subsystem performance predictions which use these properties as inputs can be meaningfully compared to subsystem test results. For example, transmission properties of cover plates and radiation properties of absorbing surfaces used in test collectors should be accurately known. Adequate instrumentation should be employed. For instance, in performance testing of abosrption cycle cooling systems inlet and outlet temperatures, pressures, and concentrations of all components should be monitored, if possible, as well as temperatures of all heat sources and heat sinks. Such practices have not always been followed in the past, or if they have, the results have not always been thoroughly documented. This is probably due, in part at least, to inadequate funding. Whatever the cause, incomplete measurements or lack of documentation of all significant results has made it difficult for other investigators to build efficiently on prior work. Rectification of this situation would increase the rate of advancement of the state-of-the-art.

In spite of the fact that the practical application of solar heating and cooling has not been widespread, the literature relevant to the area is voluminous and covers a rather long time period (at least one hundred years). Increased funding for R&D will draw workers into this field who are unacquainted with much of this literature. Therefore, preparation of literature reviews and annotated bibliographies of high quality would contribute to the orderly advance of this area of technology.

A final observation which may be appropriate in this context is that the high level of technology required for economically realistic implementation of solar heating and cooling has not been fully appreciated in the past. This is probably due, in part, to the fact that almost any handy homeowner can at least attempt to fit his house with some sort of solar collector for water or perhaps space heating. This is in contrast to the situation in some other areas of energy production and utilization, such as nuclear power, and has undoubtedly caused some engineers and scientists to shy away from the solar heating and cooling area.

It cannot be overemphasized that solar heating and cooling R&D deserves the efforts of some of the nation's highly qualified engineers and scientists.

Demonstrations of SH/CB, in addition to the past and current efforts cited elsewhere in this report, should be conducted to evaluate solar equipment and systems R&D.

Demonstrations of SH/CB can serve two purposes. First, they can provide information on equipment design and performance, and second, they can serve as an educational device to promote public acceptance of solar heating and cooling. Demonstrations using buildings are expensive, however, and should only be initiated as part of a carefully planned program. Each demonstration should be a thoroughly planned experiment with definite measurable performance goals. The buildings should be completely instrumented to measure the performance of the equipment and the ability of the equipment to maintain design environmental conditions. Care must be taken to insure that these experiments will yield valid fundamental design and performance information.

It would be preferable to have a few experimental buildings which would provide good complete engineering data, rather than many which do not advance the state-of-the-art of the technology. All of the demonstration building experiments should be coordinated so there can be a maximum interchange of information. In addition, these demonstrations should be planned for representative climatic and insolation regions of the country to provide working data for the development of a design procedure for SH/CB.

If many design innovations are being made in addition to solar heating and cooling, it may be difficult to assess the success or failure of the solar equipment. In some such cases it may be useful to build two identical buildings, one solar heated and cooled and one conventionally heated and cooled, in order to have a reference for performance comparison.

It should be reiterated that experiments on basic problems, such as cooling processes or novel collector designs, should be conducted as laboratory experiments whenever possible and not as "solar building" experiments in order to maximize the knowledge gained for the amount of time and money spent.

11-3. DESIGN PROCEDURE FOR SOLAR HEATING AND COOLING IN BUILDINGS

The logical step following the establishment of technical feasibility and R&D is the development of a design procedure for solar heating and cooling in buildings (SH/CB). This procedure should consist of design considerations, design standards, and computer codes and handbooks to relate design objectives to the considerations and standards. Furthermore, the procedure should be universally applicable, in contrast to current design methods for SH/CB which are limited to the design of a specific building in a specific location.

A design procedure of the scope outlined above does not currently exist. Computer codes for simulating and calculating the heating and cooling loads of standard building designs have been developed by the National Bureau of Standards (NBS), MIT, ASHRAE, and Dubin-Mindell-Bloome Associates, Inc. (and others), but they have not been integrated into a standard design package for SH/CB. The development of a complete design procedure for SH/CB is an undertaking of great complexity requiring extensive systems studies. The intent is not to tackle the full problem here, but rather to outline an approach to the analysis required. This first attempt should serve as a blueprint for recommended future efforts to implement a full design procedure for SH/CB.

In this section, the following points are considered:

- How the concept area---SH/CB---was selected.
- A suggested methodology for elucidating design considerations (the elements of design).

- Real-world examples of SH/CB to exercise and test the methodology, and to point up general problem areas (impediments) in the design of SH/CB.
- Documentation of the results of these example analyses.
- A schematic extension of design considerations to regional and national scales.
- Conclusions and some recommendations for future studies resulting from this brief investigation.

Concept Area Selection. The concept area under consideration is SOLAR HEATING AND COOLING IN BUILDINGS (SH/CB) - that is, the utilization of solar energy to provide space heating, space cooling (air conditioning), and hot water in buildings. The route taken by the Design Group to select this concept area may be of some interest to the reader.

First, a set of sixteen controls (constraints and criteria) was determined by Group consensus; see Table 11-1.

TABLE 11-1

CONCEPT AREA CONTROLS

- Proof-of-Concept Demonstration Implementable Within 2-3 Years
- Economically Competitive With Equivalent Standard Systems
- Minimal Disruption of Environment and Ecology
- Where Possible, Compatible With Existing Energy Systems
- Aesthetically Acceptable
- Functional, Maintainable, Reliable, Durable, and Foolproof
- High Profile (Visibility) and Publically Acessible
- Marketable (Broad Public Acceptability)
- Positive Impacts Upon Society
- Components Mass-Producible With Current Technology
- Compatible With Legal Requirements and Political Realities
- Significant Displacement of Depletable Energy Forms, Ultimately

- Flexible, Adaptable, and Evolutionary
- Take Into Account Both Public (Government) and Private (Industry) Sectors
- Minimal Hazards to Users
- Exemplify the Conservation Ethic

Second, concept areas involving the utilization of solar energy were considered in the context of these controls, and SH/CB surfaced as the obvious choice.

Finally, when real-world examples (see following) were chosen to test the methodology, they were first restricted by these controls. In addition, limitations of time led to the exclusion from consideration in the examples of the following concepts:

- Electrical power generation (e.g., photovoltaics)
- Process steam production (e.g., high temperatures)
- Central stations and space systems

As a result, the solar systems employed in the examples are in the low-temperature thermal regime (e.g., non-concentrating or flat plate collectors, etc.).

Methodology. Following the determination of the technical feasibility of SH/CB, it will be necessary to have standard solar equipment, solar energy professionals, incentives, manufacturing capabilities, and sales and service organizations in order to effect a large-scale implementation of SH/CB in the United States. The necessary and unifying element which is prerequisite to these latter stages of commercialization is a design procedure for SH/CB. Lacking this, progress will be spotty at best, and most of the frustrating and time-consuming mistakes of the past will be prepetuated indefinitely into the future; in addition, SH/CB would lack the economical edge which it must possess to be a viable, competitive industry.

A design procedure, with its computer codes and design manuals (handbooks), combines the following elements to produce an optimal design for SH/CB:

- Sunlight on earth
- The components of solar equipment systems
- A type of building
- A location (site) for the building

Figure 11-3 illustrates this idea.

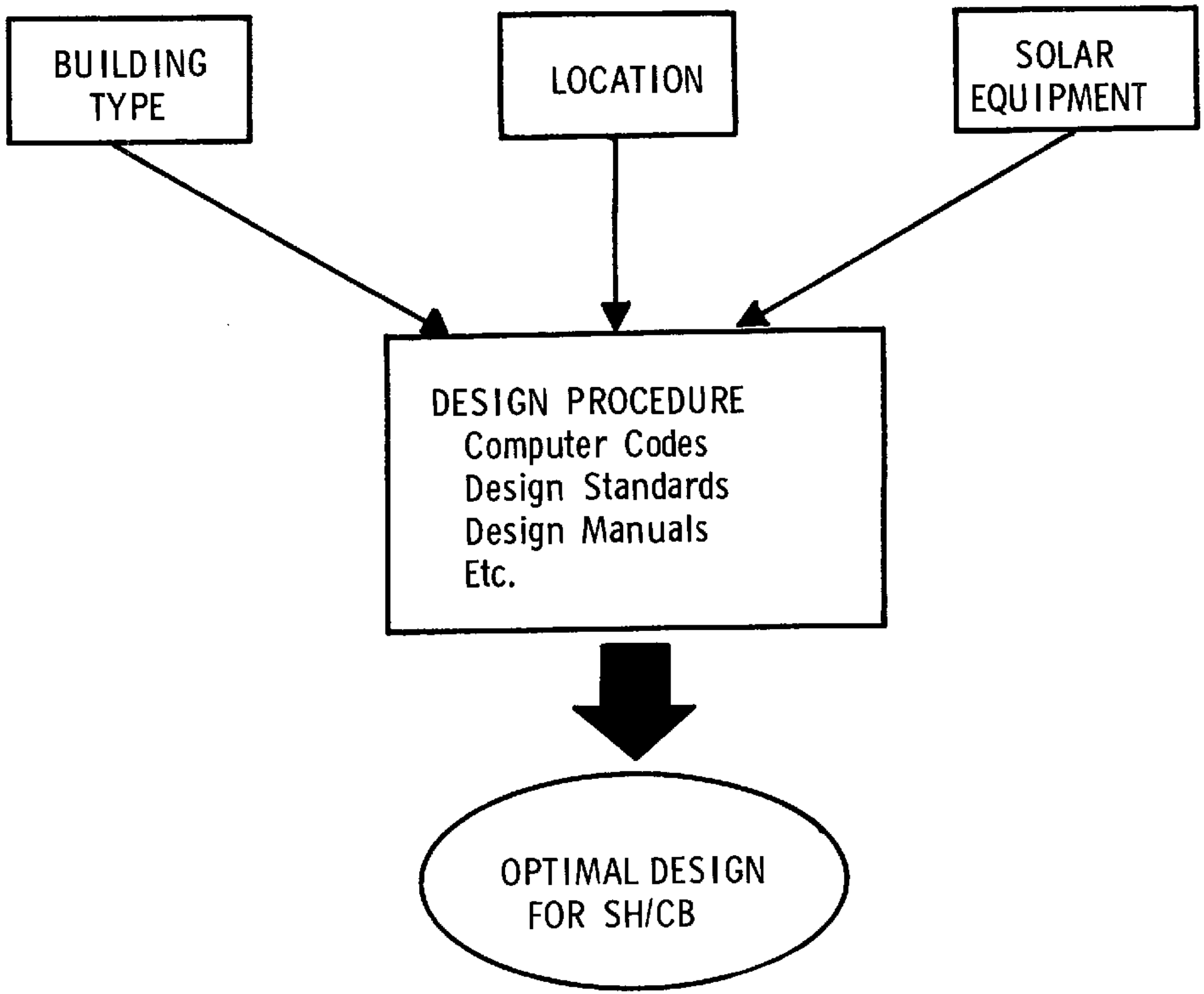


Figure 11-3. USING A SH/CB DESIGN PROCEDURE

The first step in devising a design procedure is to spell-out the elements of design. Every building design involves the same generic considerations; the only added item for SH/CB is the solar equipment. Since any good design exhibits synergism - the properties of the total interacting system transcend those of the individual parts or their arithmetic sum - this additional element completely changes the character of the building design for SH/CB. Figure 11-4 shows the systems approach used to determine and clarify the general design considerations (elements) involved in SH/CB. The fifteen broad areas identified as being significant are given meaning by the following defining statements:

- LOCATION --- The geographical, political, and social environs which position the building nationally, regionally and locally
- RATIONALE ---The general reasons (purposes) for the building's existence and location
- SPONSORS --- The individuals, groups, and/or institutions responsible for the initiation, conceptualization, implementation, and continuing maintenance of the building
- SITING --- The detailed nature of the site, the relationships of the building to the site, and the reasons for the choice of the site
- BUILDING TYPE --- The general classification and style of the building
- BUILDING FUNCTIONS --- The functions to be performed, people served, and activities accommodated by the building
- BUILDING CHARACTERISTICS --- The architectural and construction specifications of the building (a quantitative blue-print)
- SOLAR DATA --- The types, quantities, and reliability of the data needed to specify the solar insolation characteristics of the site
- CLIMATIC DATA --- The types, quantities, and reliability of the climatological data needed for determining and satisfying the heating and cooling requirements of the building
- BUILDING THERMAL DATA --- A quantitative specification of all pertinent materials aspects of, and human activities within, the building for determining the heating and cooling demands (loads)

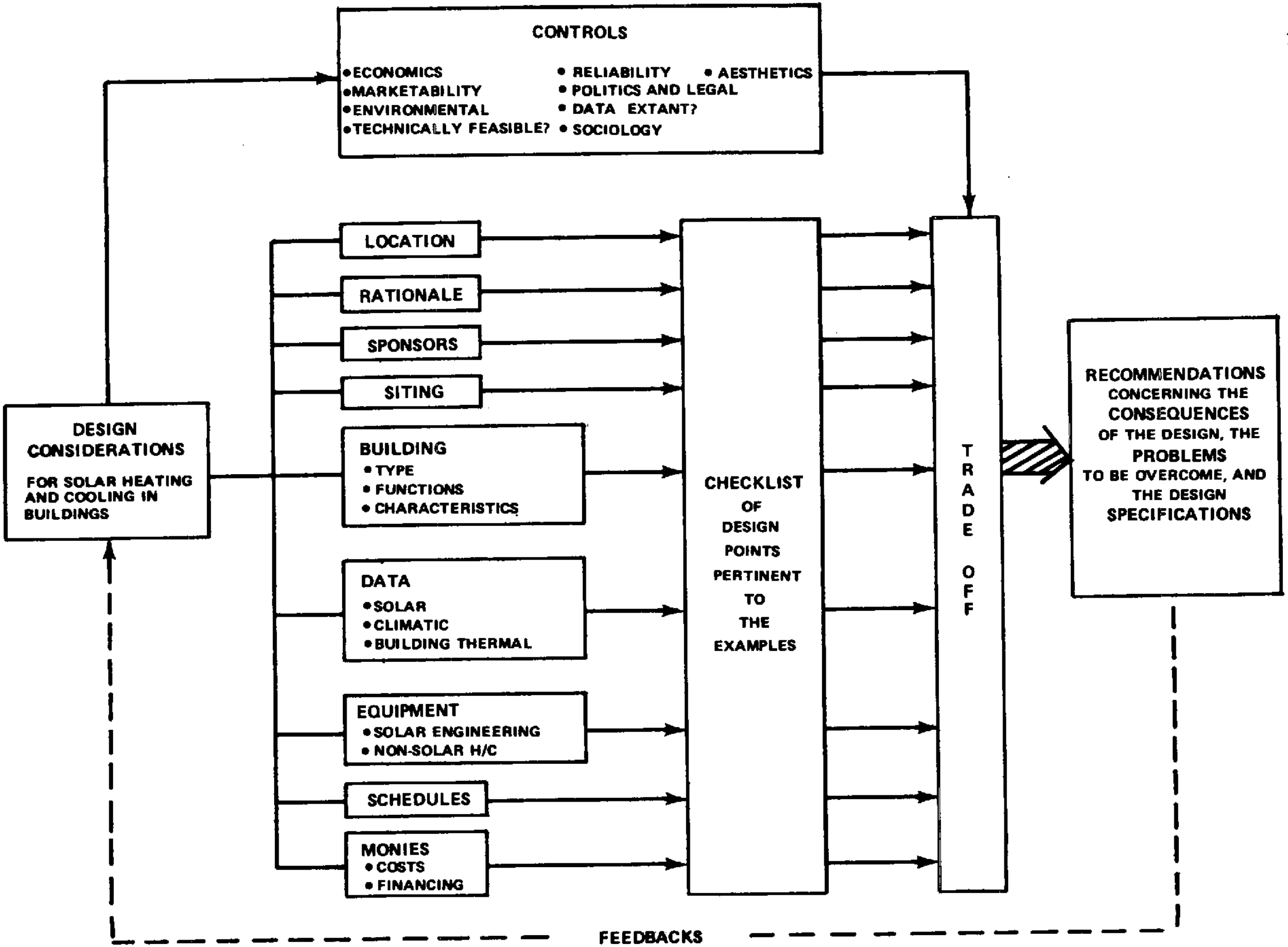


FIGURE 11-4. SYSTEMS APPROACH TO DESIGN CONSIDERATIONS

- SOLAR ENGINEERING --- Complete characterization of the solar-heating-and-cooling systems for the building, and their performance expectations

- NON-SOLAR HEATING AND COOLING EQUIPMENT --- A description of the supplementary and backup (non-solar) heating and cooling systems for the building

- SCHEDULES --- The timetables of (a) activities within the building, (b) the building implementation from conception to end of construction, and (c) securing the necessary monies

- COSTS --- A complete breakdown of all costs accruing to (a) the site, (b) the building design and construction, (c) the equipment design, development, manufacturing, and installation, and (d) the continuing maintenance of all proposed items

- FINANCING --- Those responsible for securing the funds, their methods and timetables, the organizations approached for the monies, and the accounting procedures

Actual Examples Analyzed. To progress further with the design procedure, some actual examples of solar-heated-and-cooled buildings were selected and run through the design methodology described above. Time limitations permitted the detailed analysis of only two such examples, for which abundant information was available and which were approaching implementation.

- The Massachusetts Audubon Society small (8000 sq. ft.) commercial office building in Lincoln, Massachusetts [11-1]

- The Saginaw, Michigan, large (51,600 sq. ft.) Federal office building

Many other possible examples exist for which such an analysis may be run in the future. One of these examples is Harry E. Thomason's sequence of five (solar-heated-and-hot-water) houses, built during the last ten years in Washington, D.C. [Floor plans and blue-prints are available from Edmund Scientific at $10 each, and a building license may be purchased for $20.] Of special importance are building examples which employ photovoltaic conversion of sunlight to electricty, for these examples may be used to extend the design procedure considered here beyond the realm of low-temperature thermal solar heating and cooling. Two such "electrical" examples are:

- The Boer House (under construction) at the University of Delaware in Newark, Delaware

- Mrs. Wilson's house (Burt-Hill Associates, Inc.) in Shanghai, West Virginia (still in the conceptual stage)

Perspective drawings of the "Audubon" and "Saginaw" concepts are displayed in Figures 11-5 and 11-6. Figure 11-7 illustrates how these examples are used to begin to construct a design procedure. Finally, in Appendix E is shown the worksheet for the two examples, where questions are raised, some answers found, and problem areas identified --- in the context of the generic areas mentioned above (LOCATION, RATIONALE, etc.).

To Regional and National Considerations. Each specific example considered aids in spelling-out the design procedure (manual), but in a strictly local (on-site) way. If enough examples were available nationwide, one could group the results of example analyses by region (climatic, insolation, marketing, etc.) to elucidate regional design considerations. Then the entire set of results might be integrated into a national design picture. At present, the scarcity of exemplary solar-heated-and-cooled buildings precludes such a "simple" maneuver, but computer simulations of building types by region may assist in filling this gap. Figure 11-8 is a schematic representation of such a design "extrapolation" from local to regional/national bases.

Conclusions and Recommendations. As a result of this cursory design investigation, it is possible to list several useful conclusions and recommendations concerning design procedures for buildings with solar heating and cooling systems. [The area of solar/climatic data is so critical that it is considered in detail in the next section.]

- Solar-heating-and-cooling systems are capital intensive: a large investment is required initially to install the equipment (and the supplementary non-solar equipment which presently acts as a backup heating-and-cooling system), but the continuing costs (fuel and maintenance) can be reduced to a negligible level. Studies should be conducted in the next few years of modes of financing and insuring solar heating and cooling systems (perhaps with governmental financial assistance to consortia of banking and insurance institutions).

- Building codes and current construction practices do not generally favor "tight" (i.e., energy-conserving) buildings, which are necessary when solar heating and cooling systems are employed. Studies should be conducted now (with governmental stimulation) to determine the nature and means of implementation of rational building codes (nationwide) --- with energy conservation as a primary consideration; the results of previous investigations into energy-conserving concepts in buildings (e.g., by the National Bureau of Standards; ASHRAE; Dubin, Mindell, Bloom, Associates; etc.) should be reviewed and promulgated to the building industry as "better standards."

- Equipment difficulties which currently preclude a good design include (a) the marginal technical feasibility of

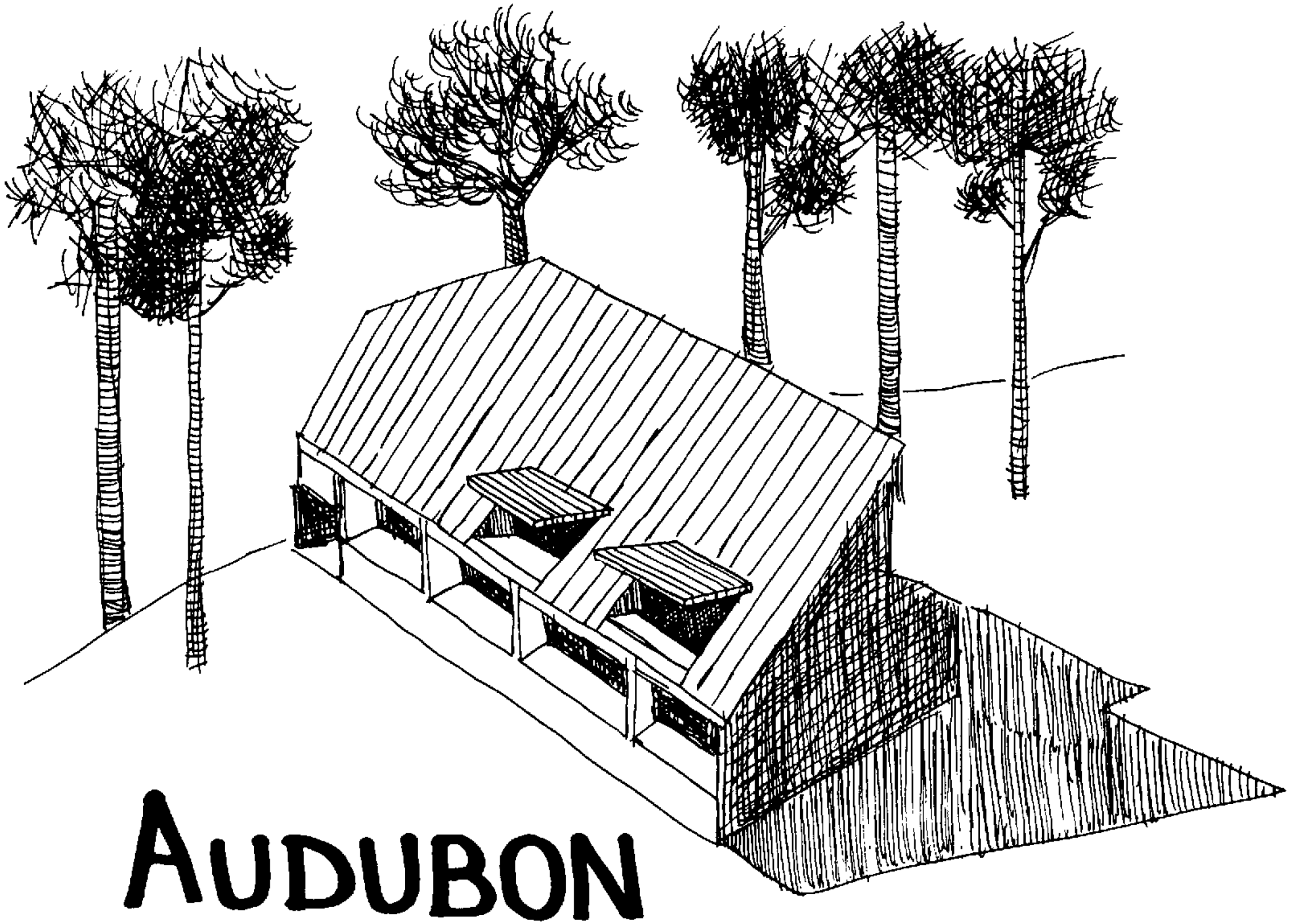


Figure 11-5. PERSPECTIVE OF PROPOSED "AUDUBON" BUILDING

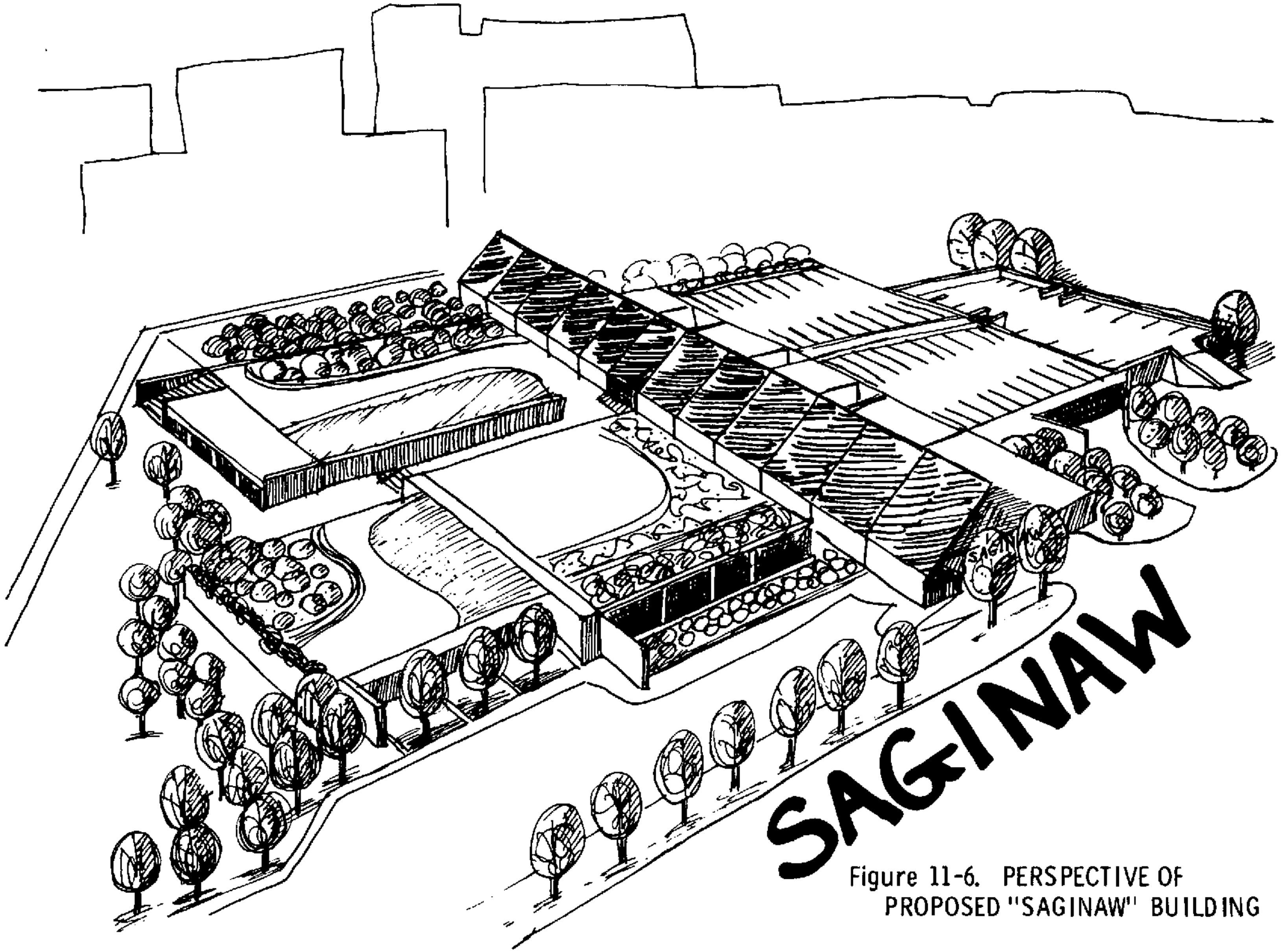


Figure 11-6. PERSPECTIVE OF PROPOSED "SAGINAW" BUILDING

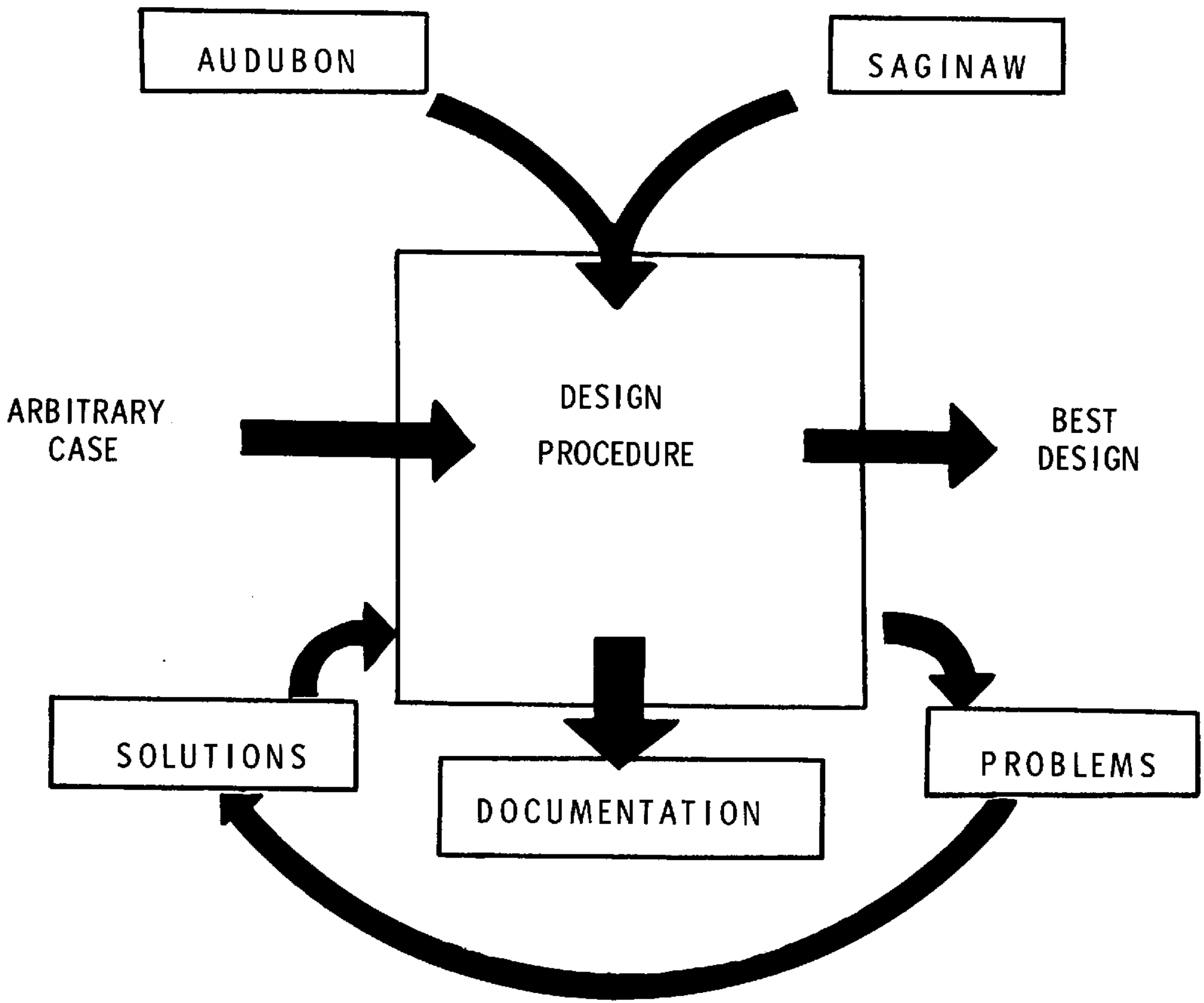


Figure 11-7. DESIGN PROCEDURE CONSTRUCTION WITH EXAMPLES AND EVENTUAL USE

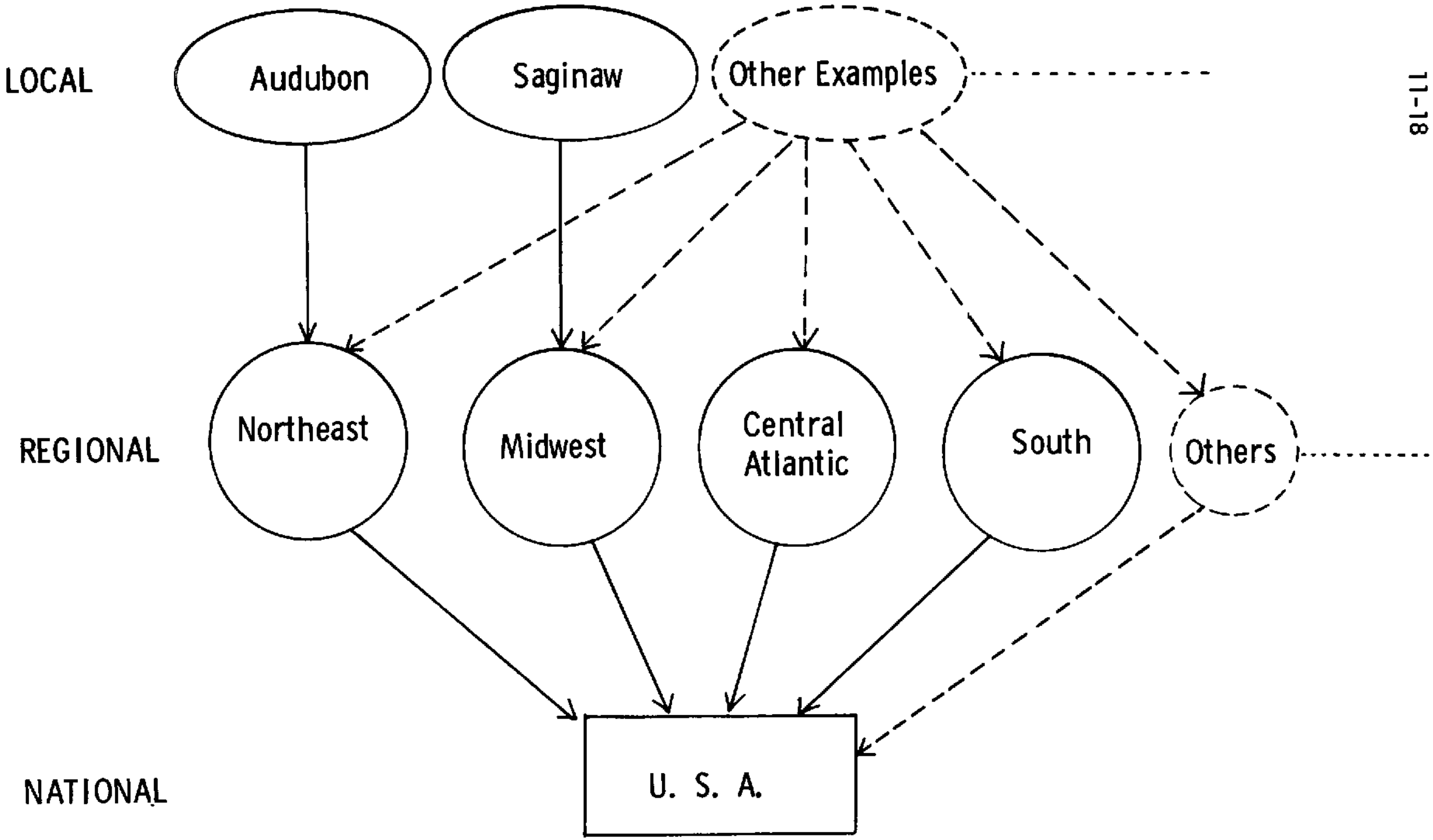


Figure 11-8. EXTRAPOLATION OF DESIGN PROCEDURE

solar space cooling (air conditioning) with flat plate collectors [see sections 11-1 and 11-2 above], (b) expensive thermal storage systems, (c) the use (in many cases) of complete non-solar supplementary and backup systems for heating and cooling in buildings, and (d) little knowledge concerning the maintainability of solar systems. Extensive R&D efforts with government funding (academia?) are indicated here during the next five years (see section 11-2 above).

