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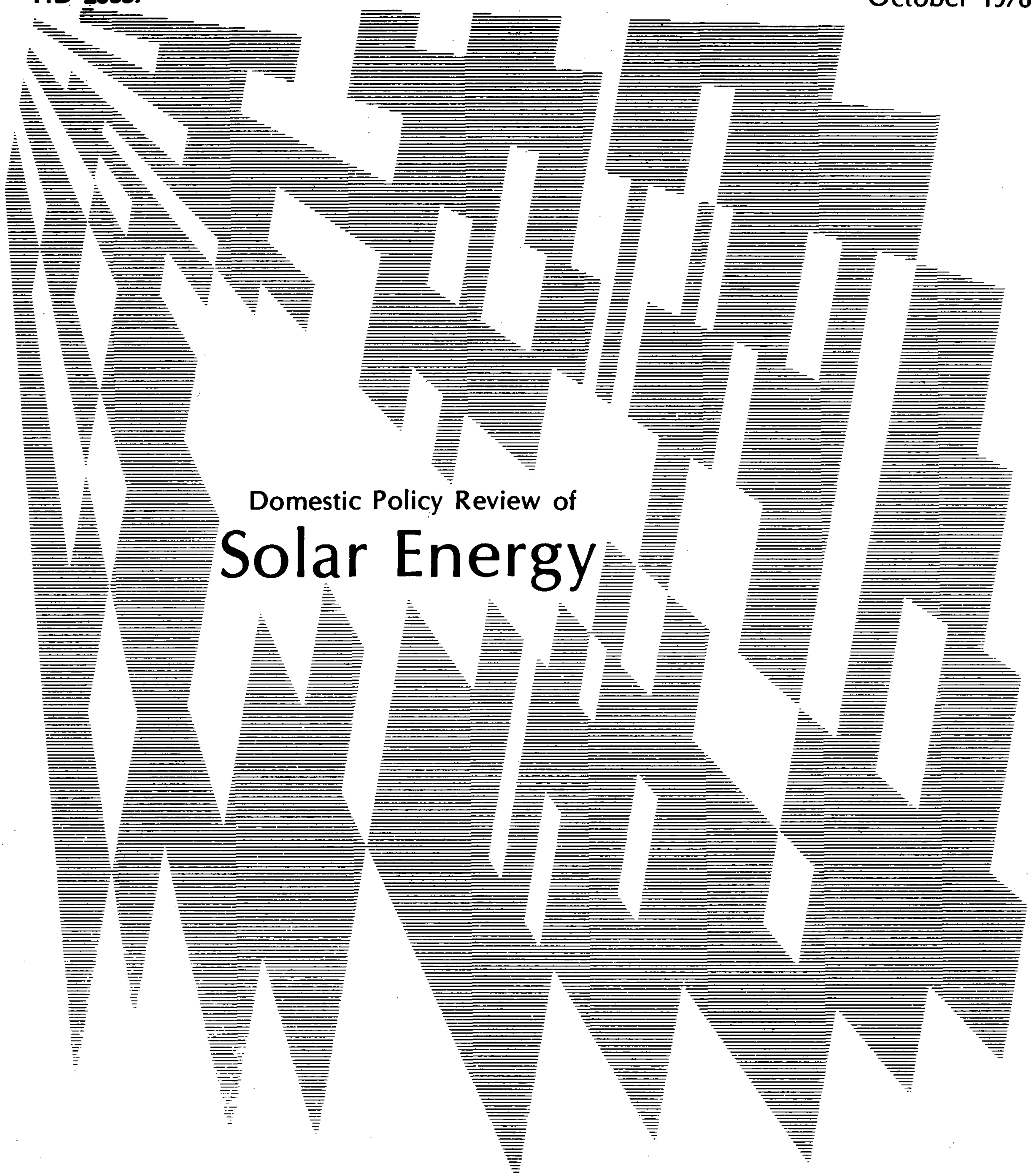
TID-28837

October 1978



Domestic Policy Review of
Solar Energy

Final Report
Research, Development and Demonstration Panel

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price: Printed copy: $11.00
Microfiche: $3.00