- Current solar heating and cooling systems are susceptible to "accidents": broken glass in the flat plate collectors, fluid leaks, the release of obnoxious and/or toxic materials (e.g., from lithium bromide absorption air conditioners), and the thermal destruction of flat plate collectors which have lost their fluids (with the attendant possibility of fire). Sub-studies of the safety aspects of solar heating and cooling in buildings should proceed simultaneously and in conjunction with the systems R&D. A thorough literature review should be implemented immediately to assess the current "safety" picture and to make the information available in a single place and format.

- Legal and political complications of buildings with solar heating and cooling are only now being recognized: building code adjustments, property taxes, "sun rights" (i.e., what happens when someone erects a high-rise structure to the south and blocks the sun from one's solar collectors?), unionization of solar systems workers, elimination of tax revenues on some fuels in locations where solar heating and cooling becomes predominant, etc. To preclude extensive problems in the future, a careful study of these (and other) legal/political aspects should be conducted soon.

- Systematic design criteria (standards, etc.) and procedures for solar-heated-and-cooled buildings are not available. A concerted effort, coordinated by the National Science Foundation, should begin immediately to produce a preliminary design procedure, using the results obtained in this report, by ASHRAE and the National Bureau of Standards, and in the literature. A prerequisite to this study is a complete, annotated review of the literature to date.

- Finally, no governmental organization has been given the charge to oversee the large-scale <u>implementation</u> of solar heating and cooling in buildings in the United States, though the National Science Foundation is responsible at present for solar energy R&D funding. Those agencies which should become involved in the near future include (a) the Energy Research and Development Administration, (b) the Department of Energy and Natural Resources, and (c) the Environmental Protection Agency (EPA).

11-4. DATA

A major impediment to the construction of a design procedure for SH/CB is revealed when actual building examples are considered. This barrier may be termed "the data gap". The following problem areas have been identified:

- Solar insolation data ---

  (a) Types of data needed (horizontal, direct, normal, diffuse, hemispheric, etc.).

  (b) Frequency of data points (continuous, hourly, daily, monthly, seasonally, annually, etc.).

  (c) Formats of information presentation.

  (d) Localization extent of data gathering (on-site, local, regional, national, etc.)

Liu and Jordan [11-2] state that the performance of a flat-plate collector can be predicted from a knowledge of the monthly-average daily total radiation on a horizontal surface (and the monthly-average day-time ambient temperature) at the locality being considered. On the other hand, Fred Dubin of the New York consultants Dubin, Mindell, Bloome, Associates, Inc. (private communication) feels that the local nature and unpredictability of solar data (and weather data) preclude any trustworthy conclusions at present.

- Climatic data --- The situation appears to be more encouraging, but for a good design many unanswered questions remain concerning the type, frequency, format, and localization of the data required. The primary quandry centers upon the micro-climate at the building site, and the validity of interpolating the data records from nearby weather monitoring stations.

- Solar insolation monitoring network --- The network in the United States is exceedingly sparse (see Section 3-6). In addition, the United States National Weather Service recently warned users of their solar insolation data that some of the records contain errors as well as calibration inconsistencies.

- Weather station network --- The network in the United States is well-coordinated and generally tight (a closely-spaced mesh), but the usefulness of the data formats is questionable and there do exist some large gaps in the network.

Several in-depth investigations, conducted in sequence (phased), are necessary to clarify and resolve these data problem areas. Figure 11-9 outlines the flow-chart of studies recommended here to implement the data (solar and climatic) needed for first-rate design of solar-heated-and-cooled buildings. The steps are the following. First, detailed

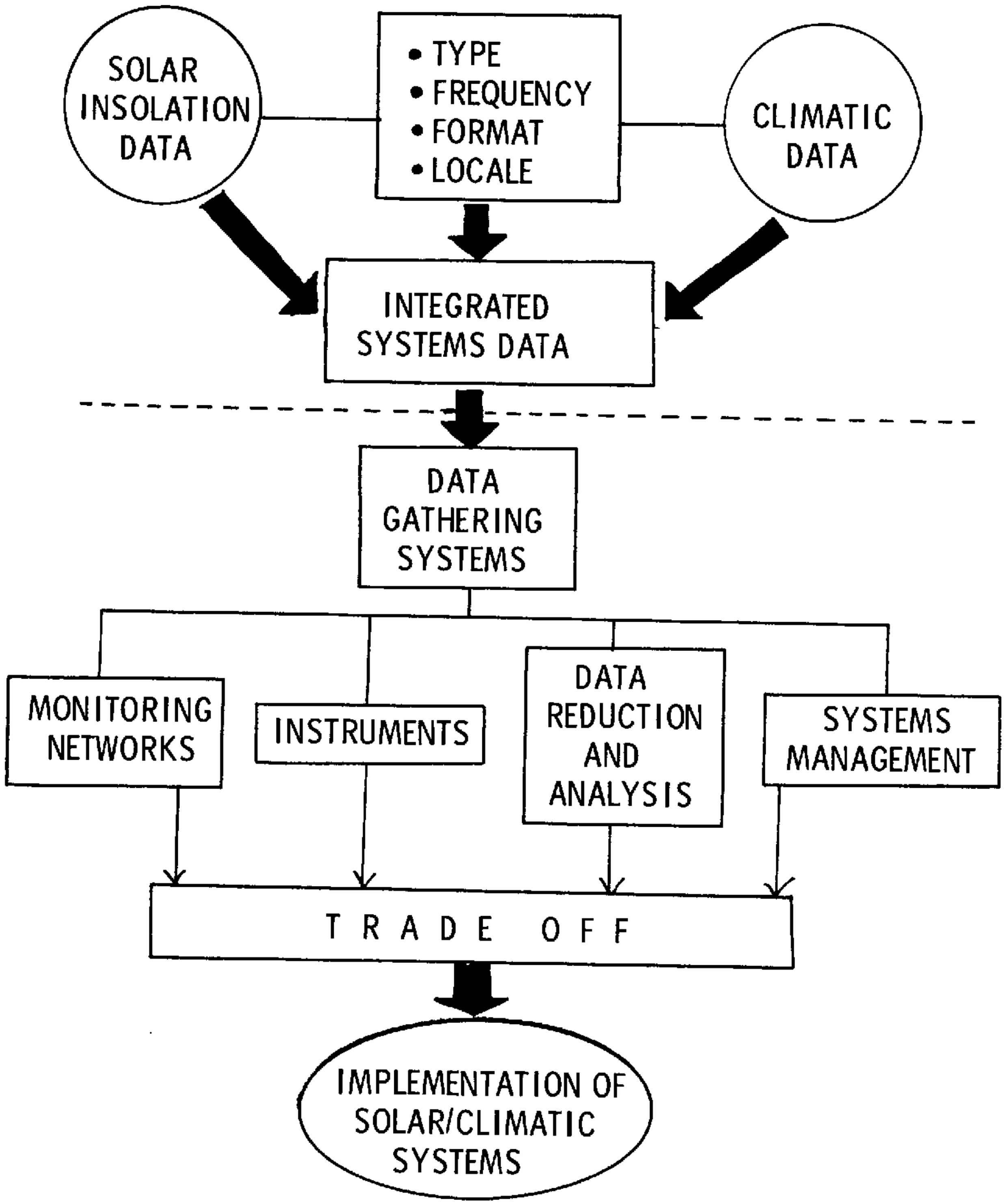


Figure II-9. FLOW CHART OF RECOMMENDED DATA STUDIES

studies, funded by the National Science Foundation and undertaken by academic and consultant groups, should be conducted of the solar insolation data and the climatic data needed to design solar heating and cooling systems and buildings throughout the Untied States. Major areas of consideration are:

- Types of data needed
- Frequency of data collection
- Formats of outputs from data
- Extent of data-collection localization

Second, for optimized economical design a study of integrated SH/CB systems should be conducted with funding from government and private industry.

Third, having determined the characteristics of the necessary data, an analysis of various data-gathering systems may begin with the involvement of the National Weather Service and National Bureau of Standards. Sub-studies of the following pieces of these systems should proceed simultaneously:

- The network of "monitoring stations"
- The instrumentation to collect the data
- Methods of analyzing, reducing, and displaying the data in useful formats
- Modes of managing the system

Finally, an intercomparison of the data systems considered should be made (a trade-off), so that the "optimal" system is selected and implemented. An important consideration in the trade-off will be the cost of the data system chosen.

11-5. OPTIMIZATION STUDY

An optimization study of a range of typical building types and solar heating and cooling equipment using energy conservation techniques should be conducted for a wide range of climatic and solar insolation combinations in the United States. The optimization study should be correlated with proof-of-concept studies conducted in the R&D phase and may suggest additional necessary or useful experimental evaluations. Factors to be considered in the optimization study are indicated in section 11-3.

The optimization study should result in a listing of equipment types by size for these climatic and insolation combinations for the range of typical building types. The list of equipment could then be made available to prospective manufacturers. It would then be necessary to evaluate the market to determine if the manufacture and sale of such equipment would be profitable. The Federal government might have to provide incentives to push the introduction of the equipment into the economy if manufacturers are reluctant to test the market.

It should be mentioned that a modified optimization study would be beneficial to a national general energy conservation program, even if solar heating and cooling is not adopted. The optimization process is of such a magnitude that no individual could afford to run a thermal optimization of his home or small business. However, if such an optimization scheme were available as a government service the nationwide savings in fuel consumption could affect the energy demand picture, thus reducing the impact of the energy problem.

11-6. EQUIPMENT DESCRIPTION BY REGION

The output of the optimization study should be the identification of standard equipment types for SH/CB by region for the United States. In addition, the optimization study should identify the sizes and types of buildings most amenable to solar heating and cooling by regions for the equipment identified; thus, there would result a matrix of buildings by types and sizes versus equipment types and sizes for each region of the United States. Analysis of this matrix would identify solar heating and cooling equipment that could be manufactured for modular use, thus standardizing the equipment manufactured and reducing manufacturing complexities. This step in the strategy may have to be modified as the strategy progresses but basically what has been outlined constitutes the initial thinking in the overall strategy.

11-7. SOLAR POWER SYSTEMS PROFESSIONALS

Professionals knowledgeable in the principles and applications of solar energy systems, the economics, potential impacts and other areas germane to solar energy systems should be identified and communicated with during all steps in the strategy. These professionals would constitute the initial cadre for developing the solar heating and cooling market.

Technical societies, educational institutions and government laboratories should provide the forums, educational processes and research necessary to identify these professionals, develop additional professionals for the application of solar energy, and conduct research necessary to encourage the inclusion of solar energy in the economy.

11-8. INCENTIVES

The detailed identification of the various incentives (economic, professional, personal, etc.) for the development of solar power systems as viable alternatives for heating and cooling in buildings would be accomplished by the market analyses which must be done during the second phase of the strategy outlined in this chapter. The marketing analysis cannot be completed in detail until solar heating and cooling equipment applicable to a wide range of building types by regions has been identified. This does not mean that during the early stages of such a strategy incentives are not needed or are unidentifiable. The funding by the Federal government proposed in this chapter for R&D in the area of SH/CB is certainly one identified incentive. This incentive is designed to interest the appropriate parties in the country in solar energy applications, and to begin to promote the adoption of these applications predicated on their feasibility.

Since the energy problem is a national problem with international implications, it is apparent that the Federal government will have to take the lead in developing ways to alleviate the problem. The application of solar energy presents opportunities for helping to alleviate the energy problem, but the development of the many possible applications of solar energy is an expense that private industry apparently is not anxious to underwrite. The strategy as developed here therefore relies heavily on the Federal government during the first phase of the strategy. The first phase constitutes an overall incentive for the free enterprise system. The private sector is expected to take over the primary funding and R&D at the stage where manufacturing and installation of equipment for SH/CB becomes attractive.

Incentives will be necessary in all steps of the first phase of the strategy. Feasibility studies are currently being conducted by a number of people. Research and development is contemplated by a number of educational institutions and private industries, with funding coming predominantly from the National Science Foundation. The construction of a design procedure for SH/CB is a task remaining to be performed in detail, and the logical group to develop this design procedure has not been fully identified. It is proposed that the technical societies acting in concert would produce these design procedures. Societies --- like the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE), the American Society of Mechanical Engineers (ASME) and the Institute of Electrical and Electronics Engineers (IEEE) --- would have an interest in tackling the design procedure problem. Funding for the development of the design procedure would probably have to come from the Federal government, although private industry would certainly express some interest and could be counted on for contributions of monies and expertise.

The solar insolation data required will probably have to be provided through a program tied into the present weather service program. The availability of these data is a key to the optimization studies previously proposed. The optimization studies would have to be financed by the Federal government, although private industry again would have an interest in the outcome of the investigations and could be counted on for funding. These optimization studies could be conducted by Federal laboratories, educational institutions, and industry.

Incentives for professionals to enter into the field of solar energy applications will have to be developed. A professional is certainly not going to undertake studies in this area unless there is a demand for his services and adequate funding. The professionals who constitute the SH/CB profession must be well versed in disciplinary areas such as engineering, economics, marketing, political science, etc.; they will bring the depth of understanding of these areas into play in developing a multidisciplinary approach to solar energy applications in SH/CB. Appropriate incentives to encourage this effort are sorely needed.

Incentives readily identify themselves at appropriate times during any study of a problem; to try to mention each and every one in this section is impossible. However, it is important to realize that incentives will have to be developed in order to encourage the implementation of SH/CB on a large-scale in the United States. A careful reading of the TERRASTAR report, expecially section 11-9, will reveal a multitude of other possible incentives and incentive areas.

11-9. MANUFACTURING AND MARKETING

The literature consulted on manufacturing and marketing (see References 11-3 through 11-22) serves to identify some of the principles, concepts, models, cases and analogies needed to evaluate solar energy implementation in our economy. Both macro and micro considerations are suggested. This discussion is limited to SH/CB.

An effort is made to identify pertinent factors and their interactions affecting this application of solar energy. This involves the identification of information requirements, decision-makers, strategies, constraints and impacts. For example, information requirements consist of studies on costs/ benefits of initial installation and product life-cycle of alternatives, component requirements, manufacturing engineering, and information transfer to decision-makers.

Decision-makers imply considerations of "profiles" of key innovators, influencers, action takers, users -- active and passive intermediaries in the process from the conception of the idea to the application of the methodology, technique, product or service. Among the key innovators, influencers and users in the decision-making process in SH/CB, the following are considered: utility companies, materials manufacturers, component manufacturers, distributors, builders, architects, engineers, land developers, investors, and final users -- residential, commercial, public and industrial buildings.

Once these different segments for application are identified -- in terms of demographic and behavioral characteristics, institutional and economic constraints and the special needs of these groups -- specific strategies and incentives for the diffusion of the application are outlined.

Innovation and Diffusion of Innovation. "Innovation is a term describing certain activities by which our society improves its productivity, standard of living, and economic status " [11-3]. In one study [11-3] on innovation, the investigators looked at ten recent cases of technology and its application (heart pacemaker, hybrid grains, electrophotography, input/output analysis, organophosphorous insecticides, oral contraceptives, magnetic ferrites, and video tape recorder). In the case of "input/output analysis", an analytical tool, the study looked at the diffusion of its application. The other cases resulted in marketable products.

From this analysis, the authors tried to identify all the significant, decisive and nontechnical events which led the process of technology, innovation, diffusion and adoption from the point of "conception" of the idea, through the "innovative period" to the "post-innovation" (application) period. They identified five areas which were probably instrumental in the direction and rate of the process:

- Motivated influences
- Management action
- Peer group forces
- Unplanned events
- General environmental factors

In terms of their importance, the following specific factors were identified:

- Recognition of the need (market pull)
- Independent inventor
- Technical entrepreneur
- External invention
- Government financing
- Informal transfer of knowledge
- Supporting inventions
- Merging of technology

Even though these factors indicate technological and marketing opportunities, many obstacles slow down the process. A historical review of the literature on technology and innovations [11-4] suggests the following "obstacles":

- Interference risks (labor, government, industry structure)
- Market (customer/consumer) risks
- Timing (improper use -- used for other purpose or improperly used for suggested purpose)
- Production/management risks (controls over the market or supplies, patents, licenses)

- Technical and financial barriers (economics of scale labor vs. capital intensiveness)

Specific examples of innovations, obstacles and applications will be used where they pertain to the manufacturer, builder or consumer.

It is difficult to identify all the significant, decisive and nontechnical events in the process of innovation-diffusion-and-application. However, in the case of new products and their application (displacement or conversion of present applications) for the same need or new needs, where historical-statistical data are lacking, analogies may be useful.

The subject of solar energy has received attention in much of this historical literature. In the 1950's and 1960's the main interest in applying solar energy was for the developing countries (e.g., solar cookers, solar refrigerators, solar engines, etc.). However, in the 1970's the emphasis has shifted to applications in industrialized countries (SH/CB, generation of electricity, solar farms, and satellites). Many of the events that promoted interest in solar energy and searches for technological and marketing opportunities for its application are of recent origin. Some may be considered as significant events (technological advancements, transfers of technology, various research efforts), others as:decisive issues of "crisis" as presented by the Government, industrial sector and special interest groups, regional issues of resource allocation, studies of costs/ benefits of alternative supply sources and demand sector patterns and directed research efforts such as those of the NSF and nontechnical events (e.g., moral suasion by the Government and utilities on energy conservation).

In view of the assessment of technical feasibility and economic practicality of SH/CB, a number of macro and micro strategies (along with some obstacles and incentives) for the acceptance of solar energy --- in its application to SH/CB --- are suggested in the following sub-sections.

Identification of Opportunities for Utilization of Application (Market Needs). Aggregate and specific segments for utilization need to be identified in terms of their needs. Specifically, potentials for utilization may be defined in terms of their size (number of users for each application), demographic characteristics of user-types (geographic regions, consumption patterns, purchasing power, household sizes, building types and others), and social/psychological elements (motivational factors - economic and noneconomic).

From these considerations, homogeneous factors may be used to form composite sectors (market segments) for application.

In order to develop strategies for influence and acceptance, key elements in the decision-making process of new products or applications need to be identified. In the case of SH/CB these elements are: types of buildings, projected growth patterns, climatic regions, user comfort requirements and other need requirements, component types, suppliers, influencers and decision-makers in the installation, construction and design process. (One firm, Arthur D. Little, Inc., is currently analyzing this application in terms of specific market needs/segments in an attempt to identify the various decision-making elements and to develop strategy models.)

Since there are many interacting elements in this application process, many of the participants may be in the position of a supplier and a customer/consumer, a supplier and a developer of markets, an influencer or a combination of any of these.

The final user/consumer will probably play a passive role, at least in the initial application. Therefore, the other interacting elements will be considered first: materials supplier, component manufacturer, utility companies, construction industry, and consumers. Of course, engineers, architects, government policy-makers and regulators, distributors and financial institutions --- with their direct or indirect influences --- will also be identified.

In order to make some projections of the potential, several techniques or methodologies may be used [11-5]:

- Trend or regression analysis --- one or a combination of these variables may be used: population or housing projections by solar regions, consumption patterns, purchasing power and others (see Chapter 10).

- Survey studies by means of concept testing --- past, present and intended behavior may be discerned by interviewing architects, engineers, manufacturers, builders, and homeowners.

- User studies --- analysis of the use and use testing should lead to the identification of product/market segments, characteristics of products, needs they fill, special need requirements for product adoption and adaptations, technological forecasting, etc.

- Business volume --- projections may be made based on value analysis - initial and operating costs of different heating and cooling systems and their combinations - by housing types and climatic regions (see Chapter 10).

- Analysis of elasticities of energy consumption by use sectors and patterns, utilization of various components in relation to income levels, pricing and promotional strategies, proportion of income or total cost going for energy, and time factors for adjustment [11-6].

- Analogies --- case histories of other technological innovations and applications (for example, lead time in black-and-white television, color television, flat-top cooking range, self-cleaning oven, home air conditioning, plastic cable and others).

- Cross-sectional and correlation analysis --- demand patterns (for example, average consumption vs. peak demand, total vs. component demand, average weather vs. extreme, rates of consumption and need requirements).

- Input/output analysis --- includes an analysis of the intra and interstructure and the flow of energy, that is, energy-using industries and final users in the form of energy or product.

- Macro studies (total and regional), demand and supply studies (price and nonprice effects), studies on the relationship of economic growth and energy structure (effects of shifts of different supply sources, consumption sectors on standard of living, equalities and productivity), environmental studies and attitudinal studies.

Strategies for Acceptance. Initial development of markets for new products or applications may be furthered by efforts of small end-product manufacturers or by newcomers - "push" may come from materials manufacturers, e.g. manufacturers of glass, aluminum, steel, etc. This chain can develop a market for a new end-product to satisfy some need, such as heating and cooling, or create a new market by identifying a "new" need, such as conservation of depleting energy resources and preservation of the environment.

Present large manufacturers may be unwilling to go into new applications because initially they may offer little profit, entail a large capital investment (uncertain economies of scale), compete with existing product lines, endanger their current market share, weaken their competitive advantage, be incompatible with their manufacturing process, require new channels of distribution and present problems in servicing and maintenance of the equipment. Success of a small or new firm in building a place in the market for the new product can, of course, effect a substantial change in the motivations and perceptions of the market leaders. Many firms have "full-line" as their product strategy. Some firms search for new opportunities for market extension for their growth; others consider "product diversification" as the most important strategy for their survival and growth (for example, firms in the aerospace industry). This may come about through mergers or new ventures.

A few examples may illustrate this strategy [11-7]. Alcoa in its attempt to develop the use of aluminum in windows encountered resistance from the conventional manufacturers of window frames. For the demonstration Alcoa built its own building, called on industrial architects and finally presented a marketing opportunity for small and new manufacturers.

In another case, use of aluminum ingots was recommended for containers. However, the reluctance from the container industry gave a "push" to an end-user (a brewery) to go into the manufacture of its own containers. In both cases the materials manufacturer developed markets for its material through the fabricators or end-users. Other examples in the areas of fibrous glass, plastics and glass reinforced plastic pipes raised the requirements for information on materials, processes, end products, performance, techniques and equipment to install, component parts, maintenance and servicing.

In summary, materials producers can be instrumental in building up primary demand for end-products and selective demand for specific components. This requires a careful analysis (input-output) of the industrial structure, end-users (construction industry), component manufacturers (of conventional systems), their resistances and motivations, the development of standards for equipment and maintenance (through professional societies, associations, and Government), dissemination of economic and technical data, and definition of properties of the material. Specific market segments and their sizes will have to be identified, in terms of geographic regions, building types and their requirements, and their suitability to man-production process evaluated.

In the early stages of the product "life-cycle" [11-8], at the time when the attempt is to build up the primary demand, careful market testing and mass media education and promotion will be needed. The extent of this will depend on the identification of the need, perception, and level of familiarity with the product concept.

Up to this point, it has been assumed that the market would create its own entrepreneurial incentives and direct management-decision efforts.

Another strategy could be for the Government to subsidize the development stage of the product (pre-introduction to the market stage) by means of direct grants, tax benefits for capital investment, tax advantages for savings on potential operating costs, conservation of resources, and in general, on improved efficiency. This, in turn, could become instrumental in the technology transfer process [11-9]. It could identify the market place in terms of the technical, economic and other problems of potential users, suggest approaches to solve these problems, select promising technologies in terms of product characteristics, performance, patentability, anticipated costs and benefits, marketability, and alternative tradeoffs.

In practice, the "market concept" has often had narrow and short-run objectives. The tendency has been to define the market and its potential too specifically. Expanding it more broadly, firms can benefit by taking into consideration the long-run benefit to the consumer/customer and to the society rather than the short-run consumer wants (or the creation of these). In times of excess demand and/or shortages of supply, marketing strategies of price, product, channels and promotion may also be used to realign the general demand or specific segments of it and provide other alternatives [11-10]. Of course, many business executives and economists disagree on the role of the firm and its social responsibility.

Regardless of the point of view, Government policies, regulatory agencies, special interest groups, public opinion, market saturations for many products, approaching market saturations for others (for example, some appliances), attitudes toward advertising and packaging, rising labor and materials costs, declining profits, concern over more efficiency of products in terms of energy use (life-time value), economic growth, population growth, increasing housing needs -- indicate new problem areas and provide new marketing opportunities in solving them. At the same time, these factors may change the present institutional structure, set new priorities, create new needs, tastes and preferences.

For example, possible new price structures on energy resources may displace or reallocate their use sectors and consumption patterns (effects of price elasticities, substitutes, transportation costs). This in turn may have various regional growth consequences. According to some of the projections [11-11], GNP/capita will rise to $15,400 or $18,100 by 2030 (if fertility is at 2.8 for the former and 2.1 for the latter). With higher income, higher standard of living, lower dependency rate (due to declining population growth), increasing investment, changes in technology (increased annual improvements of 2%), fewer working days (1.5 less working days/year for the next 30 years), new marketing opportunities are inevitable.

Since many of the social costs (market externalities) will be internalized resulting in higher prices, applications of solar energy (with minimum negative environmental impacts) may provide desirable and competitive options for many firms (new rate structures on conventional energy sources). Often, for various reasons, such as intensive capital structure or slow adoption process, many new products are not profitable in the introductory stages. However, in view of the long-run considerations of social benefits, monetary returns and corporate image should be considered.

Of vital importance in the expansion of a market is the channel of distribution and reliable product standards. If there are very many manufacturers (for example, in 1967 there were 20,806 appliance manufacturers, 27,162 hardware manufacturers, and 42,472 building materials manufacturers--of which, many were directly or indirectly involved in the manufacture of components or entire heating and cooling systems) [11-12], standardization of the components and systems becomes of vital importance. Another consideration is the number and the types of different components and systems, as required by different customer needs, in terms of building types and climatic areas. In the case of combined systems (solar with conventional) additional problems over design, reliability, maintenance, and others may arise.

In addition, in the case of the channels of distribution for solar heating and cooling equipment, in 1967 there were 4438 wholesalers and agents of plumbing and heating equipment, and 2686 handling air conditioning equipment (these include also manufacturers, sales branches and offices) [11-13]. For solar equipment, these same intermediaries in the channel may also be considered. Much of this type of equipment could also be sold directly by the original equipment manufacturer to the large customers in the construction industry.

Another area for consideration is that of service. Should the service structure consist of the manufacturers, utility companies or distributors? Conditions of sale may be the determining factors. Since the initial cost of the equipment may be too high for the builder or the honeowner, the equipment could be leased and serviced by the manufacturer or the utility. Guarantees, warranties on the initial equipment, individual components and replacement parts would be necessary. This, in turn, would require rigorous standards.

Depending on the equipment, that is, whether it is to be an integral part of the building or can be individually installed, different channels and service structures will be required. In both cases, service outlets may be established by the manufacturers, utility companies, and distributors (for example, Sears has a very extensive service structure for its appliances and other products). In the case of individual installation, the degree of complexity will determine the extent of this type of a channel (for example, this has been a prevailing problem in the electronic garage openers).

Construction Industry. Projections about future population, housing and energy needs point heavily toward favorable marketing opportunities for heating and cooling equipment, with a possible significant displacement by solar equipment.

Each type of housing may have unique requirements in terms of land-use patterns and equipment needs. Physical and economic factors will predetermine its ability for integration into the total design, for example, weight and roofing requirements, material properties, initial and operating costs, aesthetic considerations and others. In addition, weather conditions will affect the type of construction and comfort requirements.

Different elements go into the decision-making process in each sector of the construction industry.

For example, trade unions, predominate among the labor involved in the construction of both one-unit and multi-unit housing. Installation practices are traditional. Depending on the product, will it change the practices, require different skills, be more or less labor-intensive? Price range of different housing types may also be a determining factor for acceptability of new equipment, and, thus predetermine the type and size of market sector and the appeal for its promotion.

Another characteristic of the one unit and multi-unit housing is their cyclical and seasonal nature.

Another determining factor for the acceptability of solar equipment (which may influence its cost) is mass-production, that is, to what extent it will lend itself for mass-production and mass-installation. For example, the mobile home construction lends itself to mass-production, and also, through factory inspection, avoids certain local codes. Would the solar equipment be suitable for the mobile home industry? This particular industry is projected to continue to grow.

Solar equipment has to meet the various building code specifications as contained in the National Fire Protection Association, American Insurance Association, Basic Building Code, Uniform Building Code, Underwriters Laboratories, and many others [11-14].

The homebuyer usually plays a passive role in the decision-making process for heating and/or cooling equipment. In the case of speculative construction, cost is of the utmost importance. In this sub-market, the contractor, upon the advice of his engineers and architects, decides on the equipment. In this case, the buyer has no choice in the initial equipment. Also, many buyers want to avoid initial increases in cost, and choose later additions or alterations to the home, for example, window air-conditioning units instead of central air-conditioning [11-15]. Even though the installation of central air-conditioning is increasing in new residential construction, especially in the more expensive homes, its use is not very extensive at this time. A buyer of a custom home makes the final decision, however, in this case he is also influenced by the architect, engineer and the contractor. This shows that the final consumer has little or no choice in the final decision. In the case of the custom-homebuyer, where initial cost may be a factor, an emphasis on the desirability of this equipment could be made. Advertising appeals to the energy conservationist, ecologist, prestige seeker, economic decision-maker could be made. The economic decision-maker could be approached with an appeal of operating-cost savings and savings over the life-span of the house.

Both the homebuilder and the homebuyer may need more "directed" incentives. A more favorable tax structure to reflect higher capital investment, cost savings on operations and resource conservation should be encourages. Other promoting factors could be in the form of subsidized loans, by the Government, and channeled through the various public, semi-public and private financial institutions (banks, savings and loan, mortgage companies and others). Changes in building codes and equipment standards, to reflect our changing national needs and priorities could also be beneficial.

Apartment builders are also very cost-conscious, especially, builders of small apartment buildings. In large apartment complexes, higher initial capital costs are easier absorbed by the tenants. Even though heating and cooling are inherent amenities in all construction, the actual selection is influenced by the advise of an engineer and/or architect. Among the small builders it is more common to have window air-conditioners. Central air-conditioning systems seem to be more practical in large buildings.

Since there is a possibility that combination systems (solar with conventional) will be more feasible for some building types and in some weather conditions, compatibility of the solar equipment to this combined system and to the building design becomes crucial. Another point to remember is that present zoning regulations and land-use patterns will determine the height of buildings and their location. Therefore, physical characteristics of the building, weather conditions, climatic areas, and various obstructions will delineate this market segment.

Similar incentives, as in the case of residential builders, should be provided to this sector. Mass education, advertising and salesmanship directed at the influencing groups, such as the engineers and architects, labor union leaders, regulatory agencies, should be encouraged by the Government, various professional groups, materials manufacturers, equipment manufacturers and the associations. In addition, mandatory changes in building codes/standards and changes in the tax structure could be significant motivational factors. For example, the Department of Interior and the National Bureau of Standards have been studying various energy conservation methods. This information will be available to architects and engineers.

Another influencing group has been the National Conference of States; they have asked the National Bureau of Standards to study the energy conservation requirements and recommend performance standards.

Tax structures should reflect savings on costs of operation and conservation.

To determine the market potential or displacement potential by solar equipment in areas other than residential housing becomes more abstract. Since the figures do not project nor show actual buildings in areas such as religious buildings, office buildings, hospitals or any other multi-purpose buildings, only very general observations can be made.

Commercial or industrial buildings usually follow population, construction and general economic trends. They are built for the owner and user of the building, for a leasee, to his specifications, or for investment purposes, that is, renting or leasing for multi-purposes after the building is built.

Capital costs are important in this sector. However, different motivational factors are involved in this sub-market. Rents in commercial buildings, for example, in shipping centers, are usually based on sales potentials of the centers. In industrial buildings, along with depreciation considerations, savings in operating costs are also important. In these cases, energy inputs are either a part of the final product or part of the overhead costs. With possible changes in the rate structure of the utilities, or shortages of energy resources (nationally and regionally), use of solar energy may be a desirable alternative.

Public construction is also very sensitive to cost. There is a distinction between the private and public sectors in terms of tax incentives, that is, on capital investment and cost savings. Private investors discount considerably possible operating cost savings because they are 100% deductive from revenues for income tax purposes, while only a portion of capital costs can be recovered each year through depreciation deductions. The government could select a number of different multi-purpose building types, in various weather regions, for the demonstration of the application of solar heating and cooling equipment (for explanation of such buildings sponsored by the government and the Audubon Society, see Section 11-3). It is not recommended for public housing. This sector may resent being used for experimental purposes. It is suggested by some scholars of the innovation process [11-16] that once the results of an innovation (proven benefits) become visible, the acceptance process is simplified.

Since the final user or the builder, without any special incentives, usually is not very receptive to this initial trial state, public and commercial buildings could form the first sub-market for the application (for example, air-conditioning was first demonstrated in public and commercial buildings before its acceptance as an appliance in the home).

In the past, innovations in the construction industry have come in the materials and components. Even these were slow in adoption, as for example in the cases of waterproofing of basements, electrical switches, plastic sheated electrical cables and many others in the areas of plumbing, insulation and design. However, less impact has been in a complete dwelling construction technique because of high costs and risks of pay-offs [11-17]. The interest has been mostly in convenience and appearance, and less in efficiency.

Also, the fragmented nature of the market and the supply makes it more difficult for a new application or innovation to be accepted. Both the horizontal and vertical structure of this industry complicates the entire diffusion process. For example, in 1967 [11-18] there were 156,400 general contractors (this number includes also ones without payroll), 78,190 plumbing, heating and air-conditioning contractors, 2,831 architectural firms, and 3,970 engineering firms. The largest builders, for example, Levitt and Sons, U. S. Home Corporation, had less than 1% of the market in 1970. Of course, there has been some move to conglomerate mergers, for example, ITT-Levitt, Inland Steel-Don Scholz and others [11-17]. This will have some influence on the industry's structure and channels of information-flow.

As was previously suggested, the construction industry is very cost-conscious. With rising interest rates, labor and materials costs, difficulties of obtaining low down-payment/long-term mortgage loans, it is looking for cost saving innovations. However, various institutional obstacles (codes/standards and industrial structure), and resistances from the unions, builders, designers, buyers and regulatory agencies -- make it a very complex process. Even with cost reducing innovations, some directed "push" is needed. For example, in the case of the plastic sheathed electrical cable, the Department of Housing and Urban Development was instrumental in its acceptance in California for public housing.

According to one author [11-9], an increase of $100.00 in the price of a house disqualified 15,000 families from obtaining a mortgage loan. Even with this consideration, savings in the cost of construction is not necessarily accepted automatically. In one case, the Urban Development Corporation of the State of New York was responsible for the change of electrical switching systems in an attempt at reducing costs.

This discussion indicates that cost competitiveness is not always a deciding factor in the initial states of the product's "life-cycle". However, without this advantage, an innovation will receive even more resistance, unless incentives for energy conservation, life-span operating efficiencies, protection of the environment and other social costs are implemented by the various influencing groups (as was suggested in the previous discussion) and given a direct incentive from the Government.

Utilities Industry. Decision-making in the utilities industry has been short-run market-oriented. It has looked at first-order effects of economic activities, that is, by offering energy at low prices to the users. Lately, the public concern has been shifting toward the long-run social effects rather that the short-run consumer benefits.

Since the industry has been very capital-intensive, marginal costs were considered to be minor in relation to total costs. The practice has been to look at marginal costs for pricing rather than fixed costs. Since the rates are set on an expanding demand ("cost plus"), there were few incentives to conserve. The incentives on rates and investments encouraged the industry to overproduce and overinvest.

With increasing financial difficulties for some utility companies (in refinancing of long-term bonds, issuing new ones and raising working capital) and rising peak demand loads--there could be a possible submarket for solar equipment--that of a "supplementary" equipment market for peak demands. The equipment could be leased and serviced by the industry. Extensive service capabilities exist in this industry. With retraining, the same service structure could be employed (of course, this awaits rigorous design standards from the manufacturers, professional/technical groups and associations). Leasing and servicing of the equipment by the industry could speed up the acceptance process and expand the consumer market. As was previously suggested, since the consumer market traditionally is not the "pioneering" market [11-15], at least where technical, economic and other benefits have not been demonstrated, public buildings offer a better potential for demonstration.

In general, there is a need to study the capital markets and determine whether the capital markets cater adequately to high-risk technical ventures, including ones that might be transferable to new and more marketable environments in the future.

Consumer Market. The most important consideration in the acceptance of a new product is to identify the need (or create a need) and satisfy it. "Degree of acceptance and practical use of the need is the best measure of the need for it" [11-19]. Many critics of advertising, packaging, proliferation of products and "planned" obsolescence of products, will not agree with this statement. They claim that this is a short-run consideration. The preservation and enhancement of the quality of life should be the long-run objective.

In reference to the first point, the acceptance of a new idea, technique or product will depend on its cost/price, available alternatives, convenience, prestige factor, appearance, efficiency, side effects, government policies, purchasing power, its share of the total expenditures, advertising, time and other quantitative and qualitative factors. Some of these are marketing strategies, planned by business executives, others are aspirational factors of the individual. However, all are interacting with each other.

According to one diffusion model [11-16], the presence or lack of factors, such as, cost/economic returns, complexity of installation, maintenance or use, visibility of its benefits, application on a small scale, compatibility with accepted or changing lifestyles -- will speed or slow down the process of acceptance. Does the solar application pass some of these requirements? Each aspect may be evaluated and conclusions may be formed by the reader in reviewing the different sections of Terrastar.

Technical uncertainties and economic and social risks -- place the consumer in a "passive role" [11-15]. The consumer wants to see certain benefits, whether they are in terms of prestige, social standing, conservation ethic or cost savings -- initial or overall. Therefore, utilities and the Government could act as the "change agents" (innovators) in the initial stages. The government could be instrumental through tax incentives and the utilities industry through leasing and servicing of equipment.

There have been many studies attempting to identify the "key" innovators, "change agents," and "early adopters." Additional research is needed in this area. Specifically, in solar applications it would be very beneficial in the development of marketing strategies to identify the "profile" of the "key" innovators and influencers. This would enable one to identify the perception of the innovation, aid in the development of mass advertising to increase awareness, arouse interest, provide information, suggest accessible demonstrations and encourage trial applications.

Since the need for comfort (heating and cooling) already exists, the creation of a need for displacement by solar equipment is necessary. This may come from increased public awareness, conservation ethic, construction industry, manufacturers of the equipment and the Government. In addition, increased prices of utilities (because of shortages and possible reconstruction of the industry) may give an economic rationale. Tax advantages on life-time cost-saving devices (considering the initial investment, interest rates and opportunity costs) and recognition of this by the lending institutions could make the application more marketable.

The assumption has been made by many that demand for utilities is price inelastic. In fact, until recently it has been quite elastic to the promotional efforts of utilities and appliance manufacturers. Of the total expenditures, consumers spend less than 5 percent on utilities and gasoline. This, of course, varies somewhat by regions and family income levels. However, recently economists [11-20] indicate that this may not hold in the future because of increasing prices. An important consideration in this analysis is the time element for adjustment and alternatives.

Since the household market consumes 23 percent [11-21] of the total energy, with an increasing share [11-22] provided by gas, oil and electricity, for example, from 1950-1970, the share for natural gas rose from 2.4 percent to 10.7 percent, and for oil from 4.4 percent to 9.2 percent, changes in this industry may force reallocation of different primary energy sources, sectors of consumption, and, in turn, population movements, housing growth, and commercial and industrial development.

The population and housing Census does not predict the future, rather they project, making assumptions about mortality, immigration and fertility.

To analyze the population and housing projections one has to consider the question of the effects of energy prices and changes in the structure of the industry. Important bases for analysis are regional distributions of population and housing, climatic variations, labor and material costs, zoning and housing codes (for example, high rise vs. low, multi - vs. single-family units), environmental conditions (for example, pollution) and behavioral factors of the decision-makers.

Regional studies could suggest potential areas for displacement of conventional sources by solar energy. Of course, future developments have to be forecast, in order to study the various impacts on solar energy applications. For example, reducing air pollution by means of public transportation systems, movement of industry away from concentration areas (because of costs, environmental pressures, or government policies), overpopulation of certain cities, shortages of land for expansion and many others, may indicate a number of "crises" areas for displacement by solar energy. These considerations and decisions may be motivated by reasons other than cost alone.

In summary, there is a need for long-term studies of the specific and broader aspects of solar application and its costs and benefits for the industry and for society. Factors such as motivations, incentives and implications of the policies of the firms, industries and the government should be studied.

11-10. CONCLUSIONS

The strategy outlined is not complete but does suggest the next steps in the path toward SH/CB. There are many opportunities for research, development and analysis by governmental agencies, educational institutions, industry and foundations. A strategy is required to give each of these efforts a focus.

The strategy presented here may not be the ultimate strategy agreed upon, but it is presented as a catalyst.

BIBLIOGRAPHY

11-1. Ackerman, R., "How Companies Respond to Social Demands", Journal of Environmental Sciences, March/April 1973.

11-2. Alexander, R. S., Cross, J. S. and Hill, R. Industrial Marketing, 3rd. ed., R. D. Irwin, 1967.

11-3. Alfman, M., Telkes, M. and Wolf, M., "The Energy Resources and Electric Power Situation in the U. S.", Energy Conversion, Vol. 12, 1972.

11-4. American Management Association: Developing a Product Strategy, New York, 1959.

11-5. An Assessment of Solar Energy as a National Energy Resource, Prepared by the NSF/NASA Solar Energy Panel, Dec. 1972.

11-6. Applications of the Sciences in Marketing Management, Bass, King, Pessemier, eds., John Wiley, 1968.

11-7. Appraising the Market for New Industrial Products, NICB, No. 123, 1967.

11-8. Bass, F. M., "A New Product Growth Model for Consumer Durables", Management Science, Jan., 1969.

11-9. Bass, F. M., King, C. W. and Pessemier, E. A., eds., Applications of the Sciences in Marketing Management, John Wiley, 1963.

11-10. Bellas, C. J. and Samli, A. Coskun, "Improving New Product Planning with GERT Simulation", California Management Review, June, 1973.

11-11. Berg, T. L., and Shuchman, A.(eds.): Product Strategy and Management, Holt, Rinehart and Winston, Inc., New York, 1963.

11-12. Bliss, P., ed., Marketing and the Behavioral Sciences, 2nd ed., Allyn & Bacon, Boston, 1967.

11-13. Board of Governors of the Federal Bulletin, Federal Reserve Bulletin, Washington, D. C., issues for 1970-1973.

11-14. Bohlen, J. M., Couphenour, C. M., et. al., "Adopters of New Farm Ideas", Robertson, T. S., "Social Factors in Innovative Behavior" in Perspectives in Consumer Behavior, eds. Kanarjian, H. and Robertson, T. S. Scott, Forestman Co., 1968.

11-15. Wittreich, W. J., "Product Acceptance of Off-Peak Air Conditioners", Conservation and Better Utilization of Electric Power by Means of Thermal Energy Storage and Solar Heating, NSF/RANN/SE/GI 27976/TR-72/10, 1972.

11-16. Rogers, E. M., Diffusion of Innovations, Free Press, New York, 1962.

11-17. STARSITE --- Toward a Decision - Making Mechanism for Housing, NASA-ASEE Summer Faculty Fellowship Program with Auburn University at MSFC, January 1972.

11-18. Census of Construction Industries, Bureau of the Census, U.S. Department of Commerce; Washington, D.C., Series CC67-I-18, 1967.

11-19. Löf, G.O.G., et al., "A Philosophy for Solar Energy Development", Solar Energy, Volume 12, 1968.

11-20. Mount, J. D., Chapman, L. D. and Tyrell, T. J., Electricity Demand in the U.S.: An Econometric Analysis, Oak Ridge National Laboratory, ORNL/NSF/EP/49, June 1973.

11-21. Altman, M., Telkes, M. and Wolf, M., "The Energy Resources and Electric Power Situation in the U.S.", Energy Conversion, Volume 12, 1972.

11-22. Briefings [Before the Task Force on Energy of the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, U.S. House of Representatives, 92nd Congress, 1971 (U.S. Government Printing Office, Washington, D.C.)], Volumes I, II, III.

REFERENCES

11-1. Solar Heated and Cooled Office Building for the Massachusetts Audubon Society (Final Report on Initial Planning and Design), C-75457, prepared by A. D. Little, Inc., and Cambridge Seven Associates, June 1973.

11-2. Liu, B. Y. H., and Jordan, R. C.,"A Rational Procedure for Predicting the Long-Term Average Performance of Flat-Plate Solar-Energy Collectors", Solar Energy, Volume 7, Number 2, 1963.

11-3. Globe, S., Levy, G. W, and Schwartz, C., Science, Technology and Innovation, prepared for the National Science Foundation, February 1973.

11-4. Stranmann, P. W., Risk and Technological Innovation, Cornell University Press, 1959.

11-5. Moyer, R., "International Market Analysis", Journal of Marketing Research, Volume V, Number 4, November 1968.

11-6. Energy and the Future of Alabama (Proceedings of the Conference and Workshop), School of Engineering, Auburn University, 3 May 1972.

11-7. Corey, R. E., The Development of Markets for New Materials, Riverside Press, 1956.

11-8. Levitt, T., "Exploit the Product Life Cycle", Harvard Business Review, November/December 1965.

11-9. Foster, R. N., "Organize for Technology Transfer", Harvard Business Review, November/December 1971.

11-10. Kotler, P., and Levy, S. J.,"Demarketing, Yes, Demarketing", Harvard Business Review, November/December 1971.

11-11. Enke, S., "Population Growth and Economic Growth", Public Interest, Summer 1973.

11-12. Census of Manufacturers - 1967, Bureau of the Census, U.S. Department of Commerce; Washington, D.C.

11-13. Census of Business, Bureau of the Census, U.S. Department of Commerce; Washington, D. C., 1967:
Volume I - Retail Trade
Volume II - Wholesale Trade.

11-14. Ramsey, C. G., and Sleeper, H. R., Architectural Graphic Standards, 6th Edition, John Wiley, 1970.

11-15. Boer, K. W., "A Combined Solar Thermal and Electrical House System", International Congress, Paper E-108, Paris, July, 1973.

11-16. Brian, J., Corporate Market Planning, John Wiley, 1967.

11-17. Britt, S., ed., Consumer Behavior and The Behavior Science John Wiley, 1966.

11-18. "Builders See a Bleaker Future", Business Week, June 9, 1973.

11-19. Buttner, F. H. and Chearney, E. S., "An Integrated Model of Technological Forecasting." Technological Forecasting for Industry and Government, J. Bright, ed., Prentice-Hall, 1968.

11-20. Buzzell, R. D., Slater, C. C., "Decision Theory and Marketing Management", Journal of Marketing, July, 1962.

11-21. Cauler, B. A., Energy Research and Development and National Progress, U. S. Government Printing Office, 1964.

11-22. Cherry, W. R. and Morse, F. H., Conclusions and Recommendations of the Solar Energy Panel, ASME, 1972.

11-23. Chamber, J., Mullick, S., et. al., Harvard Business Review, July/August, 1971.

11-24. Clayton, E. R. and Moore, L., "Pert versus Gert", Journal of Systems Management, Feb., 1972.

11-25. Conference Board Business Record, 1970-1973.

11-26. "Construction is Leveling Off", Business Week, Oct. 21, 1972.

11-27. Corey, R. E., The Development of Markets for New Materials, Riverside Press, 1956.

11-28. Council of Economic Advisors, Economic Indicators, issues for 1973.

11-29. Cox, K. K., Enis, B. M., Experimentation for Marketing Decisions, International Textbook , 1969.

11-30. David, E. E., Jr., "Energy: A strategy of Diversity", Technology Review, June, 1973.

11-31. Day, R., ed., Marketing Models: Quantitative Applications, International Textbook, 1970.

11-32. Day, R., Ness, T. E., eds., Marketing Models, Behavioral Science Applications, International Textbook, 1970.

11-33. Doctors, S. I., The Role of Federal Agencies in Technology Transfer, MIT, 1969.

11-34. Mr. E. Elliott Wilburn, A. D. Little, Inc., telephone conversation, July 23, 1973.

11-35. Engel, J., ed., Consumer Behavior: Selected Readings, R. D. Irwin, 1968.

11-36. Enis, B. M., Broome, C. L., Marketing Decisions: A Bayerian Approach, International Textbook, 1970.

11-37. Etzold, D. J., "Considerations and Approaches Toward Developing Effective Management for Solving Environmental Problems" Journal of Environmental Systems, Vol. 3, Spring, 1973.

11-38. Energy and the Future of Alabama, Proceedings of the Conference and Workshop, "School of Engineering, Auburn University, May 3, 1972.

11-39. Egel, J. T., Kollat, D. T., and Blackwell, R. D., Consumer Behavior, 2nd ed., Holt, Rinehart and Winston, 1973.

11-40. Enke, S., "Population Growth and Economic Growth:, Public Interest, Summer, 1973.

11-41. Foster, R. N., "Organize for Technology Transfer", Harvard Business Review, Nov./Dec., 1971.

11-42. Iulmer, R. M., ed., "Organizational Constraints on New-Product Success", Washington Business Review, 1967.

11-43. Globe, S., Levy, G. W., Schwartz, C. , "Key Factors and Events in the Innovation Process", Research Management, July, 1973.

11-44. Globe, S., Levy, G. W., Schwartz, C., Science, Technology and Innovation, Prepared for National Science Foundation, Feb., 1973.

11-45. Gustavson, M. R., Towards An Energy Ethic, MITRE, M72-43, March, 1972.

11-46. Heller, W. H., "Ecology and Economic Growth", Economic Impact, Spring, 1973.

11-47. Henderson, H., "Ecologists versus Economists", Harvard Business Review, July-August, 1973.

11-48. Hobson, J. E. "The Economics of Solar Energy", Solar Economics, Phoenix Conference, International Solar Society, 1955.

11-49. Howard, J. and Sheth, G., <u>The Theory of Buying Behavior</u>, John Wiley, 1970.

11-50. Jordan, A., et al, "Fossil Energy", <u>Annals New York Academy of Sciences</u>, May, 1973.

11-51. "Input/Output Analysis," <u>Scientific American</u>, 1970.

11-52. Kaplan, A., On the Strategy of Social Planning", <u>Policy Sciences</u>, Vol. 4, 1973.

11-53. Kapp, W. K., <u>Social Costs of Private Enterprise</u>, rev. ed., S. Boder, 1971.

11-54. Kasenjaeger, J., "The Role of Marketing in Environmental Affairs", <u>Business Inquiry</u>, Vol. 9, 1971-1972.

11-55. Kanarjuan, H. H. and Robertson,eds., <u>Perspectives in Consumer Behavior</u>, Scott, Foserman, 1968.

11-56. King, W. R., <u>Quantitative Analysis for Marketing Management</u>, McGraw-Hill, 1967.

11-57. King, C. W. and Summers, J. V., "Technology, Innovation and Consumer Decision Making", <u>Changing Marketing Systems</u>, American Marketing Association Proceedings, Winter Conference, 1967.

11-58. Kollat, D. T., Blackwell, R. D., Robinson, J. S., <u>Strategic Marketing</u>, Holt, Rinehart and Winston, 1972.

11-59. Konopa, L. J., <u>New Product: Assessing Commercial Value</u>, American Management Assoc., Bulletin no. 88, New York, 1966.

11-60. Kotler, P., <u>Marketing Decision - Making a Model - Building Approach</u>, Holt, Rinehart and Winston, 1971.

11-61. Kotler, P. and Levy, S. J., "Demarketing, Yes, Demarketing", <u>Harvard Business Review</u>, Nov./Dec., 1971.

11-62. Kotler, P., <u>Marketing Decision Making</u>, Holt, Rhinehart and Winston, 1971.

11-63. Kottenstetle, J. P. and Rusnak, J. J., "Transfer and Diffusion - Two Ways to Transmit Technology", <u>Research Management</u>, July, 1973.

11-64. Lanford, H. W., "A Penetration of the Technological Forecasting Jungle", <u>Technological Forecasting and Social Change</u>, vol. 4, 1972.

11-65. Lee, S. M., "Goal Programming for Decision Analysis of Multiple Objectives", <u>Sloan Management Review</u>, Winter 1972-1973.

11-66. Levitt, J. "Marketing Myopia", Harvard Business Review, July/ Aug., 1960.

11-67. Levitt, T., "Exploit the Product Life Cycle", Harvard Business Review, Nov./Dec. 1965.

11-68. Löf, G. O. G., Cose, D. J. and Duffie, J. A., "A Philosophy for Solar Energy Development", Solar Energy, vol. 12, 1968.

11-69. Madden, C. H., Clash of Culture - Management in an Age of Changing Values, National Planning Association, Report no. 3, 1972.

11-70. Management of New Products, Booz, Allen and Hamilton, 1968.

11-71. Mansfield, E., The Economics of Technological Change, W. W. Norton and Co., 1968.

11-72. Mansfield, E., "Intrafirm Roles of Differsion of an Innovation", Economics and Statistics, vol. 45, 1963.

11-73. Mansfield, E., "Size of Firm, Market Structure, and Innovation", Journal of Political Economy, vol. 21, 1963.

11-74. Marcin, T., Projections of Demand for Housing by Type of Unit and Region, U. S. Department of Agriculture, Forest Service, Ag. Handbook 428, May, 1972.

11-75. Massey, W. F., Webster, F. E., Jr., "Model Building in Marketing Research" Journal of Marketing Research, May, 1964.

11-76. Meadows, D. H., et. al., The Limits of Growth, Universe Books, 1972.

11-77. Miller, R. J. and Duffie, J. F., "Thoughts on Economic - Social Implications of Solar Energy Use", International Solar Energy Society Conference, Melbourne, Australia, March, 1970.

11-78. Montgomery, D. and Urban, G. L., Management Science in Marketing, Prentice-Hall, 1968.

11-79. Moyer, R., "International Market Analysis, Journal of Marketing Research, Vol. V, no. 4, November, 1968.

11-80. Myers, J. and Reynolds, W., Consumer Behavior and Marketing Management, Houghton-Mifflin, 1967.

11-81. National Aeronautics and Space Administration, Solar Energy for Terestial Use,Twenty-Year Development Plan, MSFC/PD-SA-0, September 8, 1972.

11-82. National Industrial Conference Board, Inc., Appraising the Market for New Industrial Products, Studies in Business Policy, no. 123, New York, 1967.

11-83. Nicosia, F. N., Consumer Decision Processes: Marketing and Advertising Implications, Prentice-Hall, 1966.

11-84. Oil and the Environment: The Prospect, Shell Oil Co., June, 1973.

11-85. Pessemier, E. A., New Product Decisions, McGraw-Hill, 1966.

11-86. Pessemier, E. A., "New Product Ventures", Business Horizons, Aug., 1968.

11-87. Pessemier, E. A., Models for New Product Decisions, Institute for Research in the Behavioral, Economic and Management Sciences, Purdue University, May, 1969.

11-88. "Plastic Wiring Wins Another Victory", Business Week, June 24, 1972.

11-89. Pratt, J. W., Raiffa, H. and Schlaifer, R. O., Introduction to Decision Theory, McGraw-Hill Co., 1965.

11-90. Quinn, J. B., "Technological Forecasting", Harvard Business Review, 1967.

11-91. Ramsey, C. G. and Sleeper, H. R., Architectural Graphic Standards, 6th ed., J. Wiley, 1970.

11-92. Raiffa, H., Decision Analysis - Introductory Lectures on Choices Under Uncertainty, Addison-Wesley, 1968.

11-93. Reynolds, W. H., Products and Markets, Appleton-Century-Crofts, New York, 1962.

11-94. Richman, B. M., "A Rating Scale for Product Innovation, Business Horizons, Summer 1962.

11-95. Roberts, M. J., "Is There an Energy Crisis?" The Public Interest, Spring, 1973.

11-96. Robertson, T. S., "Purchase Sequence Responses: Innovators Versus Non-Innovators", Journal of Advertising Research, March, 1968.

11-97. Robinson, P. J., Faris, C. W. and Wind, Y., Industrial Buying and Creative Marketing, Allyn and Bacon, Inc., 1967.

11-98. Rogers, E. M., Diffusion of Innovations, Free Press, New York, 1962.

11-99. Sales Management-Survey of Buying Power, Bill Brothers Publishing, 1972.

11-100. Samli, C. A. and Bellas, C., "The Use of GERT in the Planning and Control of Marketing Research", Journal of Marketing Research, August, 1971.

11-101. Schlaifer, R. O., Analysis of Decisions Under Uncertainty, McGraw-Hill Co., 1967.

11-102. Schurr, S. H., Netschert, B., et al., Energy in the American Economy, 1850 - 1975, John Hopkins, 1960.

11-103. Sherman, H. A., "Marketing Organizations in the Defense/Space Industry", New Directions in Marketing, American Marketing Association, 1965.

11-104. Shepard, H. A. "Innovation-resisting and Innovation-producing Organizations", Journal of Business, Oct., 1967.

11-105. Sporn, P., Possible Impact of Research on the Electric Power Industry, Conference on Research for the Electric Power Industry, Sponsored by IEEE/ASME, Washington, D.C., Dec. 1972.

11-106. Shanmann, P. W., Risk and Technological Innovation", Cornell University Press, 1959.

11-107. Sheridan, N. R., "Criteria for Justification of Solar Energy Systems", International Solar Energy Conference, Melbourne, Australia, March, 1970.

11-108. Sissors, J. Z., "What is a Market?", Journal of Marketing, vol. 30, July, 1966.

11-109. Solo, R. A., and Rogers, Everett M., ed., Inducing Technological Change for Economic Growth and Development, Michigan State Unviersity Press, 1972.

11-110. Sporn, P., "Possible Impact in Environmental Standards in Electric Power Availability and Cash" in Schurr, S., ed., Energy, Economic Growth and the Environment, John Hopkins, 1972.

11-111. Stanton, W., Fundamentals of Marketing, 3rd. ed., McGraw-Hill, 1971.

11-112. Staudt, T. A., Taylor, D. A., A Managerial Introduction to Marketing, Prentice-Hall, 1965, ch. 8.

11-113. Swalm, R., "Utility Theory-Insights into Risk Taking", Harvard Business Review, Nov/Dec., 1966.

11-114. Swaper, W. L., "Strategic Planning II: Policy Options", Technological Forecasting and Social Change, vol. 4, 1972.

11-115. "The High Price of More Electric Power", Business Week, Aug. 19, 1972.

11-116. The National Energy Problem, Shell Oil Co., June 1, 1973.

11-117. The National Energy Outlook, Shell Oil Co., March, 1973.

11-118. The 1970 National Power Survey, Report to Federal Power Commission, Parts I-IV, U. S. Government Printing Office, Washington, D. C., 1971.

11-119. Toward a Decision Making Mechanism for Housing, NASA/ASEE. Prepared by Summer Faculty Fellowship Program, Marshall Space Flight Center, supervised by School of Engineering, Auburn, University, January, 1972.

11-120. Tucker, W. T., Foundations for a Theory of Consumer Behavior, Holt, Rinehart, Winston, 1966.

11-121. U. S. Bureau of the Census, Census of Business, Vol. I Retail Trade and Vol. II Wholesale Trade, 1967.

11-122. U. S. Bureau of the Census, Census of Construction Industries, Series CC67-I-1B, 1967.

11-123. U. S. Department of Commerce, Census of Manufactures 1967, Bureau of the Census, Washington, D. C.

11-124. U. S. Department of Commerce, Census of Housing, 1970, Bureau of the Census, Washington, D. C.

11-125. U. S. Department of Commerce, Merchandising Week, Bureau of the Census, Washington, D. C., 1971.

11-126. U. S. Department of Commerce, Social and Economic Statistics, Population Estimates and Projections, Series P-25, No. 477, Bureau of the Census, Washington D. C., March, 1972.

11-127. U. S. Department of Commerce, Statistical Abstract of the United States 1972, Bureau of the Census, Washington, D. C., 1972.

11-128. U. S. Department of Commerce, Survey of Current Business, issues for 1970, Washington D. C., 1973.

11-129. U. S. House of Representatives, Committee on Science and Astronautics, 92nd. Congress, Briefings Before the Task Force on Energy of the Subcommittee on Science, Research and Development, Vol. I, II, III, U. S. Government Printing Office, Washington, D. C., 1971.

11-130. U. S. House of Representatives, Committee on Science and Astronautics, 92nd. Congress, Energy Research and Development, Subcommittee on Science, Research and Development, U. S. Government Printing Office, Washington, D. C., 1973.

11-131. U. S. Department of the Interior, Minerals Yearbook 1971, Vol. I, U. S. Government Printing Office, Washington, D. C., 1973.

11-132. U. S. Department of Labor, Monthly Labor Review, Washington, D. C., issues for 1970-1973.

11-133. "U. S. Faces Many Options in Natural Gas Shortage", Christian Science Monitor, June 25, 1973.

11-134. Economic Report of the President, transmitted to the Congress, U. S. Government Printing Office, Washington, D. C., 1973.

11-135. Urban, G., "A New-Product Analysis and Decision Model", Management Science, April, 1968.

11-136. Urban, G. L., "Market Response Models for the Analysis of New Products", Proceedings of the American Marketing Association, Denver, August, 1968.

11-137. Walters, C. G. and P., Gordon W., Consumer Behavior, R. D. Irwin, 1970.

11-138. Wasson, C. R., and McConough, D. H., Buying Behavior and Marketing Decisions, Appleton Century Crofts, N. Y., 1969.

11-139. "Ways to Avoid Oil Crunch or Crisis in U. S.", Christian Science Monitor, July 5, 1973.

11-140. "Weeding Out the Losers", Business Week, March 18, 1972.

11-141. Wittreich, W. J., "Product Acceptance of Off-Peak Air Conditioners", Conservation and Better Utilization of Electric Power by Means of Thermal Energy Storage and Solar Heating, NSF/RANN/SE/GI27976/TR-72/10.

PART IV. CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations given here were adopted by the group as a whole after thorough consideration and discussion. Those conclusions which apply to the total energy picture are presented first, followed by those which apply specifically to the solar heating and cooling of buildings. The recommendations presented last apply to the total energy picture.

Conclusions

- The long-term rate of growth in U.S. energy consumption must be slowed down. The nation cannot and should not sustain an exponential growth in energy usage.
- An energy crisis will occur if the country experiences exponential growth in energy consumption in the future.
- Governmental organization and policies, or lack thereof, have, to a significant degree, contributed to the current energy problem.
- Many industries do not utilize energy as efficiently as technologically possible due to the current relatively low cost of energy.
- Conservation of energy must become the concern of all citizens, industry and government.
- Fossil fuels should be conserved for non-energy uses.
- The growth rate in electrical power usage is significantly greater than the growth rate in total energy usage. Particular emphasis should be placed on reducing the growth in consumption in this sector because the energy conversion losses are high.
- The United States should pursue the research and develop the technology necessary to provide a variety of energy resource options.
- Solar or geothermal energy, coal gasification and liquefaction and the breeder reactor cannot contribute significantly to the energy supply market until 1985 at the earliest and thus they will not solve the near-term crisis associated with current exponential growth.

- Solar energy has vast potential as an energy resource for the world. The combined characteristics of inexhaustibility and relative freedom from pollution make it an ideal energy resource.

- Solar energy can be utilized in virtually all regions of the United States.

- R&D in the solar energy field has been relatively uncoordinated, often poorly documented and under-funded in the past.

- Solar insolation data collection in the past has been inadequate for solar engineering.

- Comprehensive design procedures for solar energy systems are not available.

- Solar cooling of buildings to present U. S. comfort standards is not a demonstrated concept at the present.

- Maximum impact of solar heating and cooling will only be realized in energy-conserving buildings.

Recommendations

To slow the growth of total energy consumption in the United States it is recommended that:

- The Federal government adopt a national energy policy which has as one of its main objectives reduction of the growth rate in energy consumption. This objective should be sought primarily through education and economic incentives, but also, where necessary, by direct controls.

- The country adopt an energy and natural resources conservation ethic. This ethic should be promoted by government, industry, educational insitutions and technical societies. Adequate funding to fulfill this educational mission should be provided.

- Individuals and agencies who are involved in the design of buildings should endeavor to make them more energy conserving. Government agencies such as FHA, HUD, NBS, and GSA should lead the way in this endeavor. Architects, engineers, and manufacturers should urge modification to building codes where needed to promote this concept. Colleges and universities should train the technical personnel needed to aid in the design of such buildings.

- Appropriate regulatory agencies consider progressive energy rate stuctures which establish higher rates for energy used in excess of certain levels. These levels should be determined on an end-user basis. Also, the rate structure should encourage the use of off-peak electrical energy.

To promote the utilization of solar energy it is recommended that:

- The Federal government fund solar energy to the extent proposed in the 1972 NSF/NASA Solar Energy Panel report at least to the first decision point for each concept. This would require from 50 to 88 million dollars per year for approximately four (4) years. Continued funding should be contingent on evaluations at those points. A decision should be made at that time on which concepts should receive further R&D funding.

- Educational and governmental agencies acknowledge solar energy for its great potential as a major energy source of the future and promote the recognition of this fact.

- The Federal government establish a national Solar Energy Commission to identify and mobilize support from those individuals and groups interested in the growth and development of solar energy utilization.

- The Department of Energy and Natural Resources (DENR) should, in conjunction with other appropriate government agencies, set up a study group to determine what combinations of public (governmental) and private (industrial) innovation will best promote the utilization of solar energy.

- The Federal government undertake a full marketing study to determine the market potential of solar energy systems in the United States and to ascertain the barriers to their acceptance by the American people.

- The Federal government should sponsor a comprehensive study of solar insolation data collection and analysis for engineering use to determine the types of data to be collected, the locations at which it should be collected, and a data format adapted to the design of solar facilities.

- The technical and professional societies formulate and publish solar energy systems design procedures and handbooks.

APPENDIX A. ACRONYMS, ABBREVIATIONS AND DEFINITIONS

A-1. ACRONYMS AND ABBREVIATIONS

A/C, A.C. - Air Conditioning

AC - Alternating Current

AEC - Atomic Energy Commission

ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers

DC - Direct Current

DD - Degree Day

EGM - Extrapolated Growth Model

EPA - Environmental Protection Agency

FPC - Federal Power Commission

GNP - Gross National Product

GSA - Governmental Services Administration

H/C - Heating and Cooling

IECEC - Intersociety Energy Conversion Engineering Conference

JSC - Johnson Space Center

MAS - Massachusetts Audubon Society

MHD - Magnetohydrodynamics

MIT - Massachusetts Institute of Technology

MSFC - Marshall Space Flight Center

NBS - National Bureau of Standards

NASA - National Aeronautics and Space Administration

NSF - National Science Foundation

R&D - Research and Development

RGM - Reduced Growth Model

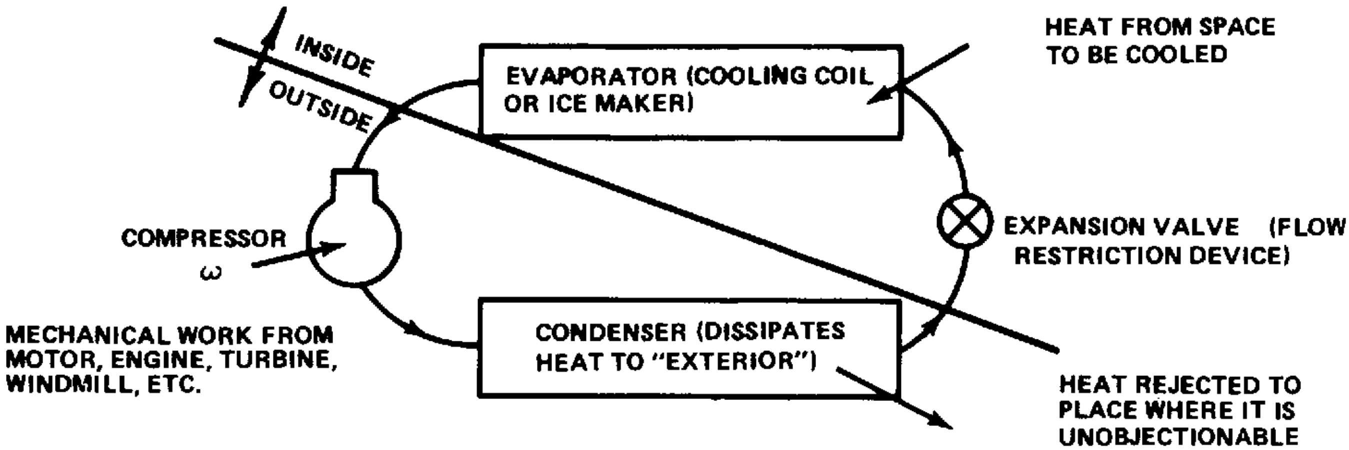
SH/CB - Solar Heating/Cooling of Buildings

SSPS	- Satellite Solar Power Station
T/O	- Tradeoffs
TVA	- Tennessee Valley Authority
U.S.	- United States of America
ZPG	- Zero Population Growth

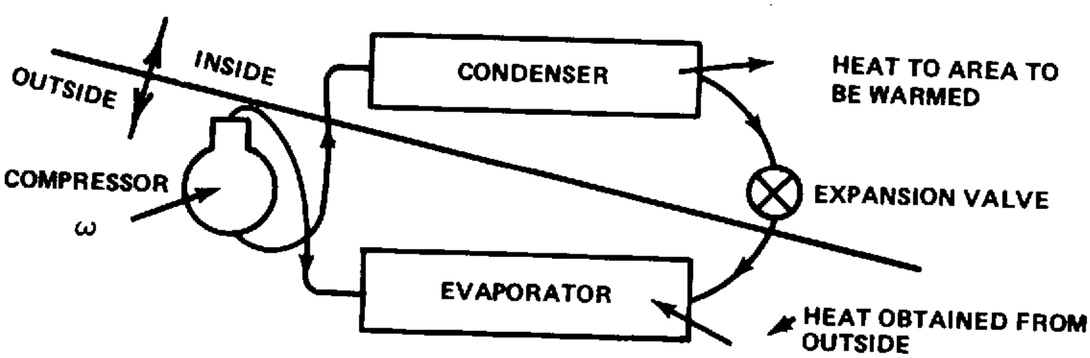
A-2. DEFINITIONS

Air Conditioning	- Simultaneous control of air temperature, humidity, cleanliness and distribution within an enclosed space
Ambient	- Surrounding
Btu	- British thermal unit. The amount of heat that must be added to, or subtracted from, one pound of water to change its temperature 1°F
Calorie	- The amount of heat that must be added to, or subtracted from, 1 gram of water to change its temperature 1°C (equivalent to 3.968×10^{-3} Btu)
Constraint	- An upper or lower limit on the system or strategy
Criterion	- Measure of the desired performance of the system or strategy
Dalton's Law	- The total pressure of a mixture of gases is equal to the sum of the partial pressures (individual pressure of each gas in the mixture)
Degree-Day	- There are as many "degree-days" in a 24 hour period as there are degrees Fahrenheit difference between the average outdoor temperature for the day and 65 degrees Fahrenheit. Normally used for heating calculations only.
Demand-Price Elastic	- Demand dependent on price
Demand-Price Inelastic	- Demand independent of price
Ecosystem	- The interrelationship between living organisms and the non-living environment
Energy	- Having the capability to do work
Giga	- One billion (1,000,000,000 or 10^9)
Heat Pipe	- Special pipe for transferring heat. A pipe filled with a "wick" material and a liquid at very low pressure
Horsepower (hp)	- 1 hp = 2545 Btu/hr

Hp-hr	- 1 hp-hr is 1 hp being used for 1 hour
Insolation	- Local total solar radiant flux (power per unit area) intercepting a horizontal plane on the Earth (biosphere)
Kilo	- One thousand (1000 or 10^3)
Kw-hr	- 1 kw-hr is 1 kilowatt being used for 1 hour
Kw, thermal	- may be used in place of Btu when discussing heat flow
Langley	- One calorie of radiation energy per cm^2
Latent Heat of Evaporation	- That amount of heat that must be added to one pound of a liquid to change it to vapor without a change in temperature
MBtu	- One million Btu
Mega	- One million (1,000,000 or 10^6)
One Ton of Refrigeration	- One ton of ice changed from ice at 32°F to water at 32°F over a period of 24 hours
Power	- Rate at which work is done
Quad	- One quadrillion (10^{15})
Q	- One quintillion (10^{18}) Btu
Watt (w)	- 1 w = 1.341 x 10^{-3} hp
Work	- The transference of energy when a force produces movement of a body



Cooling Mode



Heating Mode

Figure A-1. ELEMENTS OF A COMPRESSION REFRIGERATION CYCLE

Technically any refrigeration machine is a "heat pump" as it moves heat from a place where it is undesirable to a place where it is unobjectionable. By "every day" definition a "heat pump" is an installed air conditioner (space cooler) where the functions of the evaporator and condenser are exchanged in order to provide space heating. In less mild climates the heating phase must be supplemented by 2 to 4 Kw of resistance heaters when the outside temperature drops to around 20°F.

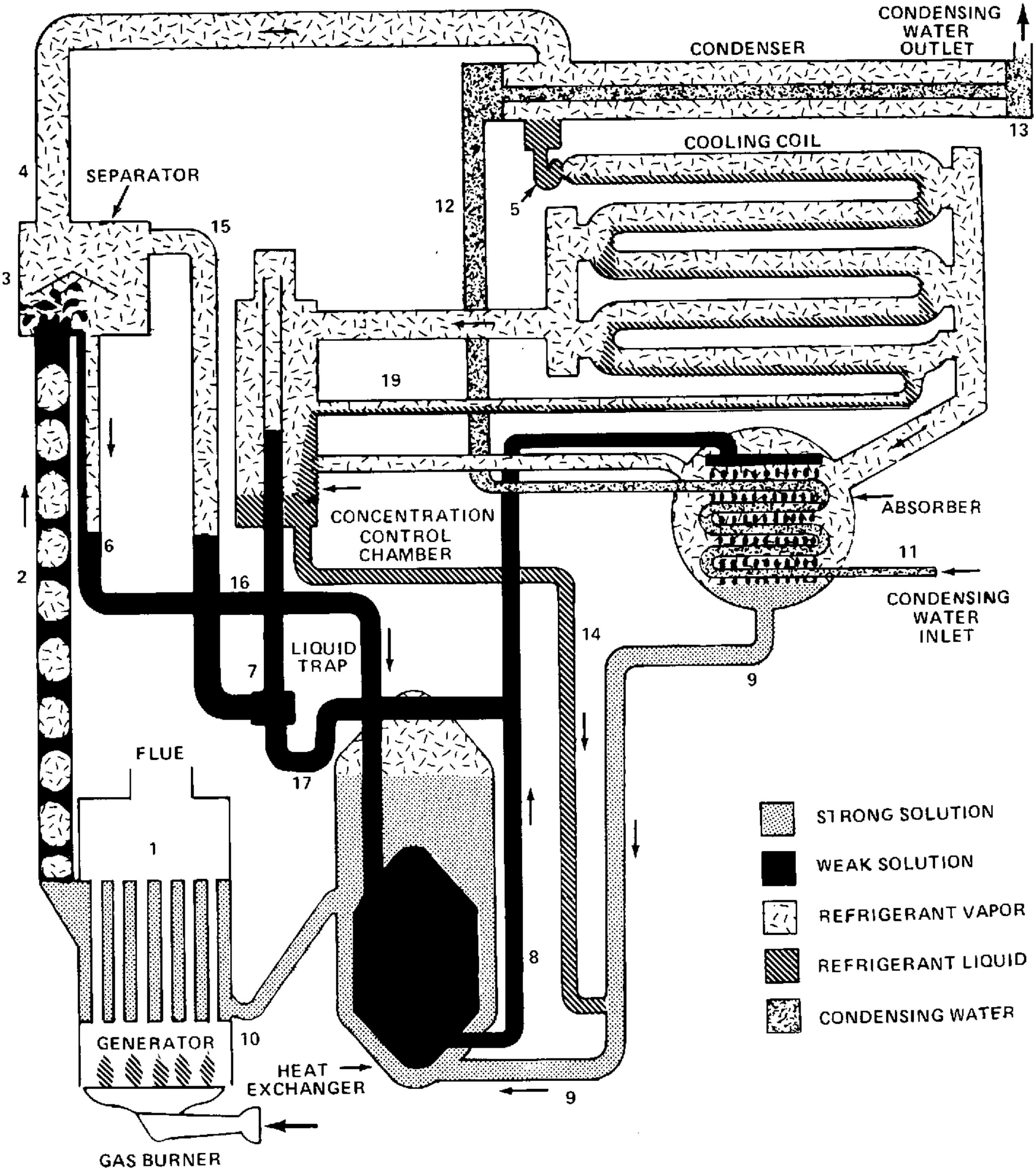


Figure A-2. COOLING CYCLE

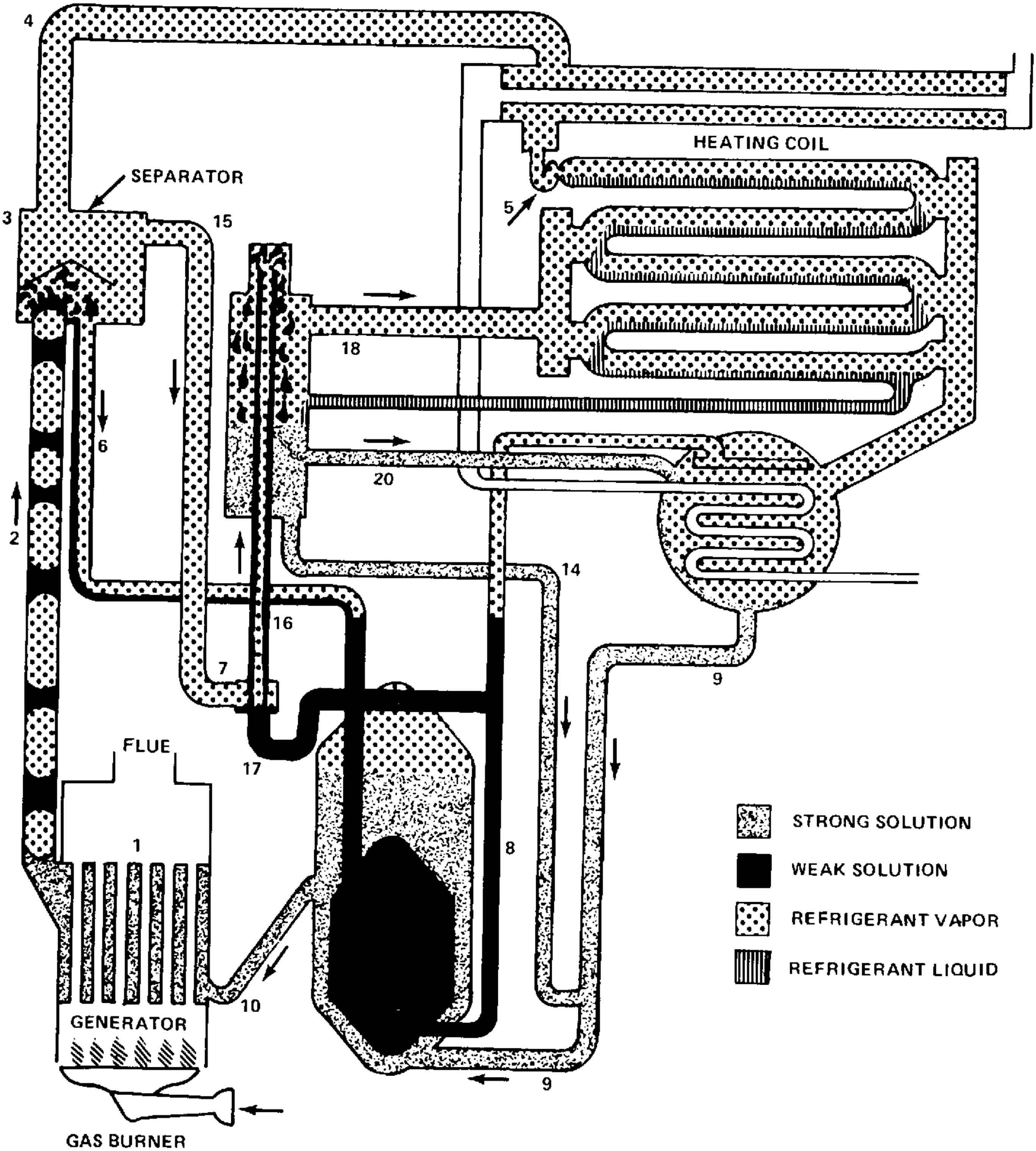
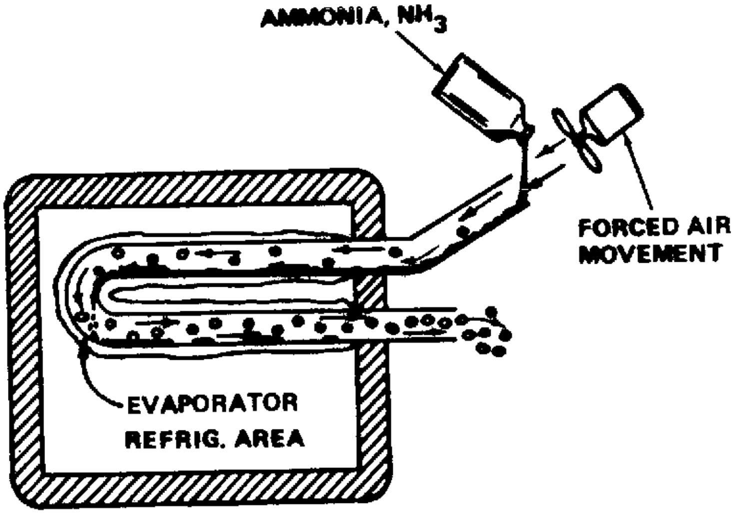
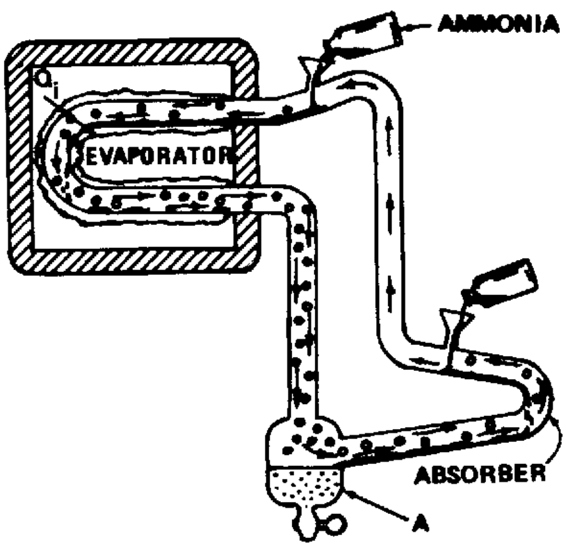


Figure A-3. HEATING CYCLE



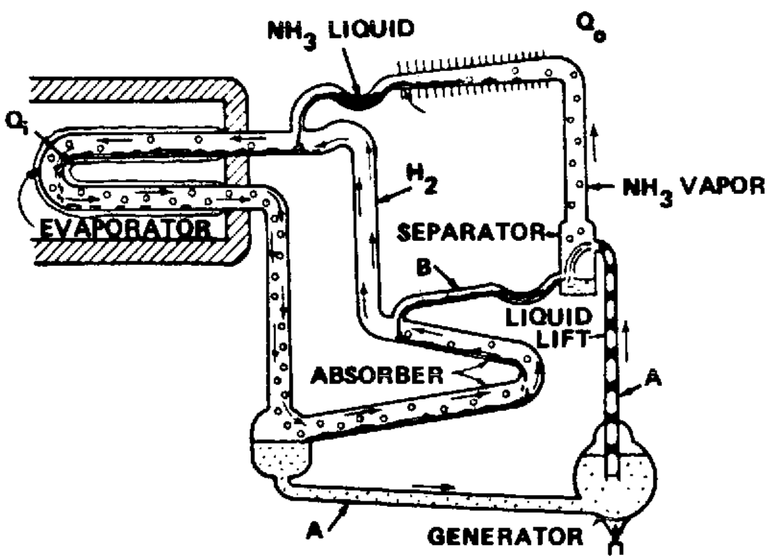
The Concept

- evaporator loop is cooled as the NH_3 evaporates, absorbing its latent heat of evaporation



The Concept, absorber added to conserve NH_3

- A non-condensing gas is added to the loop and circulated by temperature difference

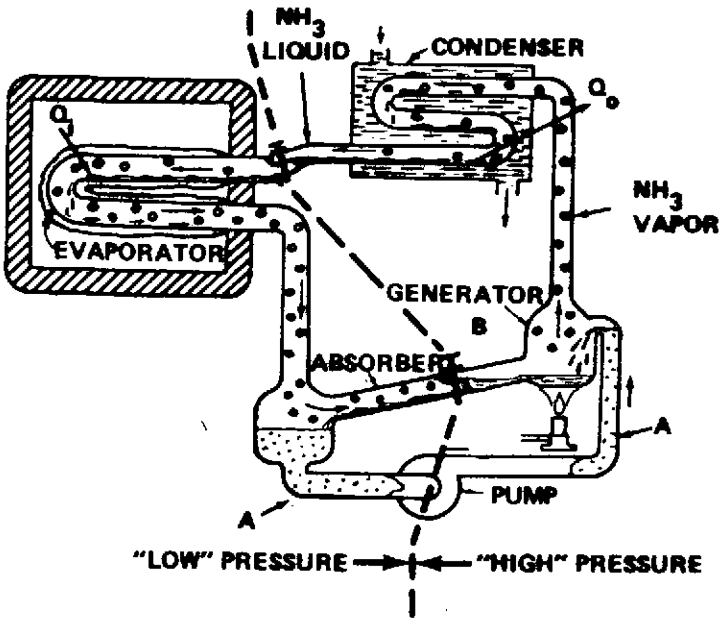


Basic "Servel" Cycle

- The NH_3 refrigerant either evaporates or condenses, depending upon temperatures and partial pressures
- Closed loop, entire system at a partial vacum
- Motive power is percolation at generator (liquid lift)

A - strong liquor, rich in NH_3
B - weak liquor, lean in NH_3

Figure A-4. ABSORPTION REFRIGERATION UNIT FROM CONCEPT TO YEAR AROUND SYSTEM



Larger "Servel" Type System

- Condenser shown water cooled but could be air cooled
- Valves and pumps replace the reliance on partial pressures and eliminate a third gas (H_2) as a carrier

Figure A-4. (Continued)

APPENDIX B SUMMARY OF SPEAKERS' SEMINARS

A summarization of each talk given by the various guest speakers during the course of the 1973 Summer Faculty Fellowship Program is given in this appendix. Little attempt is made to quote the remarks that were made by each speaker and in many instances the opinions of the faculty fellows are woven into the fabric of the summary. The summaries are arranged in chronological order.

SOLAR ENERGY SYSTEMS

Erich A. Farber
Professor
Department of Mechanical Engineering
University of Florida
Gainesville, Florida

Dr. Farber divided his presentation into three general areas: (I) introductory remarks on the energy situation in toto and solar energy in particular; (II) flat plate solar energy collectors; and (III) solar energy concentrators. Dr. Farber's comments are summarized in outline form as follows:

I. Introduction

- We must look objectively at the whole problem of solar energy conversion.
- By making good use of all of our available resources, we can maintain our high standard of living.
- The energy crisis is really just another problem to be solved.
- Solar radiation is the only incoming, inexhaustible source of energy.
- The main energy sources for the foreseeable future will be fossil fuels and solar radiation. Nuclear energy will probably be only significant in large metropolitan areas, unless the fusion process can be controlled and developed.
- The energy planning curve shows exponential growth which will result in serious trouble for us and mankind by the year 2000. Obviously this growth must be either stopped by us or it will be stopped by nature.

- Presently, energy comes from the following sources:

  1. Coal 50%
  2. Oil and natural gas 35%
  3. Farm wastes 10%
  4. Wood 4%
  5. Misc. (incl. nuclear) 1%

     Note that some nuclear wastes must be stored for 250,000 years or otherwise disposed of safely.

- Energy is distributed among many users which can be categorized as follows

  1. Industry 30%
  2. Transportation 25%
  3. Utilities 23%
  4. Residential 22%

- One should consider the total energy picture; for instance, if we did not make insulation, but instead let the heat leak out (or in), we would be ahead in terms of total energy. It was stated that it takes more energy to make insulation than is saved by installing it in a house for 30 years. The home owner does save more money in utility bills than the insulation costs over the 30 year period.

- The windmill is an example of an adequate energy source that was not manufactured and improved to meet an energy demand, thus forcing the farmer to depend on Rural Electrification.

- The average person in the U.S. uses 600,000 Btu of energy per day.

- Costs for fuel runs from $0.005 per kWh for fossil fuels to $12.40 per kWh for caviar.

- The use of fossil fuels for energy is just a narrow spike when mankind's energy needs are considered on a time scale of many centuries starting with the year 1900.

- Solar energy does not pollute the environment, which from the environmental standpoint is very important.

- About 1 hp of solar energy falls on 1 sq. yard of surface area on the Earth. Two to three times more energy falls on the average roof top than can be used inside.

- Solar energy use does not require large central stations, instead, energy can be made available at the point of use.

- Radiation energy from the sun arrives at a surface in two ways:

  1. Direct rays where the energy can be concentrated. This only occurs, in large quantities, on clear days.

2. Diffused radiation where the energy cannot be concentrated by lens. However, energy in this form is available on cloudy days.

II. Flat Plate Collectors

- Flat plate collectors can effectively utilize both direct and diffused solar radiation.

- One of the properties of material used in solar energy conversion is that it must be able to withstand the outside environment. Dr. Farber stated that glass makes the best collector. (A good collector passes the short wave length energy associated with heat.) NOTE: Iron content in glass (visible by a green color in the edge) limits its transmission capabilities.

- Efficiency is not a real factor in solar energy generation. A Solar Calorimeter can be used to measure reflection, absorption, and transmission characteristics of various materials under actual solar irradiation.

- Paint absorption characteristics are important. A green paint was found to be better than black in converting solar insolation into thermal energy.

- Normal cloud cover has little effect on the amount of solar energy reaching the Earth's surface even though the radiation is more of the diffused type.

- In the colder northern latitudes, two glass plates should be used in the solar-to-thermal flat plate converter in order to cut down on heat losses.

- The solar converters described by Dr. Farber are inexpensive and easy both to construct and to mass produce.

- The thermal energy in hot air can be stored by passing the air through crushed rock, or hot water can be stored in an insulated water tank.

- Solar energy can be used to distill water.

- Cooling by using solar energy can be accomplished by the absorption cycle.

III. Solar Energy Concentrators

- Concentrators use only the direct rays of the sun.

- Concentrators yield higher temperatures, but have more losses.

- A Fresnel lens yielded a temperature of 2,000° F.

- Cottonseed oil used in a parabolic heat unit reached a temperature of 900° F at a flow rate of 2 ft/min.

- There are many ways of making cheap parabolic or near-parabolic shaped mirrors.

- A searchlight reflector was used to reach a level of 25,000 times natural sunlight. This is thought to produce a temperature of approximately 8,000° F.

- Heating materials in a device that concentrates solar radiation has the advantage that the heat is located at a point or area, which means that nearby areas are not subjected to the high heats.

- Solar energy to mechanical energy conversion methods include:

  1. Windmills
  2. Steam engine (flat plate collector using Freon)
  3. Hot air engines (or heat engines)
     a. $12 to produce such an engine
     b. 0.2 brake hp (depends on the size of the mirrors)
  4. Water pump with no moving parts (uses check valves)

- Solar cells are too expensive and the theoretical limit to their efficiency is about 22 percent.

- The University of Florida has a solar house with graduate students living in it. It will eventually derive almost all of its energy from the sun.

  1. Hot water is generated using a 4 ft. by 12 ft. solar converter with the water stored in a 100-gallon tank.
  2. Heat for the house is supplied by a 270 square foot (at about $2.50/sq. ft.) solar panel and a 3,000 gallon storage tank.
  3. Cooking will be done by the addition of a solar-heated oil unit.
  4. Projected installation costs of such a system is about 2 1/2 times the cost of conventional equipment.

- There are over 40,000 solar water heaters in Florida and some of them have been in use for the past 40 years.

- Present lead-acid batteries are designed for high current operation over a short period of time, while, for the electric car, they should be redesigned for low current operation over a long period of time.

- Geothermal energy sources may be significant as far as steam power plants are concerned; also, the steam is not very clean.

- There are several reasons, at the present time, why people do not make wider use of solar energy.

  1. People are not aware of the potential and possible uses of solar energy.
  2. Many systems and components are not commercially available.
  3. Contractors are not interested in the operating costs of the devices they install; rather, they are interested in low initial costs.

Dr. Farber concluded his presentation with the remark that solar energy should be used to supplement, not replace, present energy sources. As an ideal reference for Dr. Farber's presentation see "Solar Energy Research and Development at the University of Florida Solar Energy and Energy Conversion Laboratory" by Dr. Erich A. Farber.

SOLAR ENERGY AT MSFC

Georg von Tiesenhausen and
Walter Whitacre
PD-SA, MSFC
Huntsville, Alabama

Mr. Georg von Tiesenhausen addressed the following points:

A. Review of Solar Energy Concepts

1. Solar Cells - Arrays presently cost $600/ft^2 and $40/watt; need to reduce this to $1/ft^2 to be competitive with existing energy sources.
2. Solar Farm - a 60 x 60 mile^2 area in the Southwestern part part of the U.S. can provide all of the projected electrical needs of the U.S. in 1985 at a cost of 7 to 50 mills/kWh; cost of collectors will probably be from $300 to$2,000/kW.
3. Hydrogen Generation by Electrolysis - It is cheaper to transport hydrogen across country than to transport equivalent amount of electrical energy.
4. Bioconversion to Fuels - Oil, methane, and hydrogen can be obtained from the bioconversion process.
5. Photolysis - Use plants to breathe (expel) hydrogen.

B. Main Subsystems (common to any solar conversion process)

1. Energy Collector
   a. Flat Plate to get 200° to 300° F for heating and cooling.
   b. Parabolic Cylinder to get up to 1000° F for driving a steam turbine.
   c. Dish Parabola to obtain temperatures of several thousand degrees for reducing metals, chemical reactions and gasification of coal.
2. Energy Transport Medium
   a. Use water for temperature ranges from 200° F to 300° F.
   b. Use salt solution or special fluids with a low vapor pressure for temperatures up to 1000° F.
   c. For temperatures of several thousand degrees use energy on location, do not attempt to transport.
3. Energy Storage
   a. Pick material as a function of temperature
   b. Use proper phase change temperature for eutectics.
4. Solar Energy Should be Interfaced with other Fuels

C. Summary of Major Technical Problems to be Solved

1. Thermal Energy
   a. Low-cost solar powered air conditioning.
   b. Combined cooling and heating.
2. Electric Power Generation
   a. Low-cost solar collectors, heat transfer and energy storage.
   b. Low-cost photovoltaic cells.
   c. Being able to utilize a power source with a variable output.
   d. A low-cost, low-pressure and low-temperature turbine system.
3. Renewable, Clean Fuels
   a. Low cost.
   b. Efficient production, collection and processing of organic materials.
   c. Optimization of conversion process for different feed materials and desired end-product fuels.

D. Miscellaneous Information

1. Solar Cells
   a. On earth cost is more important than in space.
   b. In space size, efficiency and reliability are more important than on earth.
   c. Abrasion protection must be provided on earth.
   d. Higher operating temperatures in space, less energy available per unit area on earth.
2. Heat Pipes
   a. Closed system.
   b. Based on capillary action.
   c. Length and diameter are limited.
3. SSPS (Glaser)
   a. Transmits 10 cm microwaves because earth's atmosphere is transparent to this wavelength.
   b. Need 500 space shuttle trips to get in place (expected shuttle lifetime is 100 flights).
4. Solar House Operating Experience - using 50 percent solar power, total costs for heating and cooling average $26/mo. (1600 ft^2 house).

Mr. Walter Whitacre commented on the following:

A. NASA Proposed House

45° pitched roof covered on south side by flat plate collectors

B. Electric Power

1. Pilot Plant - 100 MW plant located on 10 acres, 600' x 700' (only need 2.5 acres for collectors, 2.5 acres to eliminate shadows, and 5 acres for future expansion.
2. Huntsville gets 2,700 hours/year sunshine on the average

C. Phase-Change Storage

1. Dr. Lorsch at the University of Pennsylvania is doing research in this area.

D. NASA Collector

1. Coating - α/ε = 14 with 92 percent absorption (black body has α/ε = 1)
2. Tedlar - used in place of glass plates. "Physical properties are better than glass, also less costly and lighter"
3. Cost - $1/ft^2 for total collector

E. Miscellaneous Information

1. Seattle Power and Light is considering building a solar generator
2. Kraft Ehricke's scheme is mentioned as an alternative to Glaser's scheme - both use synchronous satellites

NSF OVERVIEW OF SOLAR ENERGY

Dwain F. Spencer
Program Manager
NSF/RANN
1800 G. St. N.W.
Washington, D.C. 20550

Mr. Spencer's presentation was divided into three main areas:

I. The NSF terrestrial solar energy program,
II. Considerations in defining the role of solar energy systems,
III. Solar heating and cooling of buildings - status summary.

Much of the material Mr. Spencer presented can be found in the December 1972 report of the NSF/NASA Solar Energy Panel (S.E.P.R.) and the RFP 73-118 dated May 10, 1973.

I. OVERVIEW OF THE NSF TERRESTRIAL SOLAR ENERGY PROGRAM

A. Background

1. Current projections of total U.S. energy demands indicate a need for 150 to 300 x 10^{15} Btu/year by the year 2020.
2. 50 percent projected increase in energy demands will be supplied by nuclear power and the rest by fossil fuels.
3. Some considerations which must be brought into energy planning are:
   a. Use of energy resources should be considered on a regional rather than national level.

b. Peak load energy is normally much more expensive than base power; therefore, NSF considers solar energy as one way to address the problem of peaking power (particularly over the short term period from the present to 1985).
c. The federal government requires each new power plant to develop an Environmental Impact Statement.
d. Health and safety factors must be considered.
e. Depletion of natural resources must be realistically planned for.
f. Increasing dependence on imports of gas and oil will be required.
g. The standard of living embraced by the citizens of a country is the primary factor in determining the energy requirements that are necessary to meet these standards.

B. Why Use Solar Energy?

1. Virtually inexhaustible supply
2. Widely distributed
3. Minimum if not nil environmental stress
4. Saves fossil fuels for alternative uses
5. Contributes to improved balance of trade:
   a. No longer importing fossil fuels.
   b. Exporting solar devices.
   c. Competitive "fuel costs".

C. Broad Objectives of NSF Terrestrial Solar Energy Program

1. Define the energy demands and regions of the nation (world) in which solar energy offers a viable energy source option.
2. Decide the fractional level of total energy demand which solar energy can provide as a function of time and type (thermal, electrical, chemical, etc.)
3. To conduct research, systems studies, and proof-of-concept experiments in technical-scientific, socio-political, economic and environmental areas and to verify the feasibility of and to stimulate solar energy utilization.
4. The interest areas for Solar Energy Application in NSF are:
   a. The heating and cooling of buildings
   b. Electrical power generation by:
      I. Solar thermal energy conversion
      II. Photovoltaic conversion
      III. Ocean thermal conversion
      IV. Wind Conversion
   c. Fuel production and conversion
      I. Production and collection of organic materials
      II. Conversion to fuels (such as the electrolysis of water into hydrogen and oxygen)

D. Goals of Solar Energy Applications by 2020 (Include Supplying)

1. 35 percent of the total needs for the heating and cooling of buildings
2. 30 percent of nation's gas fuel

3. 10 percent of nation's liquid fuel
4. 20 percent of nation's electric energy

E. Solar Energy Budget Within NSF

	FY 1972 (Actual)	FY 1973 (Approx.)	FY 1974 (Requested)
Solar Energy for Buildings	0.10M	0.80M	3.00M
Solar Thermal Conversion	0.55	0.85	3.30
Photovoltaic Conversion	0.33	0.45	1.40
Conversion of Organic Materials	0.20	0.70	2.00
Photosynthetic Production	0.15	0.30	0.70
Other Solar Energy Technologies	0.14	0.40	1.20
Assessment and Program Assistance	0.19	0.30	0.60
	$1.66M	$3.80M	$12.20M

II. CONSIDERATIONS IN DEFINING THE ROLE OF SOLAR ENERGY SYSTEMS

A. Model of Solar Energy Conversion System

1. Must relate to existing systems for particular region.
2. Demand projections are soft in that one must take a more realistic approach to the forms of energy that will be demanded in future years.
3. Insolation which is the amount of flux of solar energy falling per unit area of ground must be more accurately determined on a regional basis.
4. Multi-purpose and hybrid systems should be considered.

B. Objectives and Scope of Studies

1. Formulate a methodology to evaluate alternative solar energy conversion missions/systems.
2. Assess the potential role of mission of solar energy conversion systems and identify those missions of greatest potential.
   a. Types of energy
      I. electric service only
      II. combined electrical and thermal energy services
   b. Geographic region
   c. Time period (1980 to 2000 is considered to be realistic)
3. Provide a basis for selection of preferred mission(s) for solar thermal conversion systems
   a. Large central station generating facility
   b. Municipal power plant
   c. Community power plant (substation)
   d. Power unit for individual building
4. Establish technical and economic bounds for system subsystem. and component design and performance requirements which are to be associated with the preferred mission(s).

III. STATUS SUMMARY OF SOLAR HEATING AND COOLING OF BUILDINGS

A. Why Solar Heating and Cooling of Buildings?

1. U.S. energy usage in residential and commercial buildings significant fraction of total energy consumption.
   a. Space heating 18%
   b. Hot water heating 4%
   c. Air conditioning 3%
2. Technically feasible now.
3. Economic analyses indicate solar energy competitive with conventional energy sources in certain regions of the country.

B. Heating and Cooling of Buildings Should Consider the Following:

1. Solar water heaters
2. Solar space heating
3. Solar air conditioning
4. Combined heating and cooling system
5. Combined electrical and thermal service

C. Present Status of Heating and Cooling Systems

1. Solar hot water heaters - extensive use in Florida (20's and 30's), Japan, Australia and Israel.
   a. Japanese solar heater is similar to Farber's flat plate unit.
   b. Uses plastic covers which do not last (Japan).
   c. Market peaked in mid-60s (Japan).
2. Solar heating system - limited to a few single family residences and test structures.
3. Cooling System Options
   a. Nocturnal cooling - circulating water
   b. Absorption cooling system - LiBr-H_2O, NH_3-H_2O, LiBr-Methyl alcohol
   c. Rankine Cycle - compressor refrigeration using refrigerants such as Freon - heat pump
   d. Humidity control - desicant material - solar regeneration

D. Key Technical Issues - Summary

- Accuracy of heating and cooling load estimates for specific installations may vary 30 to 50 percent depend on materials, location, design, etc.

- Development of techniques for accurate demand projections are required.

- Accurate insolation data and projections (direct/diffuse, cloud cover, etc.) are needed.

- Single unit systems or "community" level systems must be considered.

- Fraction of energy supplied by "auxiliary" (fuel oil, gas, electric) system vs. energy storage capacity must be determined.

- Determine building types most benefiting from solar systems and type of solar system (by region of country) most suited for the building.

- Integrate subsystems into combined systems.

E. Key Social and Economic Issues - Summary.

- Residential housing is extremely fragmented market in that there are many small builders.

- Key concern by builders/bankers is installed cost not life cycle cost.

- The public must be convinced that solar energy can be used for heating and cooling and that solar energy devices can compete economically with other energy sources.

- Functional vs. aesthetic design practices of architects must be considered.

- Safety and environmental considerations must be addressed.

ERISTAR REVIEWED

Andrew C. Ruppel
Assistant Professor of Commerce
University of Virginia
Charlottesville, Va.

Dr. Ruppel divided his talk into three interrelated parts: (1) A review of the summer 1972, ERISTAR (acronym for Earth Resources Information Storage Transformation Analysis and Retrieval) program during which Dr. Ruppel was a faculty participant and a project leader; (2) Personal reflections of his 1972 NASA/ASEE/AUBURN University Design Program experience; and (3) A discussion of man's limitations as they relate to the systems approach.

Dr. Ruppel's comments on item 3 included man's selective perception, tunnel vision, limited short term capacity and bounded rationality, and how these bounds on man's ability in the areas of decision making and problem solving argue affirmatively for using groups in the systems approach. Various tools and techniques are available for enhancing group creativity and interaction.

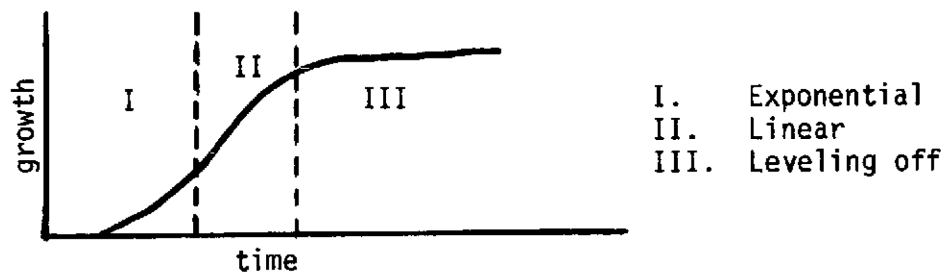
BIOCONVERSION USING SOLAR ENERGY

Bessel Kok
Research Scientist
Martin Marietta Company
Baltimore, Md.

I. INTRODUCTORY REMARKS

Dr. Kok, who was a member of the Bioconversion Committee of the NSF/NASA Solar Energy Panel, stated that there are inconsistencies in the panel report because the report was prepared too quickly. He suggested that the numbers in the report, especially those relating to biological systems, are very subjective.

He emphasized that biological studies indicate that an exponential growth model is not realistic (e.g., the Petri Dish Experiment). A more realistic model is as indicated by the curve below:



He stated that man tries to get energy from smaller and smaller packages (e.g., nuclear).

II. PHOTOSYNTHESIS

Dr. Kok reviewed in some detail the mechanisms involved in the process of photosynthesis. The internal mechanism is understood but apparently not well enough so that it can be controlled or modified by man.

A good reference on basic processes related to photosynthesis was written by Albert L. Lehninger and entitled "How Cells Transform Energy" (Scientific American, September 1961).

III. BIOCONVERSION TECHNIQUES

Complex plants lose about 50 percent or more of energy intake to respiration; on harvesting about 90 percent is discarded leaving only 10 percent as food (e.g., corn kernals). Overall, agriculture gives an energy conversion efficiency of 0.1 to 0.3. The low CO_2 content (0.03) of the atmosphere is a major contributing factor to this low efficiency.

Dr. Kok emphasized that we have to learn how to operate as a closed system; i.e., eliminate exponential or continous growth. He also emphasized the low percentage (0.5 percent) of energy needs which can be obtained by burning wastes.

He then outlined the following schemes which all begin with bioconversion:

A. Burning of the products of photosynthesis (fresh organic material

1. Tree plantation - he thinks the numbers for this scheme are too optimistic

2. Marsh vegetation - may be better than trees, algae
3. Water hyacinth - he thinks this is a "hare brained" scheme

B. Burning of Organic Wastes ("via the cow")

1. Agricultural wastes
2. Domestic wastes

C. Fermentation Producing a Mixture of Carbon Dioxide and Methane Gas

1. Advantage - can be done as "wet" process and methane is not soluble
2. Disadvantage - slow process, especially if one desires a high degree of digestion; e.g., to digest half of the material may take a week, whereas to digest 80 percent of it may take six months

D. Advanced Concept Biophotolysis of Water to Produce Hydrogen Gas

This process is theoretically possible, but has not yet been accomplished in fact. It requires an interruption of the normal process of photosynthesis. Dr. Kok discussed the details of the mechanism so far as it is known. He suggested that steady research support for about 20 years would be required to "get something that bubbles hydrogen" from this process. A crash research program is not the way to get something done on this problem. "Guys who make solar collectors should worry now about fly specks, whereas hydrogen production from algae we don't know how to do, so we don't need to worry now about dust on the cover plate of the algae."

Dr. Kok pointed out that it is very difficult to put a hard number on any of the above schemes. He also stated that he felt the literature list on bioconversion appearing in the NSF/NASA panel report is incomplete and superficial.

SOLAR SATELLITE POWER STATIONS

William C. Brown
Consulting Scientist
Raytheon Corporation
Waltham, Mass.

Mr. Brown envisages the solar satellite power station (SSPS) as contributing to the solution of our current and long-range energy problems. We will eventually need a new form of generating power for base load, not just for peaking purposes.

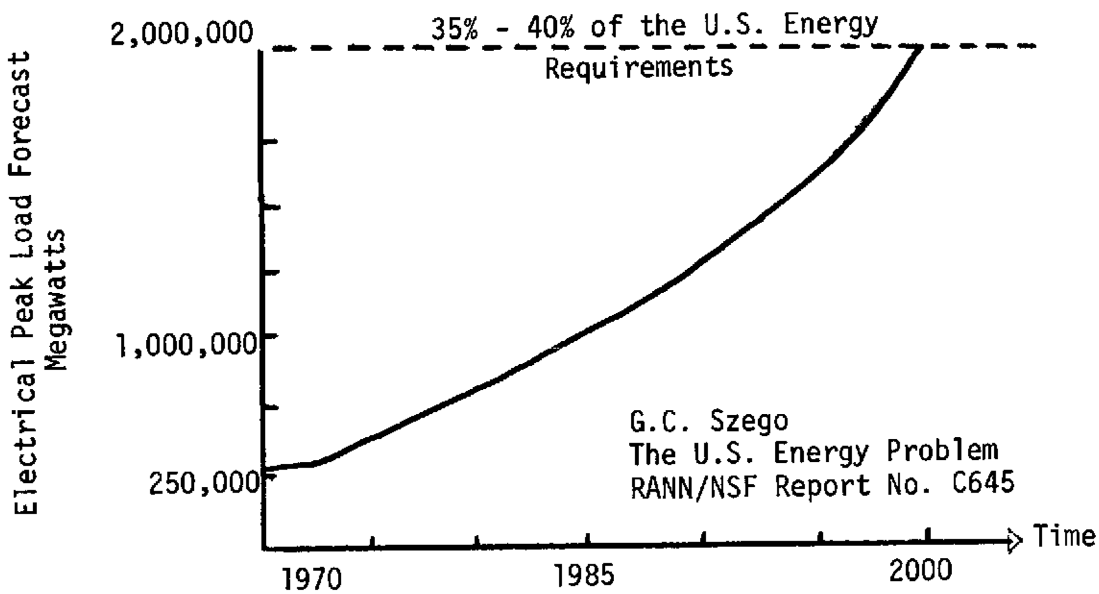
One of the major reasons for studying the SSPS is that the solar energy received on earth is quite dilute and is not always dependable. In 1958, Dr. Peter Glaser proposed in "Science" that we place our solar converters in space so that we can avoid the poor duty cycle of the solar insolation that is received on Earth.

The SSPS has been studied in detail by a four-company team (A.D. Little, Raytheon, Grumman, and Textron) resulting in an 800-page report. The team spent over $500,000 in obtaining their results which indicate:

1. No technological breakthroughs are required
2. The economics require:
    a. Production breakthrough (low cost solar cells are needed)
    b. Low cost shuttle

He also mentioned that an MIT graduate course made a systems approach study of the Satellite Solar Power Station this past year.

Mr. Brown then presented the following graph of future U.S. electrical energy needs. He noted that the usage of electrical energy doubles every ten years while the total usage of power doubles every 20 years. Part of the justification of this prediction is that the growth rate has been exponential for the last 100 years. He feels that we need an option for the breeder reactor supplying energy in the 1990 time frame. Mr. Brown thinks that in the near time frame it is correct to look at solar power for the home (heating, cooling, electricity).



The SSPS collects the solar energy with solar cells and converts the energy to micro-waves which are transmitted to a receiver on earth. The photovoltaic cell is a relatively new device which allows one to eliminate conventional conversion techniques and convert solar energy directly to electrical power. The photovoltaic cell presently is 10 to 15 percent efficient with a maximum theoretical efficiency obtainable of 22 percent.

The following table indicated the potential of a geosynchronous satellite relative to an earth collection system.

Availability Factor	Average on Earth	In Synchronous Orbit	Average Ratio
Solar Radiant Energy Density	0.11 watts/cm^2	0.14 watts/cm^2	4/5
% Clear Skies	50	100	1/2
Cosine of Angle of Incidence	0.5	1.0	1/2
Useful Duration	8 hrs.	24 hrs.	1/3
Product			1/15

Therefore, 15 times the number of solar cells are required for an earth-based system compared to the SSPS for the same power output.

The solar cell output can be enhanced by focusing; however, the cell must be cooled since efficiency goes down with temperature. The cell output can be improved at most by a factor of 2 to 1.

The SSPS will utilize three new techniques:

1. Space capability
2. Solar cells
3. A microwave transmission system

The concept of the station includes a 5 to 10 megawatt station with a 1 kilometer diameter transmitting station and a 7 kilometer collecting antenna. The effect of microwaves on the biological processes and radio frequency interference is not well established.

The microwave-to-D.C. energy conversion can be accomplished at between 80 percent to 90 percent efficiency. The structural aspects of the system have been studied by NASA-Lewis and approved. The solar cell array is always oriented to face the sun. The eclipse of the sun will cause some engineering problems; however, the reduction of solar flux will be only 0.8 percent.

The SSPS will weigh 5 lb/kW produced. Most of this weight is in the solar cell array (81 percent) and 18 percent is in the microwave antenna for a total weight of 25 million pounds. The antenna will be mechanically pointed to within 1 arc-minute toward the receiver using an electrical phase front control. If the control fails, the microwave beam would be greatly spread out.

A major restriction at this time is the cost of solar cells. Tyco Corp. has hopes of growing silicon ribbons and projects the cost of the cells to be $350/kW (present cost is $175/watt). Mr. Brown feels knowledge and experience will reduce these costs. The expected lifetime of the solar cell is 30 years with perhaps a 20 percent degradation in a lifetime. The output of the SSPS for less than one year will pay for the entire system.

On the earth the microwaves will be collected by what is termed a Rectenna. The total number of elements required for the Rectenna would be 10 billion so that 300/units/sec must be produced to manufacture the elements in one year. The Rectenna would be set at 45° if situated at Boston.

The microwaves will be transmitted using a cross-field conversion device. In both its oscillatory form (magnetron) and the amplifier form (amplitron) it has exhibited overall efficiencies of between 85 percent and 90 percent.

Mr. Brown estimated the total cost of a one gigawatt SSPS at 20 billion dollars. He commented that one shuttle payload per year would be required to furnish propulsion fuel for the SSPS. He also mentioned that the thrusters on the system would have to be well distributed, but implied this has not been studied in detail yet. The SSPS would require 500 shuttle trips plus additional trips involving ion propulsion units to be placed in geosynchronous orbit.

ARCHITECTURAL CONSIDERATIONS IN SOLAR HOUSES

Jeffrey Cook
Professor of Architecture
Arizona State University
Tempe, Arizona

Dr. Cook divided his speech into two general topics: (1) Orientation and (2) Concept of heating and cooling in building.

I ORIENTATION

Orientation consists of the relationship of any object, such as a building, to its cardinal points. The orientation of buildings is a common denominator in most ancient cultures, as buildings were normally designed so that they faced the east and the rising sun. In American culture, the orientation of buildings is not so important. However, it is believed in the United States that the southern orientation is more advantageous. In Great Britain, on the other hand, all schools by law must have an east-west orientation.

In designing buildings, one must consider several factors. Among these are the weather and all types of life. The United States, for example, is approximately half-way between the equator and the Artic Circle. Thus, the sun rises from the due east only two days in a year. The remainder of the year, the sun rises either north of east or south of east. A similar situation exists with the height of the sun--it is variable, not static.

Almost no one in the United States is currently designing homes which consider the sun and its effects. Olgyay and Olgyay, however, have published a few books which do consider weather conditions (temperature, relative humidity, etc.) for all areas of the United States and which can be of great benefit in building planning.

II. CONCEPT OF HEATING AND COOLING IN BUILDING

Here, the overall goal is to take advantage of the heat absorptivity of building materials. One of the very best building materials in terms of the absorptivity and storage of energy is earth, since a great deal of energy is necessary to raise or lower its temperature. In a word, earth acts as a thermal barrier. Likewise, earth has beneficial environmental characteristics as it returns to its natural environment through decomposition when it is not used and when the user does not furnish proper maintenance.

The use of earth as a building material was traditional in most ancient cultures. An example in North America is the adobe building structures which can be found throughout the southwestern part of the United States and in much of Central America.

During the 1950s, Solari developed the underground, domed house. Usually, the glass dome was placed over the living room area. Originally, the dome was movable so that the dweller could choose the amount of sun or shade that he desired. Today, the glass dome is normally in a fixed place.

Steve Baer, an Alburquerque designer, is currently working with "Zomeworks", which is the latest edition in the domed-house concept.

Harold Hay, on the other hand, has developed "Skytherm". In brief, "Skytherm" consists of a water bed roof which handles both heating and cooling of a building and is the most complete solar heating and cooling of a building and is the most complete solar heating and cooling system in the southwestern portion of the U.S. "Skytherm" utilizes night radiation. In effect, the system consists of a water pond on the building's roof which is laid on a metal deck. A movable system of insulation over the water pond completes the system. During the summer, the insulation panels are closed (pulled over the water pond) during the day and opened at night. During the winter, the process is reversed. During spring and fall, the process is variable, depending on specific climatic conditions.

The major advantages of "Skytherm" is that it does not require any heavy machinery. It can be operated by hand or by a light electrical motor. The major disadvantage of "Skytherm" is that it is currently designed only for a hot, dry climate. Clear skies both day and night are a necessity for its successful operation.

Finally, Hay has also done work with water walls. These can be integrated with the water bed roof for a complete system.

ELECTRICAL ENERGY AS A NATIONAL RESOURCE

William B. Harrison
Vice President for Research
Southern Services, Inc.
Birmingham, Alabama

General Comments

Southern Services, Inc. provides services to investor owned electric utilities in the states of Alabama, Georgia, Mississippi, Florida, and works on specific problems concerned with electric energy conversion.

Dr. Harrison presented an overview of his talk by referring to the "Flow of Energy" illustration contained in the September, 1971 Scientific American issue on solar energy (pages 138, 139). His main point was that compared to other machines electric power generation has a rather good thermal to electric efficiency of 33 percent. He also indicated the main source of the electric companies' energy is coal and this most likely will increase as a percentage in the future.

When discussing the sources (past and future) of energy for the electric companies, the following observations were made:

1. Dr. Harrison definitely feels that there is an energy crisis.
2. Natural gas is "running out" and will, if it has not already, become an acute problem.
3. Petroleum supply is poor. We currently import 28 percent with a projected 50 percent in the near future and we should not become that dependent on foreign suppliers.
4. Hydro power will decrease in percentage.
5. Over one-half of our energy is wasted (see ref. 1, p. 138).

In answer to questions by the group he stated that:

1. Electric utilities are now starting to do their own research instead of relying wholly on the research efforts of equipment suppliers.
2. They now only "advertise" to encourage the use of off-peak capacity.
3. An "inverse rate scale" is undesirable because the people or organizations who are the big users would simply pass along the higher rates to the consumer. They also are the job suppliers and with a repressive rate structure would probably try to locate elsewhere.

Points Made and Discussed

- "Per Capita Consumption of Electricity" (ref. 2). He indicated an exponential growth in energy use over the last 40 years and projected this growth to continue.

- "Total Electrical Energy Requirements" (ref. 2). The exponential growth of total electrical energy into the future assumes an additional 70 million people in the U.S. by the year 2000.

He further stated that no one in the power companies takes a central station, solar energy, electric generating plan seriously. Expanding on the coal situation, he indicated that the utilities are placing a high priority on methods of improving the efficiency of burning of coal.

- "Electric Generation by Source, kWh" (ref. 3). There will be increased reliance by the utilities on coal and nuclear. He then discussed the state of the art on coal-fired generation plants. The main problems the utilities face are the stringent environmental controls on emissions, as well as heat disposal problems.

- "Steam-electric Power Generation" (See Fig. 5, ref. 3). The efficiency of a plant is dependent on the temperature of water at the condenser.

  $$\text{Efficiency} = 1 - \frac{T_2}{T_1}$$, where T_1 is the temperature in the boiler and T_2 is the temperature at the condenser. This indicates that large quantities of low-grade (temperature) water is the result of an efficient plant. The alternatives being considered and used for disposal of this "waste" heat are:

  1. Deposited into fresh water streams
  2. Deposited into coastal waters
  3. Deposited into ponds and lakes
  4. Cooling towers - wet and dry processes

- "Illustrations of Cooling Towers (Wet Method)" (shown as Fig. 2.3 ref. 4). There are some problems with cooling towers in addition to their very high costs. They are:

  1. A potential fogging problem
  2. A potential icing problem
  3. A consumptive loss of water to streams below the plant site. This could be a real problem during low flow periods.
  4. The dry process is not technically or economically feasible at this time on the size scale required

- Potential Uses of Waste Heat

  1. Green House Heat
  2. Warm water fisheries (now being done on a small scale)
  3. District heating - i.e., airport runways, farmland
  4. Warm water irrigation
  5. In the desalinization process.

- Harrison stated that the utilities have been looking for sometime for ways of using their waste heat but that with few exceptions no economically viable schemes have been proposed.

The talk then switched to air pollution requirements and the effect they have had on the utility business.

- "EPA Air Quality/Emission Standards" (Table 1, page 8, ref. 3). Harrison commented on the unscientific manner in which the standards were put together and the resulting high cost of compliance by the utilities. He made the point that once investments have been made to satisfy these standards, that they are irreversible or sunk costs even if the standards should be loosened based upon further study. He also thought that standards should not be placed on emissions at the stack but that air quality at the human or ground level should be controlled.

Dr. Harrison's final slide was entitled "A Compliance Plan Decision Tree".

Constraints: Environmental Law
Fuel Availability
Technology
Economic Impact
Time

- Fossil Fuels
  - Gas
  - Oil
  - Coal
    - Low Sulphur
    - High Sulphur
      - Fuel Processing
        - Gasification
          - High BTU
          - Low BTU
      - Flue Gas Processing
        - Lime/Limestone Scrubbing
        - Catalytic Oxidation
        - Magnesium Oxide Scrubbing
        - Caustic Soda Regeneration
        - Molten Carbonate
        - Sodium Sulfate/Elemental Sulphur
        - Double Alkali Scrubbing
        - Dry Absorption

The function of this tree was to illustrate the procedures the electric utilities are pursuing to improve the burning characteristics of coal so that high sulphur coals can be used and still permit the generating plants to meet air quality standards.

In conclusion Dr. Harrison stated that the electric utilities will vigorously pursue research in the areas of:

Nuclear Power (the breeder)
Coal Utilization (gasification, liquefaction)
Others - including solar, tidal geothermal, winds, etc.

This research will be sponsored by the newly formed Electric Power Research Institute (EPRI).

Ref. 1 - Scientific American-September 1971.

Ref. 2 - Felix-Electrical World-7/6/60.

Ref. 3 - "Power Generation and the Environment", W. B. Harrison, August 1972.

Ref. 4 - Statement to the Florida Department of Pollution Control, November 23, 1971, Orlando, Florida by W. B. Harrison.

MSFC SPINOFF TECHNOLOGY APPLICABLE TO RESIDENTIAL HEATING AND COOLING WITH SOLAR ENERGY

Robert L. Middleton
Chief, Environmental Control Section
Propulsion and Thermodynamics Division
MSFC, Alabama

Mr. Middleton discussed possible NASA funding of a proposal of a demonstration project on the utilization of solar radiation for residential heating and cooling. The discussion emphasized the need for NASA's efforts in space to be directed toward benefiting man on earth. The multiple facilities of MSFC provide a great deal of technological support for attacking a problem of the scope of that of the implementation of solar energy.

At a meeting in late 1969, Dr. Wernher von Braun presented the idea of developing a Solar Absorption Cycle Heat Pump for a space vehicle. Lockheed Corp. was awarded a $150,000 contract for the initial space vehicle study and system test. A later $40,000 feasibility study grew into the Marshall Proposal for a Solar Powered Absorption Heat Pump. Spin-offs of subsequent vehicle environmental control studies were:

- Thermally powered refrigeration for ECS applications
- Thermally selective spacecraft coating
- Thermal energy storage for orbital transient dampening
- Solar and Thermal analysis techniques
- Fluid systems analysis techniques

The present MSFC idea will utilize two surplus house trailers to demonstrate the concept of the proposed Tedlar covered flat plate solar collector roof panels for a domestic/industrial heating/cooling system.

A system performance based on a 1600 ft^2 house in Nashville, Tennessee and U.S. Weather Bureau data was summarized as shown in the accompanying table.

	Solar System	All Electric & Heat Pump
Heating Capacity	116,000 BTU/hr.	38,000 BTU/hr. 78,000 (electric)
Cooling Capacity	36,000 BTU/hr. (3 tons)	36,000 BTU/hr. (3 tons)
Water Heating	4,000 BTU/hr.	4,000 BTU/hr. (1,200 watts)
Collector Area Required	1,300 ft^2	-
Thermal Storage Required	1.0×10^6 BTU	-
Peak Electric Winter	400 watts	28,900 watts
Summer	400 watts	6,900 watts

NOTE:
- The Solar Collector and thermal capacitor size is based on a cost optimization study for a full year period. Three cloudy days and nights are included as a design limit.
- For the worst design case a back-up with gas or electric is available to account for more severe conditions.

Mr. Middleton concluded his presentation with several good remarks.

- Feasibility of solar powered heat pump indicates that
  - modified commercial units are possible.
  - MSFC developed coating process permits cost reduction and performance improvement.
  - An interim and demonstration program (in-house and contract) be implemented to define better the system and reduce cost.
- Near term return for general public from NASA space technology is possible.
- Thermal storage is weak link in chain of the proposed use of solar energy. MSFC system is to use 5,000 gallons of water for heat storage.
- Next time phase of Marshall system will involve striving to reduce the cost.
- Optimistic prediction: proposed concept will demonstrate collection of 60 percent of solar radiation from the flat plates at a cost of $1 per square foot.

THE FEDERAL GOVERNMENT, THE ENGINEER, AND THE ENERGY CRISIS

William P. Miller
Technical Representative
American Society of Mechanical Engineers
Washington, D.C.

Mr. Miller is the Washington representative for the ASME and it is anticipated that other technical societies will soon have counterparts. A technical society representative scans technical legislation, provides technical assistance to legislators and finds technical consultants for members of both the executive and legislative branches. The latter need is evolving into the selection of congressional Fellows, who will advise congressmen on technical matters and who will have a tenure of one year. Eventually eleven fellows will be selected.

The energy crisis as described in the Congressional Quarterly is an economic crisis consisting of:

- Cleanup costs to meet ecological demands;
- Undesirability of imports;
- Canadian or Alaskan route for the Alaskan or North Slope pipeline;
- Off-shore oil supplies must be tapped;
- Nuclear power plants are blocked by lawsuits, and construction costs are mounting;
- Heat pollution must be diverted into useful efforts such as improving production in fish farms.

Import oil, off-shore oil, and land oil are ordered most expensive to least expensive to process for the USA market.

The McCormack bill directs NSF to study advantages of a national electric grid. A national grid could reduce requirements for the generation of peaking power.

The Japanese electrical rate policy is regressive to conserve use of energy:

500 kWh at 10¢ per kWh
700 kWh at 20¢ per kWh on total
900 kWh at 40¢ per kWh on total

Dr. Thomason is responsible for present NSF interest in solar energy. Dr. Thomason is presently designing solar energy utilization for an Ohio industrial plant.

Dave Freeman of the Ford Foundation is writing a book on the energy crisis and will investigate the social, political, international, defense, and environmental aspects of the energy problem. The scope of the text seems large to present a practical solution to the energy crisis.

Miller's reactions to solar energy utilization are that it can be used for:

- Heating purposes
- Hydrogen generation
- Electric power generation, which is less efficient, largely due to high transmission costs.

Miller suggests that Congress be informed of solar energy studies.

THE BASIC PROBLEM: No overall energy management exists in this country. In fact, there is not even a national energy policy to guide the thinking of planners.

The Office of Technology Assessment (OTA) is a congressional body. Congressman Daderio will be OTA's first leader. Miller deems OTA unsound because it is a political court judging science.

Credibility of engineering and scientific societies is high within legislative branch. All such societies will or should unite for action on technical matters in government policy.

UAH ENVIRONMENTAL STUDIES

Ken Johnson
Associate Director, and
Dave Christiansen
Research Associate
Center for Environmental Studies
University of Alabama at Huntsville
Huntsville, Alabama

Ken Johnson:

The Alabama Legislature has provided funds to establish an Environmental Research Center whose basic task will be applied, basic, and service-style research. In the first two years the research has been of a "very" applied and service-type nature; such as, sample analysis, handling some of the State of Alabama's environmental research programs and preparing "Environmental Impact" statements.

One major interest is to use NSF support to develop and/or apply hardware that will employ solar energy for the heating and cooling of buildings; however, NSF is not convinced that the time is "ripe" to attempt the total environmental control of a building by the use of solar energy.

It is believed that the Environmental Research Center is expected to be a catalyst to start "environmental" motion in Alabama. At present, a mobile air analysis unit is operated by the Center.

Dave Christiansen:

Christiansen was introduced by Dr. Johnson as the "UAH Solar Energy Expert". He presented a series of slides, some by NASA artists and others, showing their thoughts on utilizing solar energy to heat and cool buildings. Other thoughts he presented and elaborated on were along the following lines:

- It is hoped that the building that will house the UAH "Center for Environmental Studies" will be the model for future solar energy buildings.

- A NASA plan envisions hot water storage at 400° F to 500° F that would provide steam to drive a turbine 24 hours/day, as well as an electrolysis unit to generate hydrogen. The plan envisions flat plate collectors on one building and focusing (concentrating) collectors on another, plus additional collectors in the parking lots.

- A study to evaluate the various kinds and arrangements of solar collectors is one of the first projects envisioned.

- Another plan is to develop a demonstration cottage on the campus with perhaps a 200 ft^2 collector and reflector similar to one developed by Thomason (see the June 1973, POPULAR MECHANICS).

- A company in Athens, Alabama, has developed a modular construction cottage in which the modules are 4' by 8' panels with 2 1/2 inch polyurethane insulation is equivalent to 6 inches of fiberglass insulation; hence, a cottage with floors, walls and ceiling of this material with thermally tight windows and doors would not require much refrigeration in summer nor heating in winter. It is estimated that a 12 foot by 24 foot cottage of this type would need about 1/2 ton of refrigeration for adequate cooling during a typical summer day in North Alabama.

SOLAR ENERGY AT HONEYWELL

Roger Schmidt
Business Manager - Solar Energy
Honeywell, Inc.
Minneapolis, Minnesota

Mr. Schmidt's talk outlined Honeywell's involvement in solar energy research:

A. The programs and their funding
B. Thoughts on the current energy situation
C. Honeywell's SUN-STEAM-ELECTRICITY scheme
D. Work related to heating and cooling of buildings

A. Honeywell Programs/Funding

1. Honeywell and the University of Minnesota have almost $1 million from NSF to study central electric power generation from "sunlight".
2. Much in-house work (some proprietary) on house heating and air conditioning.
3. Two very recent procurement contracts with NASA-Lewis:
   a. Study solar central electric power system with Black & Beech, 10 months, $350K (1/2 from Honeywell).
   b. Small (6 months $50K) program of flat-plate-collector analysis, design, fabrication, and testing.

B. The Current Energy Situation

1. Causes of Crisis
   a. Balance-of-Payments -- net zero now with $5 billion in and $5 billion out, but a projected $25 billion deficit in 1985 (see Chase Manhattan Bank "Annual Energy Report").,
   b. Strategic Issues -- "We depend upon Arab oil, but the sheiks can turn off the faucet at any time.",
   c. Resource conservation and pollution (relatively unimportant).,
2. "Economic Uncertainty"
   a. Mismanagement/Inefficiency -- need resource conservation and better buffering, etc.,
   b. Crisis was foreseen (Malthus) -- Schmidt believes a "technological fix" will always be found (e.g., fusion power).,
   c. Plenty of energy available -- but economics is all-important.
3. Different Resources
   a. Enough COAL for 500 years at current usage, but getting more expensive (present cost is $300 /kW electric installed).,
   b. Plenty of power in BREEDER REACTOR, but problems with feasibility, pollution, economics ($1500/kW electric installed versus $400-$500/kW electric installed for regular FISSION REACTOR).,
   c. "The SOLAR POWER hitting the Earth is equivalent to burning all the World's fossil fuel reserves in one week!" The world energy needs of 2000 A.D. can be met with 20 percent conversion efficiency of "sunlight" hitting an area of 250 miles square.
4. USA Energy Consumption by Fuel, 1850 A.D. - 2000 A.D.
   See the 1972 Battelle Report, "Energy Uncertainty".
5. Testimony to House Subcommittee on Energy

Schmidt was "optimistic" about solar energy, but congressmen were almost "fanatic". McCormack said that there should be only technical and not financial limitations on solar energy research (spend at least $1 billion). Congress is really worried about balance-of-trade and strategic problems. Schmidt thought solar-central-power-plant possible by 1990, but congressmen want it by 1982!

C. Honeywell's "Electricity from the Sun" Scheme

1. General Introduction
   a. Honeywell selected "thermal collection of sunlight via concentrators" -- similar to Meinels' "Solar Farm".
   b. Schmidt discussed other techniques, especially solar cells. he doubts Glaser's optimism concerning costs, and notes many technical problems with SSPS. Texas instruments hints at solar cell costs of $100/kW, but Schmidt is skeptical, since the collection area cannot be decreased.
   c. The overall Honeywell system is a modularized (mass-producible) parabolic-cylindrical-mirror concentrator which focuses sunlight onto a heat pipe and produces aobut 48 kWh/day from a trough 40 feet long.

d. Background comments:

i) Beat the high costs of labor by modularizing and simplifying the fabrication.

ii) Honeywell has 15 years' experience with solar selective coatings.

iii) Showed a Smithsonian photo (from Dr. Jordan's University of Minnesota report) of the 1913 Egyptian plant on the Nile that generated steam from "sunlight" and ran a 50 hp motor.

iv) Schmidt reviewed Honeywell's recent work for the Air Force on providing 6 kW of solar thermal power to a Voldemeier cryogenic cooler for space optics (research continues at the Flight Dynamics Lab at Wright-Patterson); contract was for $120k.

2. "Solar Field" Concept

Schmidt described the NSF contract work in great detail (see the Honeywell/Univ. of Minn. report NSF/RANN/SE/GI-34871/PR/72/4, entitled "Research Applied to Solar-Thermal Power System", 1972).

a. The essence of the idea is to concentrate "sunlight" onto a selective-absorber-coated heat pipe, using a trough mirror (parabolic cylinder) oriented E-W and steerable to track the sun N-S. The heat pipe transports the thermal energy to a steam chamber, where the steam is used to generate electricity via a turbine. A POCE (proof-of-concept-experiment) module that is 15 feet in length is to be built and tested in about a year.

b. Schmidt expounded upon the following details:

- Isothermal heat pipe tilted to become a "thermal diode",
- Temperature range 300°C to 500°C,
- A characterization of heat pipe fluids (H_2O, H_g, K, N_a),
- Each trough module will cost about $1500,
- Selective absorber coating,
- Could eventually coat 40-foot heat pipe of stainless steel for $25-50,
- High-temperature diffusion-of-coating elements, measured via Auger-electron--spectroscopy and sputtering of surface,
- Thermal shocking and cycling of the coating -- will last 20 years at 400°C, but faults at 600°C,
- Honeywell "working with" Meinels on coatings,
- Comparison of heat pipe with "flowing fluid" system: -Latter has great thermal losses, costs more (Aerospace analysis and report), and requires vast pumping power (especially for gases) - "Honeywell and McDonald-Douglas analyzed Meinels' system, and found more power used in pumping the liquid metal than generated by power plant!"; difficult to optimize pipe when fluid is pumped,

- Comparison of 3 collector systems: Honeywell's heat pipe with pyrex vacuum tube, and Aerospace rotating reflector in vacuum tube ... all come out about the same in heat loss; Honeywell wants the vacuum tube to last 20 years at 10^{-4} atmosphere without pumping,
- Thermal storage with eutectics (or "accumulator") in different temperature ranges,
- Insulation and heat losses,
- Testing of reflectors (aluminized materials) in Florida, Arizona, and Minnesota (rain is bad!),
- Monte Carlo analysis of collector performance with actual insolation data and computer stimulation,
- Honeywell economic analysis (corroborates Aerospace's more complete analysis) -- "solar field" would produce power at about twice current costs for fossil/nuclear plants,
- POCE on "solar field" in a year, discussed,
- Commented upon wind loads.

D. Honeywell's Work on Heating and Cooling of Buildings

1. House Heating and Air Conditioning -- Schmidt "thinks this is the way to go, especially air conditioning, to prevent electric brown-outs." Honeywell is funding its own in-house research in field (and appears to be interested in the NSF RFP on heating and cooling of buildings).
2. Systems -- Use "concentrators" or "flat-plate collectors?" Combined flat-plate collector plus Rankine (Freon fluid) air conditioning system ... mentioned Arkla absorption air conditioning with water at 210° F. Stratified thermal storage for rapid response. Use fossil fuel auxiliary power at the home.
3. Flat Plate Collector -- Standard design. Complete computer simulation of a unit, with emphasis on transient response (10 minute time constant). Using Bob Middleton's coatings, since Honeywell coating is too expensive for flat-plate collector. They like glass, not Tedlar. "Most important to keep costs down!"
4. Other Examples -- French convective heating and cooling of houses. Legal and zoning problems ("air rights"?) to prevent shadowing of a solar house. Showed Japanese solar hot-water heater ($100), and commented on negative effect of rising Japanese affluence. The solar house of Mrs. Wilson in West Virginia where the sun satisfies 80 percent of the energy needs (designed by Burt-Hill Assoc. Architects in Pennsylvania). Finally, noted that one Honeywell (10 ft x 40 ft) trough provides the equivalent of 5 tons of cooling.

CHARACTERISTICS OF SOLAR RADIATION

Glenn E. Daniels
Aerospace Engineer
Terrestrial Environment Branch
Aero-Astrodynamics Laboratory
MSFC

The speaker's background is in astronomy and has worked with solar insolation measurement for 30 years. Mr. Daniels brought out the following points:

1. Spectral distribution of sun's energy:

   a. Above the Atmosphere. The total irradiance (all wavelengths), is 0.353 watt/cm^2.

0.2 to 0.4 microns (μm) (ultraviolet)	7% of total
0.4 to 0.7 microns (visible)	45%
0.7 to 50 microns (infrared)	48%
over 50 microns	very little

   b. At Ground Level. The direct irradiance is 0.1111 watt/cm^2 on a clear day, with the sun at the zenith (air mass 1). Ozone absorbs all wavelengths below 0.29 μm. Other deep absorption occurs in particular wavelength regions, such as near 1.4 μm.

2. Instruments:

   a. The Eppley pyranometer (cost: $350) measures with many thermocouples in series the temperature difference between cocentric coplanar rings painted white and black, respectively. The manufacturer says the voltage output is proportional to the incident radiation to 1 percent precision over a range of 0.1 to 1.5 langley [One langley is one gm-cal cm^{-2}min^{-1} = 0.070 watt/cm^2]. This instrument, formerly called a "180° pyrheliometer", receives radiation from an entire hemisphere. It is ordinarily mounted in a horizontal plane looking at the entire sky, but may also be inverted to measure radiation from the hemisphere centered on the nadir. Used in any other orientation, it must be recalibrated due to changes in the pattern of convection currents inside the bulb, which change the output by up to about 5 percent.

   Also, calibration depends on the spectral distribution of the incident radiation because, although the emissivity of the black paint is approximately constant (about 0.9) for all wavelengths, that of the white paint is not: it goes from 0.6 or so at very short wavelengths down to 0.1 in the visible (which is why it appears white) and then up to 0.9 or even more, in the infra-red (which means if only infra-red is incident, as at night, the white ring may get warmer than the black).

Ordinarily, of course, the instrument is calibrated for the normal solar spectrum. If this is carefully done, the results are good to about ± 2 percent accuracy which puts them among the most precise of all standard meteorological data. The percent accuracy becomes poor at low radiation levels, of course.

b. The pyrheliometer (Eppley's costs $750) receives radiation from a cone of apex angle 5°43'. (The sensitive element is at the bottom of a tube whose length to diameter ratio is 10 to 1.) When pointed directly at the sun, it measures the "direct" radiation (including of course the circumsolar sky within its view).

The classic Angstrom pyrheliometer consists of two precision current-carrying resistors, one exposed to the sun and one shielded. A thermocouple is connected between them and balanced to zero volts. Accuracy is 0.1 percent, cost is $2500 from Eppley.

4. Solar Radiation Characteristics:

a. The intensity of sunlight on a surface normal to its rays increases very rapidly as the sun rises above the horizon, reaching 94 percent of its midday value within about one hour after sunrise. The energy incident on a fixed horizontal surface approximates a sine curve.

b. Measured radiant power incident on a pyranometer in Yuma, Arizona has been observed to increase from the clear sky value of 1.96 langley to as much as 2.25 langley due to reflection from clouds.

c. For some purposes, we would like to know how much of the horizontal pyranometer reading is unscattered radiation direct from the sun and how much is from the rest of the sky. The speaker has published an analysis of this with graphs and tables for two locations, one in Florida and one in California. For example, one graph shows that for sun elevation 75° and total horizontal radiation 1.50 langley, the diffuse component is 0.2 langley. He writes:

$I_{DN} = (I_{TH} - D)/\sin A$, where I_{DN} = direct normal, I_{TH} = total horizontal, D - diffuse, and A = altitude of the sun. Normally D is about 10% of I_{TH}.

In the U.S., hourly readings are taken of the "total horizontal" radiation (pyranometer) at 26 stations; and "direct normal" radiation (pyrheliometer) at 7.

5. The speaker has computed and published the altitude and azimuth of the sun for each hour of the 15th day of each month as seen from MSFC. These are straightforward analytical functions of the geographic latitude and the declination and hour angle of the sun.

   It is best to work with True Solar Time (TST) which corresponds directly to the hour angle (HA) of the sun: HA = TST - 12 because of the difficulty of correlating data which use local civil time. He has a conversion chart for MSFC.

6. He described the measurement of air temperature and dew point in a B-47 at Yuma. The inside temperature was as high as 250° F.

ERTS, EAO and SOLAR ENERGY

Herman Hamby
Staff Scientist
Environmental Applications Office
MSFC

Mr. Hamby stated the general objectives of the Environmental Applications Office (acronym EAO) and made the following points.

- There is a need to identify the potential users of the information gathered by his office

- The data available comes from thermal data from the ERTS-1 satellite

- There is cooperation with the Departments of Agriculture, Interior, Bureau of Fisheries, Forestry, Mineral Resources, Marine Resources, etc.

Regarding the area of solar energy the following comments were made:

- Lockheed and other manufacturers can move into the fabrication of cheap low-temperature hardware for solar energy utilization tomorrow if asked

- He expects the utilization of small solar powered units to come "on line" before breeder reactors...

- There are all kinds of data available on the utilization of energy by consumers - effect of insulation, effective housing design (refer to STARSITE) -

- Solar systems should be immune to daily perturbation and provide a constant rather than variable output.

General Comments:

- NASA keeps an umbrella on small businesses that use NASA created technology and develop it for the benefit of the country.
- Trust only the words of scientists publishing in the responsible journals.
- "altruism has its price"...

THE NATIONAL ENVIRONMENTAL POLICY ACT

Frank L. Parker
Professor of Environmental and
Water Resources Engineering
Vanderbilt University
Nashville, Tennessee

Dr. Parker discussed the National Environment Policy Act of 1969 (NEPA), preparation of environmental impact statements and the general need to be wary of incomplete impact studies.

I. NEPA

A. Dr. Parker stated that this is the "single most important environmental act in the USA".

B. Goals -- refer to Section 101 of the Act;

C. Section 102 -- very important, 102 (C) -- most troublesome to interpret (e.g. emphasis on "major", significantly", etc.);

D. Actual effort and operation (through May, 1972):

1. By number: approx. 2033 environmental statements were filed (resulting in 200 suits),
2. By type: highways -1436,
   watershed - 400
   airports - 220
   navigation - 190
   electric power - 150
   other - 537

II. REQUIREMENTS FOR PREPARING EIS (environmental impact statements)

A. Procedure:

1. Follow CEQ guidelines (Council on Environmental Quality),
2. Send for review to governmental agencies.
3. Write the final EIS.

B. Cost/Benefit Analysis

1. In addition to economic efficiency, need to evaluate proposed activity in terms of benefits ("for whom") and cost ("who will pay for it").
2. Since many of these objectives/standards and measures cannot be determined in the framework of our competitive market structure, standards were devised:
   a. National economic efficiency, (e.g. questions asked pertain to levels of employment, allocation, and relocation of resources, etc.),
   b. Regional economic efficiency (e.g. "primary" vs. "secondary" effects, relocation, etc.),
   c. Environmental quality,
   d. Social factors.

NOTE: Since points "c" and "d" are mainly qualitative, value judgements prevail; e.g., if alternative X were not implemented, what would be some of the probable outcomes (qualitatively/ quantitatively where possible).

III. STRENGTHS AND WEAKNESSES OF THE ACT:

A. Strengths of NEPA:

1. National policies in line with public concern;
2. Stipulates how these statements are to be prepared;
3. Brings government activities to public scrutiny;
4. Forces narrowly conceived agencies to look at interdisciplinary relationships;
5. Makes citizens' suits enforceable in courts.

B. Weaknesses of NEPA:

1. Three areas or sections (recycling, strip mining, and energy) are excluded from it;
2. Two members of the Council on Environmental Quality resigned.
3. Applicants for a license must file statements, but do not have to follow advice of the Government and recommendations of the Council (there is no enforcer of NEPA);
4. Federal agencies which have special expertise or jurisdiction must respond when asked to review these environmental impact statements, but the extent of their analysis may be very superficial;
5. Expense involved in preparation of EIS is high;

IV. OTHER SUGGESTIONS AND COMMENTS:

A. Dr. Parker referred to several studies by economists (at Vanderbilt, Colorado, and other universities) where they show that after a certain point (as per U.S. model of energy consumption) the demand for energy becomes quite price elastic. He sees that a point of maximum per capita consumption of energy is forseeable in the near future (given presently-known uses);

B. Comments on environmental impact of solar energy:

1. Benefits: energy provided with little ecological impact.
2. Costs minimized: good land utilization, little or no mining, few accidents, release of present energy sources for other uses, etc.

NOTE: There is a need to show full cost cycle of solar and other sources.

SOLAR POWER FOR TERRESTRIAL USE - 100 kW PILOT POWER PLANT

Whit Brantley
Project Engineer
PD-DO
MSFC

Mr. Whit Brantley has been involved with the "high" temperature approach to terrestrial use of solar power. The accompanying Table I represents the ground rules, assumptions, and constraints that were considered by the design team of Mr. Brantley's. The modular systems for the power plant were overdesigned by thirty percent (30%) to account for storage, cloud cover, etc.

A major consideration that was to have been undertaken by the design team before a work halt was the evaluation of four candidate reflector systems. The four reflector systems to be considered were (a) segmented parabolic, (b) multiple parabolic, (c) parabolic cylinder, and (d) circular cylinder. The segmented parabolic reflector system was the only system considered in detail. The case study approach to the segmented parabolic reflector involved:

- Solar Vectors versus Day/Season
- Mirror Pointing Vectors versus Day/Season
- Mirror Shadows versus Day/Season
- kWh/Mirror/Location/Year
- Reflector Field Layout (optimized with tower height)
- Flat Plate Reflector
- Effective Concentration Ratio versus Time of Day
- Spherical Plate Reflector
- Plate Reflector Diameter/Shape Trade-off
- Reflector Pointing/Control Design
- Absorber Design Trades/Module/Shape/Size/Character
- Reflector Design/Layout
- Tower/Absorber Design/Layout
- Materials/Piece/Part Selections
- Trade Parameter Calculations

TABLE I

100 kW PILOT POWER PLANT

Ground Rules	Assumptions	Constraints
Location Accessible for R&D	Redstone Arsenal Location	
20 year Lifetime	Maintenance	
Continous Operation	a) Thermal Storage b) Recharge Time c) Supplement Heat d) (Fossil Fuel) for Certain Periods	42 hrs. min. 7 days
Excess Power Utility	Long-term Energy Storage	
Waste Heat Utility	Baseline Rejection Temperature Summer Direct Heat Utility	120° F max. 300° F max.
Conventional Conversion System	100 kWe Continous 150 kWe Peak	Turbine minimum Development effort, 30, 220/440 VAC, 60 Hz
Highest Performance/$	Practical System Design Options versus Cost Analysis	minimum cost < $10M
Modular Approach	Test Single Modules or Scale Models	
Early Demonstration	Operational Date	June 1976
Minimum Geographic Constraints	Use Flat Land	Minimum Site Preparation and Water Requirement
Winter Soltice (Worse Case Design Point)	Solar Design Day by AERO	

A projection of recurring cost allocations and goals for the pilot plant is displayed in Table II.

TABLE II

Power Plant Elements	Allocations Total ($/100kW)	$/kW	Goal $/kW
Solar Reflectors (185 at 2k each)	370k	3700	370
Tower	10k	100	25
Absorber	78k	780	78
Energy Storage (16 hours)	100k	1000	100
Steam Rankine Converstion	150k	1500	150
Heat Transfer Loops	10k	100	10
Supplemental Heat Furnace	5k	50	50
Land	o.4k	4	4
TOTAL	$723.4k	$7234/kW	$787/kW

To illustrate the high cost of the proposed system, a comparison was made to the initial cost ($750,000,000) of the Browns Ferry Nuclear Plant:

$$\left[\frac{\$750M}{3.5GWe} = \$214/kWe\right] + \text{Operations} + \text{Fuel Cost}$$

where the total plant output is scheduled to be about 3.5 gigawatt electric.

A major problem of the pilot plant was pointed out to be the boiling subsystem of the absorber.

Mr. Brantley outlined the following conclusions and recommendations of the study.

Conclusions

1. Overall efficiency expected for the 100kWe Pilot Plant would be about 15 percent.

2. Economic feasibility is dependent on detailed selection of materials and fabrication methods.

3. Several functional module design/fabrication/test iterations to reduce costs, while retaining adequate performance, are required before pilot plant construction.

4. MSFC is one of several groups investigating solar central power stations.

Recommendations

1. Individual parabolic dish concept be defined for comparison to the concept defined here.

2. Study results should be presented to OA and/or NSF.

3. Continued low-key efforts at MSFC until NASA is assigned responsibility for design/construction of such a system.

SOLAR POWER ELECTRIC GENERATION

Mr. Bill K. Davis
Senior Systems Engineer
Systems Products
MSFC

Mr. Davis indicated that, within his own areas of investigation on the utilization of solar energy, he has been able to come to some general conclusions. He suggested that an overall total systems efficiency of about 16 percent could be expected for conversion temperatures between 400° F and 1300° F. This overall efficiency figure is the net amount of power available for use, averaged through the subsystem stages of collection, converstion and storage.

Mr. Davis has confirmed a number of other observations in his laboratory work, and illustrated some of them through the following points:

A. Collector/Absorber (C/A) Subsystems

Collector-The mechanism for gathering and/or focusing of available sunlight. The collector configurations may be designed for several levels of focusing or concentration: high (over 1000), medium (50-1000), low (1-50).

Absorber-The elements of sunlight conversion to heat the output is affected by selected surfaces (selective and non-selective) and the properties of the cover over the absorber. The absorber is the key to the subsystem since heat not absorbed cannot be used; if possible, leftover heat should be salvaged. The most immediate need is the development of design data to increase absorption efficiencies, not more system feasibility studies.

B. A Concept for a C/A Segment

Recognizing the need to increase collector/absorber efficiency, Mr. Davis introduced a C/A concept that promises to save 10 percent of the incoming radiation that would otherwise be lost by reflection. He presented a concept drawing that illustrated the combined effects of using both parabolic and conical shapes (nicknamed "parabolone") to provide very good heat transfer control.

C. Description of MSFC Anodized Interference Coating

A thermochemically applied titanium dioxide coating of 1000 Å thickness of titanium that is "solar cell blue" (known as NASA blue), and operating almost in the ultra-violet range.

D. Description of Honeywell Multi-Layer Interference Coating

Three film layers (black nickel, polished nickel, bright aluminum oxide) on an aluminum substrate that is good to 400° F; this coating development is the same that is being used on the collector (flat) plate in the MSFC Spinoff Technology project conducted by R. L. Middleton (refer to R. L. Middleton's presentation on June 18, 1973).

F. Heat Transport Subsystem

1. Heat must be collected over large areas; thus, there are undesirable collector surface losses.
2. Mechanical work required in that the working fluid must be pumped.
3. Configurations possible for transporting heat.
   a. Single-phase fluid - problems such as super-heated steam not introduced here.
   b. Phase - change fluid - need to circulate ten percent more fluid per hour.
   c. Heat pipe - will cut down on mechanical work required in the system.
4. 450° F is the upper limit of some excellent insulators (e.g. 3" foam); thus, it is important to the heat transport subsystem that collector temperature, transfer work, and heat losses are all minimized (in these respects perhaps the heat pipe functions best?).

G. Heat Storage Subsystem

1. Requirements
   a. Store the required amount of heat
   b. Operate at the right temperature
   c. Transfer heat efficiently
   d. Have a long operating life.
2. Methods
   a. Phase-change materials present a number of problem considerations (viz. metals, non-metals, fused salts, wax); of the metals, tin is the most likely candidate; non-metals and fused salts have practical disadvantages; wax doesn't change state at the same temperature each time.
   b. Thermo-chemical reactions offer possibilities for the future but are not being investigated now; example reaction:

$$\text{steam with butane/or propane} \rightarrow H_2 + CH_3$$

(Which theoretically delivers back 100 percent of what was put in).

3. Devices

Concept drawing of phase-change material heat storage device was shown.

H. Thermodynamic/Electric Conversion Subsystem

1. Available example is the Sunstrant Mark III, 100kWe system.
2. Cost without controls, $50,000 --- with controls, $80,000. However, this machine has a reasonable operating efficiency for a 100kW system. Boiler heat source may be sun or any other. Combined with the MSFC collector/absorber and transport-storage component makes it an effective demonstration system.

In summary, Mr. Davis advised us that each condition has its own best application -- there are no blanket solutions for all situations ... "make specific decisions about specific requirements".

NATIONAL ENERGY NEEDS AND POLICIES

John J. McKetta
Professor of Chemical Engineering and
Chairman of the President's Energy Committee
University of Texas
Austin, Texas

Introduction

Dr. McKetta's introductory remark, which he thought adequately described the energy situation in this country, was "This country is in a hell of a mess." He believes that there should be an honest effort towards alleviating the energy crisis. The individual can't do much; however, group action could conceivably make "dents" by coming forward with solutions that will help solve the problems associated with the energy crisis. However, Dr. McKetta believes that there is no truly absolute solution to the energy problem; i.e., the problem simply cannot be solved permanently. The delineation of a prize fight was eloquently used by Dr. McKetta to describe the situation of the energy crisis in the United States. He said that we are now on the canvas at the count of nine. Our demand for energy is much greater than the domestic supply that consequently this country is heavily dependent on imported energy sources.

Dr. McKetta suggested that there could be some alleviation of our energy problem via the following considerations:

A. Buy all our needed materials from outside the country; however, there are two problems associated with this:

1. This might be impossible because other countries depend on the same countries for oil and hence are our competitors for a product that is in limited supply.
2. The U.S.A. is bankrupt; the dollar has been devalued and our trade balance is unfavorable for us.

B. Decrease the demand. This can be accomplished by:

1. Enforced rationing
2. Voluntarily (McKetta expressed pessimism in this route being truly effective. He related a Texas example in which the people were asked to decrease their consumption by 30 percent; however, only a 12 percent reduction was realized.

C. Do something about the supply curve

Dr. McKetta suggested that environmentalists might be a little too one-sided in their thinking; e.g., the Senate voted 84 to 0 in favor of the Muskie resolution to require U.S. water to have zero additional pollution. This is quite unrealistic since to remove 4,000 tons of impurities from a water system ultimately results in adding 20,000 tons of waste somewhere.

<u>Our Energy Situation</u>

Studies show that some of the world's leading nations' e.g., the United States, consume considerably more energy than they produce. An exception to this appears to be the communist countries which are apparently self-sufficient.

The countries that consume more energy than they produce must depend on the Middle East or Africa for oil since these countries produce more oil than they consume. However, because of our political involvement with Israel, the big oil producing countries intensely dislike us. Consequently, the Arab countries might desire to use their oil as a political tool.

Due to Europe's tremendous consumption of oil as compared to their production, they are also looking to the Middle East for help. The recently discovered North Sea oil fields will supply only a small fraction of Europe's petroleum and gas needs. Furthermore, Mexico is beginning to be a serious contender for Venezuelan and Peruvian oil which we now import.

Dr. McKetta expressed his pessimism concerning the belief that the U.S. would receive a continous oil supply from Canada.

The oil production for a 112-year period for the United States greatly exceeds the oil reserves. However, the Middle East has a vast reserve, so vast that there is no indication of a drop in the initial pressure in the oil fields since their discovery (over 400 billion barrels of oil is estimated to be available in the Middle Eastern oil reserves).

Since about 1957 the United States has used more energy than it could possibly produce. The schism between energy production and energy consumption has widened tremendously during the last twelve or thirteen years. Last year, the United States used 16.2 million barrels of oil per day (44 percent of the total energy used). This amounts to more than 70 quadrillion (70×10^{15}) Btu of energy (enough to evaporate 72 Lake Michigans).

The United States imported 14.9 percent of its energy in 1972 and as of April, 1973, the total energy imported was approximately 16 percent.

The amount of natural gas produced in the United States is less than the amount used. Approximately 9.8 percent of the gas consumed by the U.S. was imported from Canada. The unfortunate statistic is that new gas discoveries since 1966 are drastically inadequate when compared to the amount used. McKetta said that the amount found will never compensate for the amount used, unless the consumption drastically decreases, which is itself highly improbable.

The U.S. has been in difficulty with oil since 1958 in that the amount produced is less than the amount consumed. From a national security standpoint, the balance of payment has been "bad" since 1971 during which there was a two-billion dollar deficit (The country had not had a deficit since 1899.). In 1972 the deficit increased to 6.2 billion dollars, and in 1973 it is conceivable that our deficit will be ten billion dollars. If our dependency on imported oil continues, by 1985, we will need a 38 foot diameter pipeline to bring in the needed oil. Obviously, this is impractical and the situation as it stands cannot continue. Another problem which raises its ugly head is that if we buy oil, we simply get oil; however, if we drill for our own oil, we generally get oil and gas.

By 1985 the Arabs will probably receive 50 to 80 billion dollars a year from their oil exports. This has resulted in a major cause of our present-day pecuniary problems. Therefore, McKetta suggests that the Arabs might recycle some of our money back into the U.S. economy via investments, thereby alleviating some of our balance of payment deficits.

Through every dark cloud there passes a silver lining. Fortunately our coal reserves are tremendous and even now the production of coal is greater than its consumption. The production of coal is so great that we are able to export it; however, the exportation of coal only brings in a revenue of 329 million dollars as opposed to the 5 billion dollars paid for imported oil. The United States promised Japan and Germany a 40-year supply of metallurigical coal; however, the embarrassing thing is that both countries have an economy which has excelled that of the United States.

The U.S. has 250 trillion cu. ft. of gas in its reserve which is enough gas to last for the next ten years at the present rate of consumption. This gas reserve is kept in the ground because our long-term contracts for gas are more than our reserves. There are two problems associated with our natural gas reserves:

1. 70 percent of the 250 trillion cu. ft. of gas in in Texas and Louisiana, and still those states are going nuclear.
2. Both Texas and Louisiana import coal from Wyoming at about twice the price for which they could obtain the gas because the the gas supply can't be guaranteed.

Dr. McKetta strongly suggests going from gas to coal for generating electricity, especially since we have a relatively small amount of gas in our reserves. The cost of converting a 400 MW plant from gas to crushed, pulverized coal would be approximately 1 percent of its initial cost.

The United States has approximately 36 billion barrels of oil in its reserves which is enough for six years at the present rate of consumption. Apparently the country has a tremendous oil shortage since conservative projections only add another 18 years to our oil supply (70 percent of this oil potential is probably located in the outer continental shelf and offshore drilling is discouraged in a number of places; e.g., the Governor of New Jersey vehemently expressed a negative attitude towards New Jersey offshore drilling).

Geophysicists can detect faults (a likely place for hydrocarbon accumulation) with seismographic equipment. The chances of finding oil by this technique is one out of 40. There exist many places; e.g., stratigraphic traps, where "hard-to'find" oil might be found but the chances of finding oil in stratigraphic traps is one out of 80.

Since 1956 there has been a steady decline in oil wells drilled (the price of a well depends on several factors such as location, depth, etc.). In 1956, 59 thousand wells were drilled and in 1972 about one half as many wells were drilled.

Dr. McKetta continued to reiterate his feelings concerning our readily available supply of coal. He suggests that the country ought to triple its utilization of coal as an energy source. Dr. McKetta also suggested that solar energy and geothermal energy will be of appreciable significance in helping to alleviate the "energy crisis".

Dr. McKetta's National Energy Policy Committee wrote a 44-page report which recommended that a national energy policy be established. Their report was referred to the Secretary of the Interior.

National Energy Policy Committee Report
PB201-071
National Technical Information Service
Springfield, Virginia

Some Suggestions

Dr. McKetta concluded his talk by making the following suggestions:

a) Since 25 percent of the total energy is used at home (70 percent of which is used for heating and air conditioning), all those living above the Mason-Dixon Line should not use air conditioning.

b) "cities ought to break their windows" and let the cool air in at night and find some way to replace the windows during the day.

c) Dr. McKetta strongly advocates the immediate use of coal to help alleviate the energy problem.

d) The EPA should relax its environmental restrictions made on coal.

SOLAR ENERGY AT GENERAL ELECTRIC

William R. Terrill
Manager, Advanced Power Systems Operation
Energy Systems Program
General Electric Company
Valley Forge, Pennsylvania

Messrs. Bill Terrill, Arnold Cohen, and Don Kirkpatrick of the Energy Systems Programs (ESP) group at General Electric discussed their efforts in the solar energy field. After outlining the GE corporate line structure, Mr. Terrill indicated that the ESP activities were primarily centered around:

- Solar Energy Systems
- Topping Cycle Studies
- Clean Combustion
- Advanced Nuclear Power Systems
- Multi-hundred Watt RTG (Rankine Turbine Generator) Programs
- High-Temperature Materials Development

A proposal on solar energy has been submitted to NSF from a viable team consisting of the GE ESP group, the University of Pennsylvania, and the Ballinger Company. Among other things, the team members posess the following characteristics: corporate structure and manufacturing experience (GE), solar energy research experience (University of Pennsylvania), and building experience (Ballinger).

Mr. Terrill believed solar energy applications would be more successful in public buildings rather than private dwellings due to the greater funding potential, structural organization and systems demonstration possibilities. In addition, it was stated that solar energy would probably be used more in new starts rather than on a retrofit basis. A large market (hundreds of millions of dollars) was forecast using as a basis new starts only and a conservative collector cost of $2.00 per square foot.

The main interest at GE is to develop a market for commercial products which can be mass produced. In effect, large companies (such as GE) will commit large amounts of capital and manpower only to markets with a high profit potential. The end product should be competitive with current energy systems (air conditioners, furnaces, etc.). Some industrial inertia is present as a result of previous false starts caused by restricted market and technological analyses (e.g., heat pumps). Any proposed product must be thoroughly researched in regard to technological, economic and societal impacts.

Mr. Terrill concluded that the most probable impetus for solar energy applications would be through federal funding of research and federal encouragement of prototype systems demonstrations. Thus, after a profitable market is identified, a major corporation can enter the picture. The question of patent rights on hardware resulting from federally funded projects was raised. From the discussion that ensued, industry has some reservations on the patent right limitations in some contracts.

Mr. Cohen provided further illumination of the solar energy team effort of GE, the University of Pennsylvania and Ballinger. Mr. Cohen is the principal investigator in their proposal to NSF.

Mr. Kirkpatrick presented details on solar energy collection techniques and exhibited two sample collector models. Both models were of double-pane construction with one using common glass ($7.00/ft^2) and the other lexan ($5.00/ft.^{2}). In mass production, the lexan model approached $2.00/ft^2.

Maintenance problems, construction techniques, and light transmission characteristics of lexan were discussed. Surface wear could be overcome by adding a harder coating on the outside pane. It was anticipated that the collector panels also will serve as the roof structures. Lexan transmissibility decreases only 5% in ten years. A twenty-year life of the panels is planned.

MEETING THE ENERGY CRISIS

Kraft Ehricke
Chief Science Advisor on Space
Rockwell International
Downey, California

Dr. Ehricke discussed natural terrestrial energy flows with incident solar insolation being by far the largest. Only a minute fraction goes via photosynthesis into fossil fuel reserves, so these are for practical purposes not being renewed. Also the release of CO_2 into the atmosphere restricts their proper use.

Solar energy available, in billion kilowatt-hour per square kilometer per year: at a point on the earth's surface 0.6 to 2.2; in earth orbit (nearly constant sunshine) 11.8; on the moon (no atmosphere, but with day and night) 5.9.

Estimated exploitable fossil-fuel reserves in units of 10^{18} Btu and projected depletion date : coal 68--2470; peat 4.2; tar sand oil 1.7--2150; shale oil 2.5--3070.

Waste heat is not a limiting factor on energy generation; whether fossil, fission or fusion, for the planet as a whole. The 20 x 10^{12} kWh dumped into the environment in 1970 amounts to merely 0.05 kWh per square meter of the globe's surface per year. The amount in the year 2000 will be 2 to 4 times as great.

The thermal waste per unit area is of course higher if only land area is included. The figures are, in kilowatt hours per square meter per year:

Year:	1980	2000	2030
Western Europe	1.8	6.6	19
North America	0.5	1.74	4.05

But even these values are seen to be small compared to the solar input of about 1000 kilowatt hours per square meter per year.

We can locate on a world map the global heat sinks (arctic regions); areas of highest solar energy input (such as low latitude deserts) and regions of high energy use (generally in correlation with population density). This global view leads to Dr. Ehricke's Power Relay Satellite (PRS) concept, for getting energy whether direct solar, hydro, nuclear (in heat sink area) or other, from places where it is produced to where it is needed. The power would be converted to 10 cm microwaves and beamed at the satellite, a large passive reflector in geosynchronous orbit with precise altitude control so that the beam is reflected to a fixed receiving antenna on the ground relatively near where the energy is needed. To transmit 9×10^9 watts the reflector could be 2000 feet square, made of 1 mm diameter wire with 4 mm mesh size. Total weight which must be carried into orbit by shuttle would be 26 to 28 tons. [About 20 channels of this capacity would be needed to carry the electrical power consumed in the U.S. in 1970--0.2×10^{12} watt] the transmission efficiency will be about 68%. The losses are: DC to microwave 10%; transmission up 5%; loss on reflection 1%; transmission down 5%; microwave to DC 15%; total loss 32%. [This checks: each successive loss applies to a smaller power flow.]

THE ENERGY PROBLEM AS SEEN BY THE OFFICE OF THE PRESIDENT

William T. McCormick
Staff Assistant
The White House
Washington, D.C.

Dr. McCormick is a staff assistant in the Energy Policy Office of the White House and is responsible for R&D for energy technology. He views our current energy problem as serious with over 90 percent of the energy consumed by the U.S. being hydrocarbons, hydro contributes 4 - 5 percent and nuclear less than 1 percent. However, nuclear is starting to grow very quickly with 30 plants now in operation and some 150 under various stages of development.

Dr. McCormick feels that in this decade, well into the next decade, and perhaps even into the following decade, we will be largely dependent upon fossil fuels for our energy.

He gave the following review of the state of fossil fuels:

Natural Gas

U.S. consumption in 1973 is estimated to be 37 percent higher than in 1966. The ratio of reserves to production has been dropping from 16/1 in 1966 to an estimated 9/1 in 1973.

Part of the problem can be traced to the Interstate gas now regulated by the FPC at 20¢/1000 ft^3 has about 10^6 Btu; by comparison one barrel of oil has 6×10^6 Btu and sells for about $3.00. This means that the regulated price of gas in the interstate pipeline has been approximately 1/3 the price of domestic and import oil. We are selling our premium fuel at a price 1/3 that of other fuels.

While the price of gas has been held low, oil costs have doubled in the past four years. Dr. McCormick feels that FPC's rational was that they were protecting the consumer by keeping gas prices down.

Dr. McCormick pointed out that many suppliers are selling gas within their own state where the price may be twice the FPC regulated price. What is left goes to the pipeline.

Our gas reserves are dropping at such a rate that zero (0) reserves could occur within 10 to 15 years. Therefore, we must raise the price of gas. The President's energy message to Congress on April 18 suggested this.

Dr. McCormick made the point that most of the price paid by the consumer is transportation and a tripling of the price at the well will not change the price too much to the consumer.

The proposal to deregulate gas is for new gas only to stop windfall profits. Since only a fraction of the gas will be from new wells this would not change the price appreciably.

Coal

Coal represents 90 percent of the total fossil fuel resources of the U.S. and we have 1/2 of the world supply. However, production has dropped from 600,000,000 tons to 590,000,000 tons in the past few years. Of this 550,000,000 tons is steam coal.

McCormick feels there are three reasons for this decline in coal production:

1. The Mining Safety Health Act
2. Impending Strip Mining Legislation
3. Environmental Restrictions

The Clean Air Act has caused the coal industry difficulties in that many states have come up with both primary and secondary standard requirements at the same time. These requirements could displace from 150 to 200 million tons of coal, and this will be done during a period when there are no viable alternatives.

The proposed stripmining legislation would prohibit the stripmining on slopes greater than 15°. Most of the low sulfur coal in the East is on slopes greater than 15°.

Coal cost on a Btu basis is slightly less than oil.

Our coal status is summarized by stating that we have a lot of it but we cannot mine it or use it.

Research is underway to eliminate pollution from coal. Areas included are:

Liquefaction
Gasification
Scrubbing
Improved Combusters
Stack Gas

In the President's June 29 energy statement, he recommended a $10,000,000 R&D on energy in the next 5 years with an additional $100,000,000 for 1974. Coal will have to be our out for the immediate future.

By 1985, half of the oil used in this country will be imported. This causes several problems.

1. National Security
2. Economic (Balance of Payments) $6,000,000,000 deficit this year; projected $25,000,000,000 deficit by 1985.
3. Large amounts of money are going into the Sheiks' pockets which could be used in a manner detrimental to the U.S.

Until this year, the mandatory oil import program restricted the amount of oil imported in order to maintain domestic production. This was abolished on April 18th and replaced by a license fee system. The idea of this new system is to allow oil importation but not increase our dependence. The system is constructed in such a way as to stimulate the building of refineries in the U.S. Since its introduction, ten new refineries have been announced and no new refineries were built in the past 20 years.

The petroleum industry has been working very hard to make refineries non-polluting. The newer refineries are very good but the older ones are rather poor. It is Dr. McCormick's impression that cost is not the problem in rendering a refinery pollution free but rather it is caring at the onset of planning a new refinery.

On or since the first energy message on April 18, the government has acted on the following items: Natural Gas Supply Act, Deep Water Port Facilities Act, Electrical Facilities Siting Act, and numerous others.

Dr. McCormick pointed out that the Alaskan field would produce 2×10^6 Bbl/day but that the companies are not required to ship the oil to the 48 states. He feels that politics will dictate that the Alaskan oil will not be exported.

The point was raised that the President's energy message was only aimed at the man on the street. Dr. McCormick responded that this was not the case and pointed to the following government actions:

- Federal Government is reducing its energy usage by 7 percent.
- Federal Government has upped FHA standards.
- FAA has requested airlines to reduce speeds and conserve fuels.
- NBS has studied a home in an environmental chamber that is well instrumented. They found they can reduce energy consumption in the home by 40 percent using retrofit techniques and reduce it by 60 percent if the house is built from the ground up. These numbers are based on a modest first cost increase and no life cost increase.

Dr. McCormick stated that we did not know about the energy crisis 18 months ago. He said two years ago, it was hard to detect. The past few years there have been large changes in consumption trends. He feels the possibility of a fuel shortage this winter largely depends upon the weather.

The government's overall strategy on energy is to develop the capability for self sufficiency so that we can keep prices on fuel down.

Dr. McCormick feels that the energy crisis is not serious enough for drastic action, but we do need volunteer action by the public. He gave the Clean Air (auto) Act as an example where drastic action provided a solution for the pollution problem but cost us a great increase in energy usage. This is an example of how environmental and energy concerns have conflicted.

Dr. McCormick feels the energy projections will be proven wrong in the same population predictions of the past where shown to be wrong.

For research and development strategy, the government has taken action. The proposed R&D money for energy is $10,000,000,000 over the next five years. The strategy is:

Near Term: Develop technology to utilize coal

Mid Term: Online nuclear power development through the breeder reactor. Development of solar and geothermal energy.

Long Term: Development of solar electrical and nuclear fusion energy.

Last year we spent $643,000,000 on energy research, and in FY 74, we will increase this by $100,000,000. The proposed research effort will be three times the present rate in the next five years.

	Solar Research	Fusion Research
FY 73	$ 4,000,000	$60,000,000
FY 74	$12,000,000	$88,000,000

Dr. McCormick would expect the $12,000,000 research funding in solar in FY74 to double in FY75. He states that solar lags behind fusion primarily because no demonstration feasibility studies. He admits fusion has not been shown technically feasible but because of the great strides made in recent years by its great potential, it will be pushed.

By 1985 we will have demonstrated

coal gasification (6 pilot plants now)
coal liquefaction (several demonstrations now)

Current energy organization

Department of Interior
- Geothermal and Oil Shale
- Oil and Gas

AEC
- R&D for Nuclear Power
  - Materials
  - Breeder
  - Fusion
  - Uranium Enrichment

NSF (Solar primary responsibility)
- Geothermal
- Energy Systems Studies

EPA
Stack Gas Cleaning Research

The new organization, DNER, will be cabinet level and will centralize all energy activities.

THE MASSACHUSETTS AUDUBON SOCIETY OFFICE BUILDING

Jim MacKenzie
Scientific Staff
Massachusetts Audubon Society
Lincoln, Massachusetts

Dr. MacKenzie is Chairman of Concerned Scientists and the proposer of solar energy utilization in the new MAS office building. He served on the NSF/NASA solar energy panel. He made the following points:

- The small office building (about 8000 square feet) is in the planning stage and no construction has taken place. Mr. Jim Burke of A. D. Little, Inc. is engineer in charge of the project.

- Motivation for including solar energy in the building is to provide a major positive vehicle for solar energy utilization. Much is to be learned by doing!

- Fixed flat plate collectors and two-day thermal storage and much insulation are the basis for solar heating. Solar cooling is to be accomplished with an absorptive refrigeration machine backed up with a compression refrigerator. An available duck pond will not be used; rather, a small cooling tower will be built for heat rejection. Cold storage will be considered in a later study phase.

- A. D. Little, Inc. is conducting a solar technology assessment costing $30,000. Suggested ASHRAE type standards for solar heating and cooling will be proposed. Problems will be encountered with building codes but these have proven to be flexible in the past.

- Solar data collected after 1955 is of questionable value because of instrumentation errors. Comfort studies will be investigated. Lighting levels will be reduced to minimize heat generation.

- The MAS building will have an auditorium and high public exposure.

- Building costs are expected to be high and cost overruns are included in cost estimates. Financing is to be accomplished by public contributions although much support is expected from large banking institutions.

ENERGY CONSERVATION AND SOLAR ENERGY

Fred Dubin
President and Consulting Engineer
Dubin, Mindell, Bloome Associates
New York, New York

Mr. Dubin is a consulting mechanical engineer who has been interested in energy conservation in buildings for a number of years. He has been a practitioner of the "Systems Approach" but hasn't known what to call his approach until recently.

He began his discussion with some comments about operating or life cycle costs of mechanical equipment in buildings. He spoke of Manchester, New Hampshire GSA project Federal Office Building (F.O.B.) which is planned as a demonstration of energy conserving ideas in architecutral and engineering design.

At the outset of the design/planning feasibility analysis of the Manchester F.O.B., Dubin, Mindell Bloome, Associates, (DMBA) set for themselves the goal of 35 percent energy saving over the energy consumed an a "normal" building of this type. By computer analysis of heat flow and considering such variables as siting (site orientation), size, shape, materials, story heights, percentage of glass area, placement of glass, insulation thickness and location and shading factors among others, they were able to establish a basic value of 16×10^9 Btu/yr. building-energy-consumption for typical combinations of the above variables. By optimizing the realtionship of these factors, a basic value of 10×10^9 Btu/yr. was reached. One half of this saving was accomplished with no increase in first costs and one half of the saving with "favorable life cycle costing;" i.e., a payback expected within a reasonable lifetime at standard interest rates on first cost investment for additional equipment.

A recommendation was made for the continuation of studies of this nature by studying six basic building types (i.e., schools, residences, commercial public and industrial buildings--the largest energy consumers) under at least five different basic climatic conditions to establish parametric rules of thumb concerning energy conservation in the heating and cooling of buildings.

The Manchester project places priority on demonstration of energy conservation techniques over the demonstration of minimal environmental impact, whereas the Saginaw, Michigan Federal Office Building places emphasis on the demonstration of environmental enhancement over energy conservation and recycling will not be employed at the Manchester site because these techniques require the use of more energy.

DMBA anticipates the competitiveness of solar energy within a very few years based on projected costs, so they are recommending the incorporation of a solar heating and cooling system, with a close detailed look at collector design and cost. No engineering firm can now predict the performance of a solar collection system due to the paucity of weather data, microclimatic differences and the basic, unpredictable nature of the weather.

The question of zoning and land use planning in establishing "solarian rights" is also raised. What are the legal implications of building next to a solar collector and cutting off its access to sunlight?

There are also problems in the application of data from research done to solar houses to the conditions peculiar to high rise office buildings where the thermal mass, diurnal temperature fluctuations and nature of heating and cooling loads may be entirely different.

The possibility of heat-driven air conditioning (using perhaps the absorption principle) must be the subject of further investigation to establish a reasonable degree of confidence in its potential for success. The firm ARKLA and more recently Carrier have available units which will work at generator temperatures of 190° F. DMBA is currently considering three locations for consideration of solar driven heating and possible cooling systems: Manchester, N. H., Brattleboro, Vt. and Millbrook, N. Y. with Philadelphia as a future possibility. The systems currently being contemplated have 36 hours storage and a supplementary system (auxiliary system) which is capable of delivering full capacity. These systems will supply approximately 75 percent of the building's heating needs. The computer program used for determining heating cooling loads are those available from the National Bureau of Standards and A.S.H.R.A.E. (American Society of Heating, Refrigeration, and Air Conditioning Engineers).

Basically the Manchester F.O.B. is planned to be seven stories high, square in cross section and zoned to allow "experiments" in heating, cooling, ventilation and lighting. There are three different mechanical systems (out of 15 considered) present in the building, and one floor has an exterior wall containing 30 percent glass (with nighttime thermal barriers) to permit natural lighting around the perimeter of the floor. The south wall is the least energy consuming wall and the north wall is window free to diminish heat losses. Plans include using two 10,000 gallon tanks for hot water storage and one 10,000 gallon tank for chilled water storage. An energy generator will serve as a power source to run some fans with a heat recovery system driving an absorption air conditioner.

The 50,000 sq. ft. solar demonstration project sponsored by NASA-Lewis to be built this fall at Langley Field (George Heery of Heery and Heery, Atlanta, Georgia, Architect) was mentioned. Corning Glass and Grumman Aerospace are working on a vacum tube collector for this application. In preliminary tests these tubes have been reported to have reached internal temperatures of 400° F at zero below rate.

The DMBA project near Brattleboro, Vt. is planned as a ten-unit condominium, with each apartment at 1,000 sq. ft. The solar collector will cover the parking spaces and will have an area of 4,000 square feet. Normally insulation and constructed apartments of this nature generally have a heat loss of 12,000 Btu per degree day but DMBA has designed these to lose 8,500 Btu per degree day. The hope is to construct the collector for $6/square foot, increasing the cost of construction for each apartment by $3,000. The developer anticipates financing this increased cost out of a portion of his profits.

At this point, the group adjourned and met individually with Mr. Dubin. He expressed guarded optimism about the future of solar heating and cooling of buildings and was generally skeptical of market analyses at this point in time. He pointed out that proper energy conserving design was of first order priority and solar utilization of second priority in any fuel saving program.

APPENDIX C SCENARIO DOCUMENTATION

Brookhaven (AET-8) Projections

In April of 1972, the Brookhaven National Laboratory published their often quoted projections of the consumption and supply of U.S. energy through the year 2020. The main elements of this projection are shown in Figure C-1.

This projection demonstrates the typical approach to "solving" the energy problem, i.e., project the demand and then expand the supply to meet it, regardless of the consequences. Following is a brief outline of some of the probable impacts, assuming these projections are true:

- Nuclear: An 800 fold increase in nuclear generating capacity by year 2020 means that an equivalent of 2700 one-gigawatt nuclear plants will have to be constructed within the next 47 years. (1200 plants by year 2000). This would require a major national committment, since most of the technological, fabrication, fueling, siting, financing and environmental problems of large scale nuclear generation are still unsolved. For this much nuclear power to be economically and environmentally feasible, it will be necessary that the breeder reactor be commercially available by 1990.

- Coal: Considerable R&D effort and capital investment in pollution abatement devices and in coal gasification and liquification processes will be required before a 6 fold increase in coal use would be environmentally tolerable. Practical and inexpensive land reclamation methods for strip mining will also have to be developed.

- Oil: A threefold increase in oil would require that a tremendous amount of oil (estimated at up to $80 billion/ year be imported by the year 2020. Imports would still be significant even if off-shore and Alaskan deposits are tapped and the technology and economics of obtaining oil from shale are made more viable.

- Gas: To use natural gas at a constant rate for the next 47 years would severely deplete the known U.S. reserves, unless a considerable amount of gas were imported.

U.S. Department of Interior (DOI)

The U.S. Department of Interior's latest (December 1972) projections of consumption (total gross energy inputs) and supply through the year 2000 are shown in Figure C-2 and Table C-1. A breakdown of consumption by major users is shown in Figure C-3 and Table C-2. A percentage breakdown by supply (source) and users (sectors) is shown respectively in Table C-3 and Table C-4.

The DOI projections are based on the following assumptions:

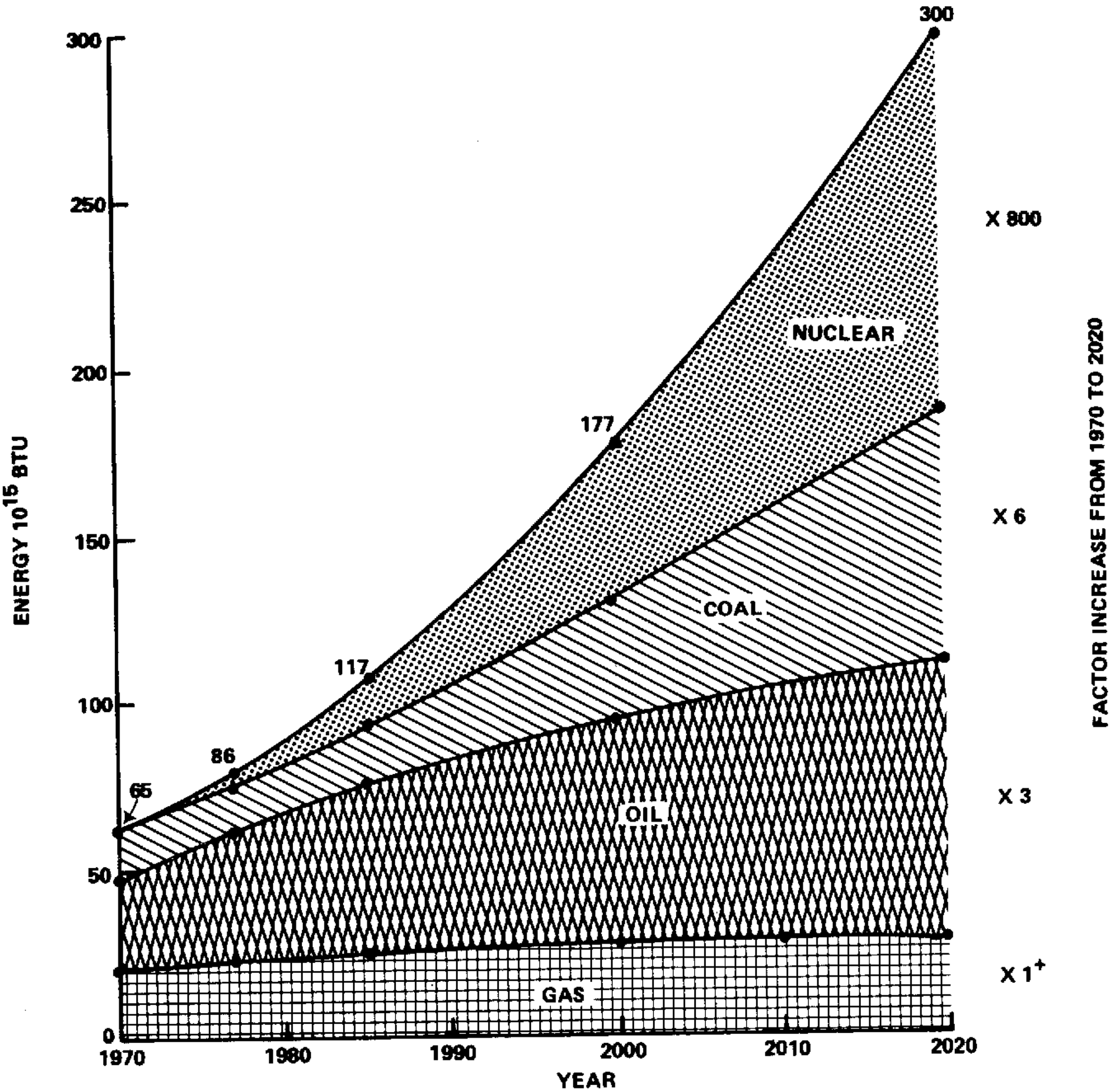


FIGURE C-1. PROJECTED U.S. ENERGY DEMAND BY SOURCE (BROOKHAVEN AET-8)

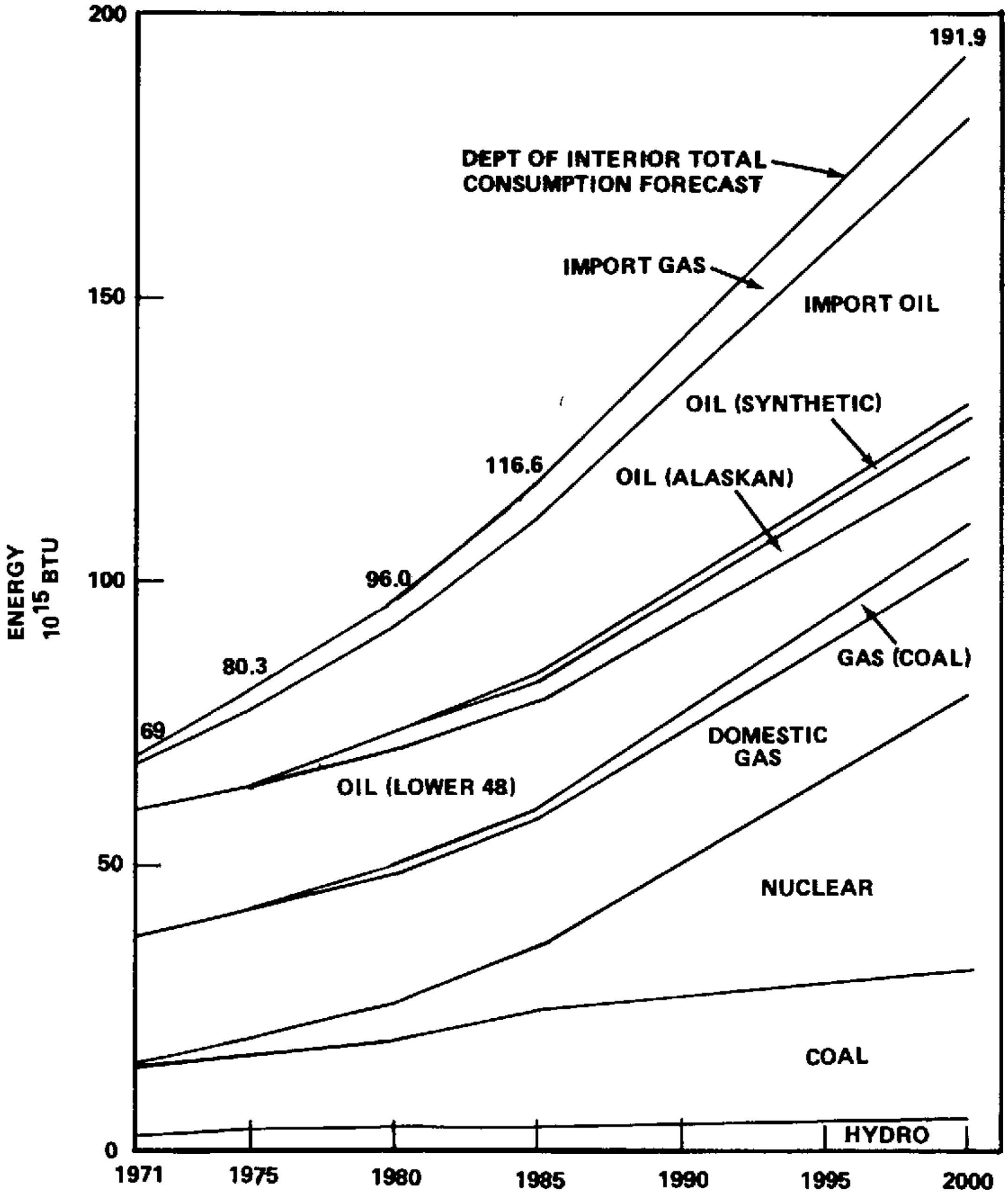


FIGURE C-2. DEPT. OF INTERIOR CONSUMPTION FORECAST BY SOURCE

Table C-1. PROJECTED ENERGY SOURCES [1, 2] (10^{15} Btu)

Energy Source	1971[3]	1975	1980	1985	2000
Domestic					
Coal	12.56	13.83	15.44	19.47	25.86
Oil (Lower 48)	22.57	22.13	20.72	18.55	12.09
Oil (Alaska)			3.05	4.05	7.12
Oil (Synthetic)				1.00	2.01
Gas (Natural)	21.81	22.64	22.96	22.51	22.85
Gas (Synth:Coal)			.70	2.00	5.50
Nuclear Power	.41	2.56	6.72	11.75	49.23
Hydropower	2.80	3.57	3.99	4.32	5.95
Subtotal	60.15	64.73	73.58	83.65	130.61
Imported					
Oil	7.92	12.96	18.42	27.10	50.16
Gas	.92	2.58	4.02	5.88	11.13
Subtotal	8.84	15.54	22.44	32.98	61.29
Total	68.99	80.27	96.02	116.63	191.90

1. U. S. Dept. of the Interior, "U. S. Energy Through the Year 2000", S.N. 2400-00775, Dec. 1972.

2. Sources allocated to meet demand projected in report[1] and include fuel and non-fuel uses of fossil sources.

3. Actual.

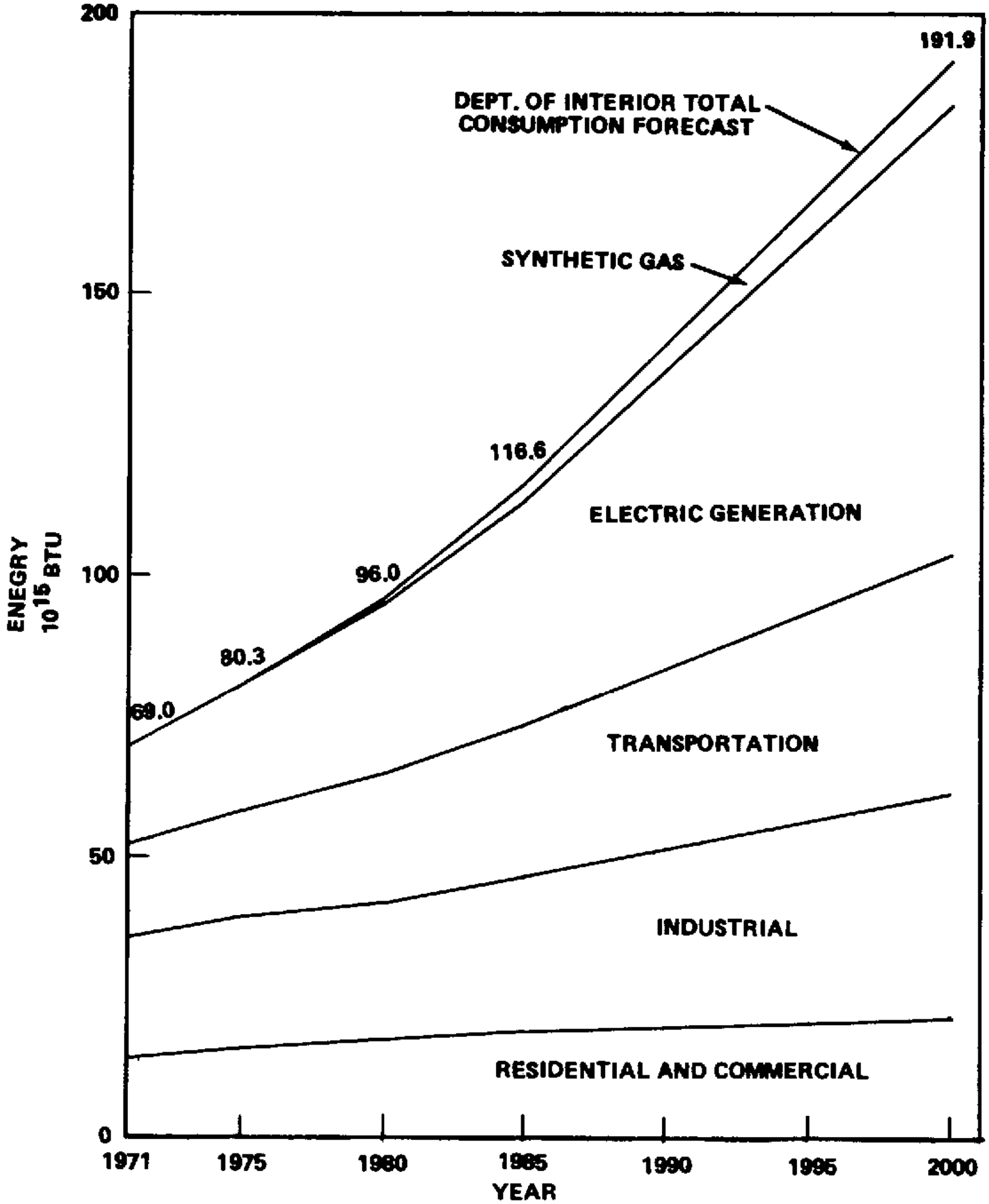


FIGURE C-3. DEPT. OF INTERIOR CONSUMPTION FORECAST BY SECTOR

Table C-2. PROJECTED U.S. ENERGY CONSUMPTION BY SECTOR[1, 2] (10^{15} Btu)

Sector	1971[3]	1975	1980	1985	2000
Residential & Commercial	14.28	15.94	17.50	18.96	21.92
Industrial	20.29	22.85	24.84	27.52	39.30
Transportation	16.97	19.07	22.84	27.09	42.61
Electric Generation	17.44	22.41	29.97	40.39	80.38
Synthetic Gas	-	-	.87	2.67	7.69
Total	68.99	80.27	96.02	116.63	191.90

1. U. S. Dept. of the Interior, "U. S. Energy Through the Year 2000", S.N. 2400-00775, Dec. 1972.

2. Sectors allocated to meet demand projected in report[1] and include fuel and non-fuel uses of fossil sources.

3. Actual.

Table C-3. PERCENT OF TOTAL CONSUMPTION BY SOURCE [1]

Source	1971[2]	1975	1980	1985	2000
Domestic					
Coal	18.2	17.2	16.1	16.7	13.5
Oil (Lower 48)	32.7	27.6	21.6	15.9	6.3
Oil (Alaskan)	-	-	3.2	3.5	3.7
Oil (Synthetic)	-	-	-	0.9	1.0
Gas (Natural)	31.6	28.3	23.8	19.3	11.9
Gas (Synthetic: Coal)	-	-	0.7	1.7	2.9
Nuclear Power	0.6	3.2	7.0	10.1	25.6
Hydropower	4.1	4.4	4.2	3.7	3.1
Subtotal	87.2	80.7	76.6	71.8	68.0
Imported					
Oil	11.5	16.1	19.2	23.2	26.2
Gas	1.3	3.2	4.2	5.0	5.8
Subtotal	12.8	19.3	23.4	28.2	32.0

[1] Calculated from "U.S. Energy Through the Year 2000", U. S. Department of Interior, S.N. 2400-00775, December 1972.

[2] Actual

Table C-4. PERCENT OF TOTAL CONSUMPTION BY SECTOR[1]

Sector	1971[2]	1975	1980	1985	2000
Residential and Commercial	20.7	19.8	18.2	16.3	11.4
Industrial	29.4	28.5	25.9	23.6	20.5
Transportation	24.6	23.8	23.8	23.2	22.2
Electric Generation	25.3	27.9	31.2	34.6	41.9
Synthetic Gas (Coal)	-	-	0.9	2.3	4.0

[1]Calculated from "U.S. Energy Through the Year 2000", U. S. Department of Interior, S.N. 2400-00775, December 1972.

[2]Actual

- Hydropower has very limited expansion capability.
- The high temperature gas reaction and the liquid metal fast breeder reactor will have to be viable to attain the nuclear power projection by the year 2000.
- The environmental and capital problem created by rapidly increasing the use of coal will be overcome.
- The processes for manufacturing synthetic oil and gas from coal will be perfected before the year 2000.
- New oil and gas reserves will be discovered.
- Obtaining oil from shale will be viable before the year 2000.
- An increasingly larger segment of the population will become saturated with central heating, air conditioning and other energy intensive devices.
- GNP will increase 4.3%/year to 1980 and 4%/year to 2000.
- Population will follow the average of the U.S. Bureau of Census Series D and E projections.
- Per capita consumption will follow its present exponential trend upward.
- Industrial production will grow at a rate of 5%/year to 1980 and 4%/year thereafter.
- Fuel prices will rise faster than other commodity prices.
- Imports of oil and gas will be allowed to increase sevenfold by 2000.

The impacts of meeting the DOI consumption curve are very similar to those previously discussed for the Brookhaven projections, since the DOI projections through the year 2000 have roughly the same trends and amounts for the same period.

Some interesting information can be gained by looking at the Tables C-5 through C-9 by the year 2000. The following statistics are projected:

- Nuclear power will increase from .6% of the total energy consumed in 1971 to 25.6%.
- Electric generation will consume 41.9% of the total energy used; whereas it now consumes only 25.3%. (Conversion losses will increase from 17.3% to 27% of the total energy consumed.)
- Fossil fuel imports will increase from 12.8% to 32%. That is, approximately 1/3 of our energy needs will be imported.

The impacts of this rapid growth in nuclear energy and foreign imports, if permitted to happen, can have an adverse effect on our environment and society.

Table C-5. U.S. ENERGY INPUTS PER CAPITA[1] (10^6 Btu)

Year	Net Energy per Capita[2]	Gross Energy per Capita[2]
1950[3]	194.8	223.2
1960[3]	211.5	246.8
1971[3]	274.8	333.3
1975	301.2	371.4
1980	330.8	418.4
1985	369.9	479.2
2000	500.9	686.1
2020[4]	675.0	962.0

[1] U.S. Department of the Interior, "U.S. Energy Through the Year 2000", S. N. 2400-00775, December 1972.

[2] Includes non-fuel uses of fossil sources.

[3] Actual

[4] Straight line projection from 1985 through 2000.

Table C-6. PROJECTED GEOTHERMAL ENERGY RESOURCES[1] AND RESERVES[2] (10^{15} Btu)

Year	Moderate R&D Effort	Intensive R&D Effort
1972[3]	0.006	0.006
1975	0.05	0.025
1980	0.35	1.20
1985	0.63	4.40
1990	1.17	8.08
2000	2.50	13.17

1. Hearings Before the Senate Committee on Interior and Insular Affairs, June 15-22, 1972, Ser. No. 92-31.

2. Reserves: (a) Known recoverable - 10^{16} Btu, (b) undiscovered recoverable - 6-12 x 10^{16} Btu, (c) paramarginal - 4 x 10^{18} Btu, submarginal - 4 x 10^{19} Btu.

3. Actual

Table C-7. ESTIMATES OF U.S. AND WORLD ENERGY RESERVES[1] (10^{18} Btu)

Source	U.S.					World
	Known Recoverable	Undiscovered Recoverable	Known Marginal or Submarginal	Undiscovered Marginal or Submarginal	Total	Total
Coal	4.6	-	29.0	55.0	89.0	350.0
Petroleum	0.28	1.16	0.23	1.71	3.4	36.0
Natural Gas	0.28	1.21	-	0.88	2.4	8.5-12.5
Natural Gas Liquids	0.03	0.14	-	0.28	0.4	1.1-1.9
Oil in Bituminous Rocks	0.01	-	-	0.06	0.07	?
Shale Oil	0.29	-	11.6	23.2	35.1	2,100.0
Subtotal Fossil Energy	5.5	2.6	41.0	81.0	130.0	2,500.0
Uranium[2]	0.22[3]	(0.28-0.51)[3]	1.4[4]-8.6[5]	0.25[4]-10.0[5]	20.0	2.17[4]

[1]Table 1 and 2, page 94, "Summary Report of the Cornell Workshop on Energy and Environment", Feb. 22-24, 1972, Senate Committee on Interior and Insular Affairs, Serial No. 92-23.

[2]Uranium reserves are in terms of light water reactors. Breeder reactors would obtain at least 5- times the energy.

[3]Minable at \$5 to \$10/ton of U_3O_8.

[4]Minable at \$10 to \$30/ton of U_3O_8.

[5]Minable at \$30 to \$100/ton of U_3O_8.

Table C-8. DOMESTIC FOSSIL ENERGY RESERVES AND DEPLETION RATES

Source (Reserves)[1]	Usage Growth Rate[2] (1971 Usage) - %/Year								
	0	1	2	3	4	5	6	7	8
Gas (1490×10^{15} Btu)									
Years to Depletion	68	52	44	38	34	30	28	26	24
Year Depleted	2039	2023	2015	2009	2005	2001	1999	1997	1995
Oil (1440×10^{15} Btu)									
Years to Depletion	64	50	42	36	32	29	27	25	24
Year Depleted	2035	2021	2013	2007	2003	2000	1998	1996	1995
Coal (4600×10^{15} Btu)									
Years to Depletion	366	154	107	84	70	61	54	49	44
Year Depleted	2337	2125	2078	2055	2041	2032	2025	2020	2015
Uranium (500×10^{15} Btu)									
Years to Depletion (LWR)[3]	1220	258	163	122	99	85	74	66	60
Year Depleted (LWR)	3191	2229	2134	2093	2070	2056	2045	2037	2031

[1]Known and undiscovered (estimated) recoverable domestic reserves (see table C-7) marginal or submarginal reserves are included.

[2]The usage growth rate over the past decade has been 6% for gas, 4% for oil, and 6% for coal.

[3]The breeder reactor (LMFBR) obtains at least 50 times the energy from uranium as the light water reactor (LWR).

Table C-9. DOMESTIC FOSSIL SOURCE USES PROJECTIONS[1] (10^{15} Btu)

Fossil Source[3]	1971[2]	1975	1980	1985	2000
Coal					
Fuel Use	12.43	13.68	15.94	21.14	29.96
Non-fuel Uses (%)[4]					
Residential/Commercial	-	-	-	-	-
Industrial	0.13(1.0)	0.15(1.1)	0.20(1.2)	0.33(1.5)	1.40(4.5)
Transportation	-	-	-	-	-
Total	12.56	13.83	16.14	21.47	31.36
Oil					
Fuel Use	19.44	18.33	19.31	18.38	12.78
Non-fuel Uses (%)[4]					
Residential/Commercial	1.11(4.9)	1.20(5.4)	1.28(5.4)	1.32(5.6)	1.60(7.5)
Industrial	2.02(9.0)	2.60(11.8)	3.18(13.4)	3.90(16.5)	6.84(32.3)
Transportation	-	-	-	-	-
Total	22.57	22.13	23.77	23.60	21.22
Natural Gas					
Fuel Use	21.12	21.94	22.91	23.71	27.45
Non-fuel Uses (%)[4]					
Residential/Commercial	-	-	-	-	-
Industrial	0.69(3.2)	0.70(3.1)	0.75(3.2)	0.80(3.3)	0.90(3.2)
Transportation	-	-	-	-	-
Total	21.81	22.64	23.66	24.51	28.35
Total Fossil Fuel Use	52.99	53.95	58.06	63.23	69.99
Total Fossil Non-fuel Uses (%)	3.95(7.5)	4.65(7.9)	5.41(8.5)	6.35(9.1)	10.74(13.3)
Total Fossil Sources	56.94	58.60	63.47	69.58	80.73

[1]Derived from "U.S. Energy Through the Year 2000", U. S. Dept. of Interior, S.N. 2400-00775, December 1972.

[2]Actual

[3]Domestic sources only.

[4]Primarily asphalt and road oil for residential/commercial sector, chemical feedstocks for industrial sector and lubes and greases (not significant above) for transportation sector.

APPENDIX D. SURVEY INFORMATION

Letter sent to U.S. Congressmen:

This summer Auburn University, with support from the National Aeronautics and Space Administration and the American Society for Engineering Education, is conducting a Systems Engineering Design Program at the Marshall Space Flight Center in Huntsville, Alabama. The topic of the program is "The Application of Solar Energy to the Energy Crisis".

As a member of the Summer Design Program, I am particularly interested in identifying the opinions of key national political decision-makers toward the so-called "national energy crisis" and in finding out whether they feel solar energy might effectively be applied to help solve the "current energy shortage". Accordingly, I would especially like to have your thoughts on these matters. Furthermore, I would be extremely interested in obtaining any related information which you might have.

Your cooperation in this matter will certainly be appreciated. I look forward to hearing from you in the near future.

Sincerely,

Solar Energy Summer Faculty Fellow

Economic and Political Leaders Interview

1. Do you believe there is, or will be in the near future (year 2000) a crisis in meeting the nation's energy needs?

2. What energy sources will become most predominant in the future?

3. Do you think that the Federal Government will supervise the supply and demand of energy more in the future?

4. What do you think the role of solar energy will be in meeting the nation's energy demands in the future?

5. Do you think the use of solar energy is a short-term technologically feasible endeavor (in terms of implementation)?

6. Would you support a proposal to implement solar energy as a means to alleviate any future energy problems?

7. Do you believe private enterprise will consider the development of solar energy as a financially sound investment?

8. Do you believe the Federal Government will invest in the development of solar energy?

ENERGY QUESTIONNAIRE (Telephone)

Summer, 1973

1. In what city and state do you live?
   City___________
   State___________

2. Do you think there is a shortage of fuel in the United States today?
   a. Yes
   b. No
   c. No Opinion

3. Do you think there is a shortage of electricity in the United States today?
   a. Yes
   b. No
   c. No Opinion

4. Today, energy is (choose one)
   a. inexpensive
   b. a reasonable cost
   c. very costly

5. Which of the following sources of energy would you prefer to use in your home?
   a. solar energy or coal
   b. nuclear energy or natural gas
   c. coal or nuclear energy
   d. solar energy or natural gas
   e. natural gas or coal
   f. nuclear energy or solar energy

6. Do you think energy from the sun could be used to solve an energy shortage in the United States?
   a. Yes
   b. No
   c. No Opinion

7. If energy from the sun were available, would you be willing to use it in your home?
   a. Yes
   b. No
   c. No Opinion

8. In the future, do you think the energy supply of the United States should be controlled and administered by
   a. Private Industry
   b. Federal Government

9. Do you favor the federal government spending your tax dollar to solve the energy problem?
   a. Yes
   b. No
   c. No Opinion

10. How old are you and what is your occupation?
    age___________________
    occupation____________

5. Which of the following sources of energy would you prefer to use in your home?

a. Solar energy or Coal
b. Nuclear energy or Natural Gas
c. Coal or Nuclear energy
d. Solar energy or Natural Gas
e. Natural Gas or Coal
f. Nuclear energy or Solar energy (No Preference)

ENERGY SOURCES	SOLAR ENERGY	NUCLEAR ENERGY	COAL	NATURAL GAS	TOTALS
SOLAR ENERGY		0	+1	+1	+2
NUCLEAR ENERGY	0		+1	+1	+2
COAL	-1	-1		-1	-3
NATURAL GAS	-1	-1	+1		-1

Resulting Preferential Order:
1. Solar & Nuclear Energy
2. Natural Gas
3. Coal

The above example illustrates the application of a "pairing technique" analysis to be applied to the results of Question 5 in the public opinion survey.

APPENDIX E. EXAMPLE WORKSHEETS

DISCUSSED IN 11-3
PAGE 11-14

Table E-1. EXAMPLE WORKSHEET OF QUESTIONS, ANSWERS, AND PROBLEMS

LOCATION

Questions:

- Where is the building situated geographically?
- What type of region is this (desert, megalopolis, plains, mountainous)?
- What are the immediate environs (meadow, suburb, prairie, forest, ghetto)?
- Is the building susceptible to vandalism, floods, hail storms, tornadoes, etc.?

Audubon Answers	Audubon Problems	Saginaw Answers	Saginaw Problems
Lincoln, Massachusetts	Cold winter area	Saginaw, Michigan	Declining Neighborhood
Country area near small town	Possible vandalism	Small city in North Midwest	Cold winter area
Heavily wooded, hilly		Fringe of urban renewal area	Vandalism
20 miles west of Boston		80 miles north of Detroit	Questionable region for engineering feasibilities
42° 21'N Latitude		43°N latitude	
		No shading problems; surrounded by low and medium high-rise buildings	

Table E-1. (Continued)

RATIONALE

Questions:

- For what purposes is the building needed?
- Why is the building located where it is?
- Is the building to serve as a demonstration of solar heating and cooling? Of the conservation or ecology ethic? Of equal rights? Etc.?

Audubon Answers	Audubon Problems	Saginaw Answers	Saginaw Problems
° MAS demonstration of solar H/C and energy conservation		° GSA environmental energy conservation demonstration	° Poor planning
° Near existing MAS building & parking		° Office space for 177 federal employees	° Solar H/C is a gimmick
° Consolidates office space and services		° Conservation and ecology ethics	
° Solar H/C demonstration		° Solar H/C demonstration	
° Conservation and ecology ethics			

Table E-1. (Continued)

SPONSORS

Questions:

- Who are the actual initiators of the building?
- Who are the apparent initiators of the building?
- Who is responsible for the building after it is completed?
- Can any joint responsibilities be spelled out, along with the anticipated consequences of defaults?

Audubon Answers	Audubon Problems	Saginaw Answers	Saginaw Problems
Massachusetts Audubon Society		Government Services Administration (GSA)	Architectural firm losing money
James MacKenzie		Arthur F. Sampson, GSA	Solar consultant not always available
Arthur D. Little, Inc.		Pittsburgh Plate Glass	Only one solar consultant
Cambridge Seven		Alcoa	
George D. Löf		Smith, Hinchman, and Grylls, Associates, Inc.	

Table E-1. (Continued)

SITING

Questions:

- What is the local character of the building site (geologically, biologically, socially, etc.)?
- What are the dimensions, shape, and topography of the site? (Need a plat?)
- What is the area of the site (square feet, acres, etc.)?
- Where is the building on the site (centered, side, etc.)?
- What is the orientation of the building (aligned east-west, facing north, etc.)?
- What relation does the building bear to nearby buildings, streets, parks, etc.?
- Will the zoning laws be a problem?

Audubon

Answers	Problems
° Site slopes 1:10 to South	° Zoning lanes require no heights over 35 feet
° 8,000 sq. ft.	
° Facing south	
° Just south of existing bldg. (Gordon Hall) & north of highway	

Saginaw

Answers	Problems
° Oriented N-S	° Bldg. excessively large for site
° Almost fills whole rectangular lot	° Bldg. should be E-W, but site doesn't permit
° 200' x 500'	° Maximum visual impact of solar collector
° 125,500 sq. ft.	
° Minimum visual impact of building	
° One story bldg., with four sections terraced up 4' each	

Table E-1. (Continued)

BUILDING TYPE

Questions:

- What is a good description of the building (small office building, apartment complex, retail food store, etc.)?
- If the building consists of several parts, can they be described generically?
- What relationship does this building bear to others of its type?
- What is the building style (split-level, multi-storied, etc.)?

Audubon		Saginaw	
Answers	Problems	Answers	Problems
∘ Small		∘ Medium sized	∘ Single story
∘ Commercial office bldg.		∘ Single story	∘ Terraced roof
∘ Energy conservation stressed throughout bldg.		∘ Federal office bldg.	

Table E-1. (Continued)

BUILDING FUNCTIONS

Questions:

- What functions must the building be capable of accommodating (8-5 office activity, lectures, service, wholesale/retail merchandising, etc.)?
- What people, and how many, must the building serve functionally?
- What is the timetable of activities to occur in the building?
- Must the building function round-the-clock (24 hours a day)?
- Will part of the building thermal control be accomplished by architectural design ("passive control")?
- Will the building serve as an advertisement for an organization, idea, etc.?

Audubon

Answers

- Promote solar H/C, environmental and conservation ethic
- White-collar workers (office space, library, active hall, darkroom, filmroom) with hours 8 a.m. to 5 p.m.
- Serves staff of 30, 40 in lecture hall, and 25 visitors
- Passive thermal control

Problems

- Low public awareness--not used after business hours

Saginaw

Answers

- Contains service function of branch offices of 4 federal organizations: Postal Service, Depts. of Agriculture, Treasury, and HEW
- Serve as aesthetic landmark in redevelopment area of city
- White-collar workers with hours of 8 a.m. to 5 p.m.
- Roof used for landscaped parking area for 120 automobiles
- Community gathering bldg. after business hours
- Demonstration for solar energy

Problems

- Relationship of business office and community center
- Psychological awareness of users

Table E-1. (Continued)

BUILDING CHARACTERISTICS

Questions:

- How complete a set of blueprints is available?
- What is the square footage of the building?
- What are the details of construction, materials, etc.?
- Can one describe all doors, windows, walkways, roofs, walls, etc.?
- Is the building to be prefabricated or architecturally unusual in any sense?
- How much (additional) space is planned for the solar system(s)?
- What safety features are there (sprinkling systems, fire escapes, etc.)?

Audubon

Answers

- Multi-split level; 2 stories
- Floor plan available
- 8,000 sq. ft. floor area
- High library roof space for ventilation
- Southern roof is 3,500 sq. ft., tilted 45° up
- Aesthetically compatible with Gordon Hall
- Exposed working
- Thermopane glass on clerestory
- U-factors in range .13-.08 BTU/°hr. ft.^{2}

Problems

- Is bldg. connected to Gordon Hall?

Saginaw

Answers

- 51,600 sq. ft. floor area
- Terraced roof
- Bldg. oriented N-S and collector oriented E-W
- Bldg. has low visual profile

Problems

- N-S orientation optimal?
- Is terraced roof optional?
- Is low lying plan of minimum environmental impact to site?

Table E-1. (Continued)

SOLAR DATA

Questions:
- What is the site latitude (for sun angle considerations)?
- What are the shadowing aspects of the site (trees, nearby high-rise structures, clear horizon to the south, mountains, etc.)?
- What are the solar insolation characteristics of the site?
- Does the local atmosphere exhibit smog, fog, etc.?
- What cloud cover data are available for the site?
- Are the solar data needed for design available, or must they be interpolated?

Audubon

Answers

- Latitude 42° 21' N
- Data from Blue Hills, Boston, Windsor Locks, and Concord, N. H.
- Pyranograph to be at site
- No shading effects from trees or other objects
- Little smog

Problems

- Had to cut down trees to minimize shading effects

Saginaw

Answers

- Latitude 43°N
- Data from APEC computer program and 1972 ASHRAE Handbook for Fundamentals
- Cleveland, Ohio, used as reference point

Problems

- Why Cleveland?
- Serious deficiency of data--design could be incorrect by factor of two or greater

Table E-1. (Continued)

CLIMATIC DATA

Questions:

- Is the climatic region of the site coastal, Sonoran, tundra, etc.?
- What types of climatic data are available for the site (temperature, humidity, wind speed and direction, cloud cover, precipitation, climatic extremes, etc.)?
- Must climatic data be interpolated to the site from nearby stations?
- What are the site characteristics in terms of heating/cooling degree-days?

Audubon

Answers

- Airport climate station nearby
- Climate data from same source as solar data
- Prevailing winds over NW (winter) and SW (summer)
- Some ice storms and much snow

Problems

Saginaw

Answers

- Climatic data from same source as solar data
- Cold climate - snow

Problems

- Same problem as with solar data, but somewhat less critical

Table E-1. (Continued)

BUILDING THERMAL DATA

Questions:

- What are the structural features of the building pertinent to thermal considerations (walls, floors, ceilings, roofs, doors, windows, etc.)?
- What are the thermal characteristics of all construction materials and structures (U-values)?
- What types of insulation are being used?
- What are the energy inputs to the building (people, lights, stoves, furnaces, sunlight, etc.)?
- What are the time schedules of human and machine activity in the building?
- What are the anticipated heating, cooling, and hot water loads?
- If energy conservation is to be taken into account, how will it be implemented?

Audubon

Answers

- U-factor, .13 to .08
- Anticipate non-solar energy inputs to bldg. available
- Heating load range 1,34, 260-320,360 BTU/hr.
- Cooling load range 17-26 tons A/C
- Hot water demands 100 gallons per day

Problems

Saginaw

Answers

- 3 feet of soil on roof
- U factor 0.2
- Cooling always required during hours bldg. occupied
- 177 regular occupants with varying transient human occupancy thermal loading
- Solar shading employed
- Glass walls for natural lighting
- Thermal load reduced from normal 4-5 watts/sq. ft. to 2-3 watts/sq. ft.

Problems

- Roof design could have water leakage

Table E-1. (Continued)

BUILDING THERMAL DATA (Continued)

	Saginaw
	Answers
	o 80 percent indirect o Recycled materials (rubbish, garbage) in wall panels o Large open office space with long roof spans and few columns

Table E-1. (Continued)

SOLAR ENGINEERING

Questions:

- What kind of solar energy collector is used?
- What are the area and tilt angle of the flat plate collectors?
- What are the thermal transport and working fluids and their properties?
- Can the energy storage system be specified in detail?
- What equipment will accomplish the space heating and cooling (hot air, heat pump, etc.)?
- What are the solar system design loads (percent of total heating and cooling)?
- What becomes of waste heat energy (cooling tower, cooling pond, thermal pollution, etc.)
- Are the solar system components modular, mass-produced, off-the-shelf?
- What precautions are taken for unusual events (fluid leaks, broken collectors, lightning strikes, etc.)?

Audubon

Answers	Problems
∘ Standard two pane, absorber flat-plate collector of 3,500 sq. ft. ∘ Water is fluid for storage ∘ Li Br fluid for A/C ∘ Organic fluids (Dowtherm or Ucon) as collector working fluid ∘ Collector tiled at 45° angle ∘ Hot/cold storage in 7,500 gallon insulated tank ∘ Wet-evaporative cooling tower (6'x4'x6')	

Saginaw

Answers	Problems
∘ Eric Farber design consultant ∘ 8,000 sq. ft. flat plate collector ∘ Collector dimensions 40 ft. x 200 ft. ∘ Collector tilted 53° from horizontal to 14° W of South ∘ Three alternative heat transport media--air, water, ethylene-glycol/water mixture ∘ Pittsburg Plate Glass performing some of engineering functions for collector design	∘ Collector of an "experimental" nature ∘ Ethylene-glycol/water mixture has unfavorable freezing/expansion characteristics ∘ If water used, 20,000 gallon storage tank necessary

Table E-1. (Continued)

SOLAR ENGINEERING (Continued)

Audubon

Answers

- Arkla Li Br absorption A/C is 15 ton with 7 1/2 ton electrical auxiliary unit
- Storage for two days in winter, less than one day in summer
- Heating unit rating of 220,000 Btu/hr.
- Principal design of solar equipment by Arthur D. Little, Inc.
- ASHRAE handbook used for design considerations
- Collector array mounted on top of roof
- 60-75 percent of annual heating load supplied
- Significant proportion of cooling load supplied
- All hot water needs supplied

Problems

Saginaw

Answers

- Interior heat pump system
- 70 percent of space heating needs supplied
- All hot water needs supplied

Problems

Table E-1. (Continued)

NON-SOLAR H/C EQUIPMENT

Questions:

- What types of supplemental and backup heating and cooling equipment is contemplated?
- What will happen to this equipment in an electrical blackout or fuel shortage?
- What are the supplementary fuels (electricity, fuel oil, natural gas, etc.) and how are they to be received, stored, and used?
- Will the heat input from people, lighting, machine activity, etc. be used to supplement the heating, and what happens with respect to the cooling?
- Is any backup equipment really needed at all?

Audubon Answers	Audubon Problems	Saginaw Answers	Saginaw Problems
° 7 1/2 ton backup A/C	° Delivery and storage of oil	° Oil fueled boiler auxiliary heating	° No natural ventilation
° 220,000 Btu/hr. backup (gas or oil) furnace		° Economizer cycle for use of outside ambient air for cooling	° Heat pumps are electricity intensive
° Electric dehumidifier		° Heat rejection cooling tower	° Future absorption cooling?
° Heat loss from lighting used as heating aid			

Table E-1. (Continued)

SCHEDULES

Questions:

- What are the anticipated time schedules for site procurement, preliminary design of building and equipment, consultation, architectural efforts, final design and engineering, construction bid letting and contracting, actual construction and installation, occupancy, etc.?
- What is the time schedule of activities within the building?
- Are there any other important time schedules?

Audubon

Answers

- Conventional breakout 12 months
- Solar climate control incorporated 20 months
- Future solar building 12 months
- Hope to have funding by 12/73

Saginaw

Answers

- GSA contract signed 2/25/72
- Peer evaluation by GSA 4/13/72
- Environmental/conservation ethic introduced 6/72
- Solar energy concept introduced between 6/72 and 9/72
- Information from other institutions (i.e., private, university, government, etc.), began requesting 10/72
- Alternative concepts of GSA presented to architect 1/73
- Began design development phase 2/21/73
- Advertise bids 10/73
- Open bids 11/73
- Let contract 12/73
- Complete construction 1/3/75 to 6/3/75

Problems

- Firm did not know this was solar building until 6 months after contract was signed
- Poor planning of schedules

Table E-1. (Continued)

COSTS

Questions:
- What is the total anticipated cost?
- Does this cost include inflation, delays and setbacks, overruns, etc.?
- What is the detailed breakdown of costs, and is such a budget available?
- What are the incremental costs due to using solar heating and cooling (total and in dollars per million Btu)?
- By what procedures have the costs been determined?
- Are there any "hidden" costs, and what are they?
- What budget is allotted to maintenance, damages, and contingencies?

Audubon

Answers

- Land $50,000
- Basic building $525,000
- Solar climate control $185,00
- Project management and public education $140,000
- Escrow (unforseen costs/ risks) $100,000
- Total solar building project $1,000,000
- Budget includes sewage system and new parking lot
- On life-cycle costing
- Maintenance costs included
- Construction costs average about $35/ square foot

Problems

- $1,000,000 total costs

Saginaw

Answers	Problems
Anticipated cost is $4,000,500 as of 1/73	First anticipated cost $3,786,000
Cost for design development (Farber) $6,000	Why only $6,000 Too low.
Cost does not include site	Cost of site?
Architectural contract on cost-plus basis	$4,000,000 total cost
Construction cost average about $75/square foot	

Table E-1. (Continued)

FINANCING

Questions:

- How will the building and its parts be financed (private gifts, grants, governmental subsidies, earned revenues, borrowed monies, etc.)?
- Who is responsible for securing the funds, how will they be secured (fund-raising drive, etc.), and on what time scale?
- Will the financing be accomplished by outright purchase (cash), amortization, life-cycle costing, etc.?
- What happens in the event that some (or all) anticipated funds don't come through?

Audubon		Saginaw	
Answers	Problems	Answers	Problems
° Donations from industry and individuals before construction begins		° Public funds	° Architectural firm losing $25,000 to $50,000
° Funding committments due 12/73		° To be bid soon	
° Allen H. Morgan and Bruce Farrell raising money			

APPENDIX F. NATIONAL ENERGY MODEL

In developing a detailed, interactive systems model, the main problem is in identifying and quantifying the cause and effect relationships and interactions among all of the important variables. In the course of this study, sufficient time was not available to do more than identify most of the energy influencing variables and their interactions. This qualitative energy model is shown in Figure F-1. It is not suggested that this model is complete and totally accurate; it represents an attempt to better understand the broader scope of the energy problem in a limited time.

Figure F-1 presents a unique method for displaying a model which is necessitated because a flow chart would be too complex to read and a matrix format would be prohibitatively large. To read this figure, consider variable 1, which is "Governmental R&D Support In Coal": In: 20, 23, 24, 28, 29 means that the variables 20, 23, 24, 28 and 29 directly influence variable 1; Out: 12 means that variable 1, in turn, directly influences variable 12.

Before discussion of Figure F-1, it should be noted that the model does not contain Gross National Product (GNP) as a parameter, which in several references on energy is, maintained to be very important. The main argument for using GNP as a model parameter is that for over 70 years the GNP and the total U. S. energy consumed have risen at roughly the same rate; hence, the conclusion: The U.S. cannot have an expanding GNP without proportionally using more energy.

As discussed in Chapter 1, energy consumption, except in times of war and depression, appears to follow population growth very closely. Also, at least from 1940, energy consumption per unit GNP steadily declined until 1965; since 1965 it has risen sharply. The relationship between energy consumed and GNP is not at all clear; hence, it is discounted as a major, direct driving force in an energy model.

To better illustrate what information is contained in this energy model, some of its interesting feedback loops will be discussed below.

Price Control Effects. The adverse effects which U.S. Government controls on natural gas pricing have had can be seen as follows: price controls (4) on gas at the well-head affect the delivered gas price (21) which, because it is held artificially low, makes it more attractive and creates a large demand (18), which, in turn, rapidly depletes the tapped reserves (30) and creates an apparently real shortage (24) which should affect the price controls (4), but as of this writing (August, 1973) it has not. Is this a real gas shortage (24) we are experiencing? No! Looking further at the model we see that the artificially low price of gas (21) has discouraged exploration (16) for new reserves (which are known to exist) and has thus created an artificial shortage

Governmental

R&D SUPPORT

1. Coal
   In: 20, 23, 24
   28, 29
   Out: 12
2. Other fossil fuels
   In: 23, 24,
   28, 29
   Out: 13
3. Nuclear
   In: 20, 23, 24
   28, 29
   Out: 14

CONTROLS

4. Price
   In: 11, 24, 25
   28
   Out: 21, 22, 26
5. Oil Imports
   In: 11, 18, 23
   24
   Out: 21, 23
6. Coal Exports
   In: 23, 24
   Out: 23, 30
7. Pollution
   In: 29
   Out: 15, 16, 17
   18, 19

Technological

R&D IMPLEMENTATION

12. Coal-Gas/Liquid
    In: 1, 18, 24, 26
    29
    Out: 21
13. Other Fossil Fuels
    In: 2, 18, 24, 26
    29
    Out: 21
14. Nuclear
    In: 3, 19, 24, 26
    29
    Out: 22
15. Anti-Pollution Devices
    In: 7, 26, 29
    Out: 18, 19, 21
    22, 32

EXPLORATION

16. Fossil Fuel
    In: 7, 9, 21, 24
    26
    Out: 9, 25, 30
17. Nuclear
    In: 7, 9, 22, 24
    26
    Out: 9, 25, 31

Economic

ENERGY DEMAND

18. Fossil Fuel
    In: 7, 11, 15,
    21, 25, 27
    Out: 5, 11, 12
    13, 21, 30
    32
19. Nuclear
    In: 7, 11, 15
    22, 25, 27
    Out: 14, 22
    31, 32

NON-ENERGY DEMAND

20. Fossil Sources
    In: 11, 21, 27
    Out: 1, 3, 8
    30
21. Fossil Fuel
    In: 4, 5, 12
    13, 15, 18
    24, 25
    Out: 16, 18
    20, 26, 28
22. Nuclear
    In: 4, 14, 15
    19, 24, 25
    Out: 17, 19,
    26, 28

Social

POPULATION

27. Growth(Exog.)
    In: -
    Out: 10, 18, 19
    20, 28

PRESSURES

28. Econ/Political
    In: 11, 21, 22
    24, 25, 27
    Out: 1, 2, 3, 4
    8, 10, 23
29. Anti-Pollution
    In: 32
    Out: 1, 2, 3, 7
    12, 13, 14
    15

Environmental

RESERVES

30. Fossil Fuel
    In: 6, 16, 18, 20
    Out: 24
31. Nuclear
    In: 17, 19
    Out: 24

POLLUTION

32. Amount
    In: 15, 18, 19
    Out: 29

LEGEND

(In = input from: input variables to variable X affect the value of X;
Out = output to: variable X, in turn, affects other variables which it outputs to; underlined numbers represent presently inactive branches.)

Figure F-1. INTERACTIVE MODEL OF PRESENT ENERGY SITUATION

Governmental	Technological	Economic	Social	Environmental
8. Resource Conservation In: 20, 24, 28 Out: 25 9. Tax Incentives In: 11, 16, 17, 24 Out: 16, 17, 26 10. Federal Reserve In: 23, 27, 28 Out: 26 11. Wars (Exog.) In: 18, 24 Out: 4, 5, 9, 18, 19, 20, 25, 28		INTERNATIONAL 23. Trade Deficit In: 5, 6, 28 Out: 1, 2, 3, 5, 6, 10 SHORTAGE OF FUELS 24. Real In: 30, 31 Out: 1, 2, 3, 4, 5, 6, 8, 9, 11, 12, 13, 14, 16, 17, 21, 22, 28 25. Artificial In: 8, 11, 16, 17 Out: 4, 18, 19, 21, 22, 28 FINANCING 26. Construction In: 4, 9, 10, 21, 22 Out: 12, 13, 14, 15, 16, 17		

Figure F-I. (continued)

(25) which should affect price controls, but in the case of a real shortage, does not.

Pollution Effect. The recent surge in environmental control can be followed in this model. As coal usage (18) increased, pollution (32) increased, which eventually caused some anti-pollution pressures (29) from society; this then pressured the Government to pass anti-pollution legislation (7) which forced industry to develop and use anti-pollution devices (15) which reduced pollution (32). On the other hand two deleterious effects have occured which were not planned: (a) anti-pollution devices (15) decrease the efficiency of power plants and, hence, force the increase in coal usage (18) to get the same output as before, and (b) the use of anti-pollution concepts (15), such as strip mining reclamation and coal scrubbing, has raised the effective price of coal (21), our most abundant fossil fuel, to a point where oil and gas, our low reserve fossil fuels, are now being used more and more to fire power plants.

Governmental R&D Funding. What is behind the government's push to develop nuclear power? The shortage of fossil fuels (24), the pressure from society (28) to have more energy, and the consequental need for more oil imports with its attendent trade deficit (23) have caused the government to greatly fund nuclear power R&D (3) which speeds up the R&D and implementation of nuclear power (14) which makes nuclear power more attractive price-wise (22) which increases its demand (19) which increases pollution (32) in the form of nuclear waste disposal, cooling water discharge temperatures, and the increased potential of nuclear accidents, which causes social anti-pollution pressures (29) which is felt as a slowdown in the R&D and implementation of nuclear power (14) but an increase in Governmental R&D funding (3).

There are many more feedback loops incorporated in the energy model of Figure F-1. It will now be shown how the development of solar energy fits into this picture.

Solar Energy Submodel.

Solar energy was shown in Chapter 3 to be (a) a viable intermediate-term candidate for easing the energy problem and (b), possibly, the only long-range alternative when the limited supply of fossil and nuclear fuels is considered.

In Figure F-1, solar energy did not play a role. For solar energy to make a significant contribution in alleviating the energy problem, its interaction with the present energy model will probably occur as is suggested in Figure F-2.

As can be seen in Figure F-2, the recognition of a need for solar energy (39) will be influenced by the increased non-energy demand for fossil fuels (20), the rise in fossil fuel and nuclear power prices (21, 22), the increasing trade deficit from importing oil (23), the shortages in fossil and nuclear fuels (24) and anti-pollution pressures from society.

Governmental

R&D SUPPORT

33. Solar Devices
    In: 1, 2, 3, 28, 39
    Out: 1, 2, 3, 35

IMPLEMENTATION SUPPORT

34. Solar Devices
    In: 26, 28, 38, 39
    Out: 36

Technological

R&D

35. Solar Devices
    In: 33, 39
    Out: 38

IMPLEMENTATION

36. Solar Devices
    In: 26, 34, 37, 39
    Out: 37, 38

Economic

ENERGY DEMAND

37. Solar Energy
    In: 27, 36, 38, 39
    Out: 18, 19, 36, 38

DEVICES PRICES

38. Solar Devices
    In: 35, 36, 37
    Out: 26, 34, 37

Social

RECOGNIZE NEED FOR

39. Solar Energy
    In: 20, 21, 22
    23, 24, 29
    Out: 28, 33, 34
    35, 36, 37

LEGEND

(Use with Figure F-1)
(In = input from: input variables to variable x affect the value of x;
Out = output to: variable x, in turn, affects other variables which it outputs to; underlined numbers represent presently inactive branches.)

Figure F-2. SOLAR ENERGY SUBMODEL

Once the need (39) for solar energy is recognized and societal pressures (28) increase, the government will increase its R&D funding (33) which will advance the state-of-the-art (35) and reduce the price of solar devices (38) which will make them more attractive (37) to the general public.

Unlike conventional power sources, solar power will probably make its early impact in the form of self-contained units for individual buildings. Since this will cause each building owner to invest in his own power equipment, it will be essential that the government develop parallel support for the implementation of solar power (34), preferably through private industry (36) which can both effectively lower the price (38) and make the devices more attractive (37).

Although considerably more work needs to be done to develop a more complete and accurate model, the models presented above were of value in this project for identifying the major interactive components that had to be studied from a systems point of view.

BIBLIOGRAPHY

F-1. Department of Interior, "Consumption to 2000", December, 1972.

F-2. National Petroleum Council, "U.S. Energy Outlook", December, 1972.

F-3. White, D. C., "Energy, The Economy, and the Environment", Technology Review, October/November, 1971.

APPENDIX G. PHYSICAL QUANTITIES, NAMES OF UNITS SYMBOLS AND CONVERSION FACTORS

BASIC UNITS (SI)

Quantity	Name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	candela	cd

DERIVED UNITS (SI)

Area	square meter	m^2
Volume	cubic meter	m^3
Frequency	hertz	Hz
Power	watt (joule/sec)	W or J/s
Work, energy, quantity of heat	joule	J
Luminous flux	lumen	lm or cd·sr
Luminance	candela per sq. meter	cd/m^2
Illumination	lux	lx or lm/m^2
Entropy	joule per kelvin	J/K
Thermal conductivity	watt per meter kelvin	$Wm^{-1}K^{-1}$
Radiant intensity	watt per steradian	W/sr

PREFIXES

Multiplier	Prefix	Symbol
10^{12}	tera	T
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^2	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

CONVERSION FACTORS

To Convert From	To	Multiply By
angstrom (A)	meter (m)	1 E-10
British thermal unit (Btu)	joule (J)	1055
calorie ( )	joule (J)	4.18
erg	joule (J)	1 E-7
horsepower (h_p)	watt (W)	746
kip	newton (N)	4448
langley	joule/meter^2 (J/m^2)	41840
phot	lumen/meter^2 (lm/m^2)	10000
kilowatt hour (kWh)	joule (J)	3.6 E 6
Btu/second	watt (W)	1055

Temperature

Celsius (C)	kelvin (K)	$t_K = t_C + 273.15$
Fahrenheit (F)	kelvin (K)	$t_K = \frac{5}{9}(t_F + 459.67)$
Fahrenheit (F)	Celsius (C)	$t_C = \frac{5}{9}(t_F - 32)$
Rankine (R)	kelvin (K)	$t_K = \frac{5}{9} t_R$