October 1978

TID-28837
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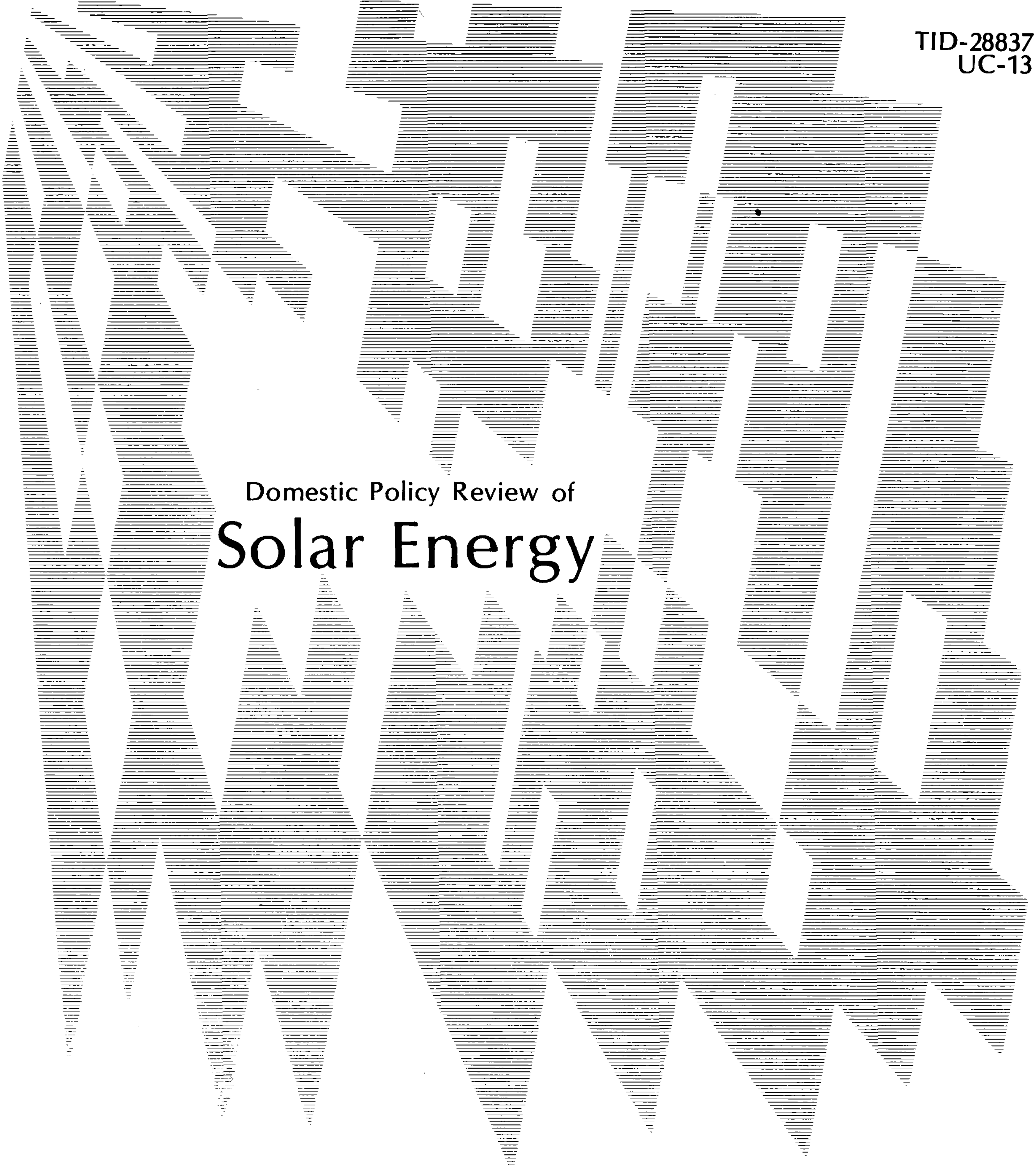

Domestic Policy Review of
Solar Energy

Printed by
U.S. Department of Energy

Final Report
Research, Development and Demonstration Panel

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Research, Development and Demonstration Panel

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Name	Organization
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Patrick Call	Solar Energy Research Institute
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Wallace Howell	Department of Interior
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Department of Energy
Washington, D.C. 20545

MEMORANDUM FOR CHAIRMAN, INTEGRATING GROUP

FROM: Robert W. Kelly, Chairman, RD&D Panel Robert W. Kelly

SUBJECT: R&D options

I. Background

In the process of research, development, and demonstration (RD&D), scientific principles are embodied in technologies which in turn are developed into market prototypes. In the process of commercialization, the market potential is evaluated and, where appropriate, developed in order to augment energy supply. In general, the degree to which RD&D is funded for specific technologies reflects the rate and timing of market introduction. However, this relationship holds only for those technologies which have advanced beyond exploratory and engineering development stages.

The President has directed the Solar Energy Policy Committee to review the current Federal programs related to research, development, and demonstration and to develop for his consideration policy options and recommendations to accelerate the use of solar energy, in both the short and the long term.[1] The RD&D Panel has addressed two of the key issues cited by the President:

1. ". . . an examination of each solar technology . . . to determine technical or scientific needs relating to their commercial use,"

2. ". . . a review of current Federal research, development, and demonstration programs for solar technologies to determine whether they are structured appropriately to address the priorities and needs."

The RD&D Panel examined priorities and policies of the existing RD&D programs to determine whether they can be improved. The RD&D Panel reviewed each technology's current scientific status, economic competitiveness, and promise for engineering, scientific, and economic advances in order to determine (1) its potential for making a contribution to the

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[1] Direct solar technologies include Heating and Cooling, Solar Thermal, Photovoltaics; while "indirect" encompasses Ocean Thermal Energy Conversion, Wind, Biomass, and Low-Head Hydro electric.

Nation's energy needs, and (2) how that potential might be realized by Federally supported RD&D. Qualitative comparisons with competing non-solar alternatives were then examined in the deliberations but are not reported by the panel.

II. Major Findings

The improvement of a technology will not assure its use. The process resulting in a marketable product also entails such considerations as interfuel competition (economics), environmental quality, institutional barriers, etc. For this reason, the Panel considered, and in a preliminary fashion assessed, the role of the technical and non-technical support in accelerating each solar technology. Table 1 below shows the Panel's findings. Category one depicts those technologies which are technically ready and economically viable in many applications. Further RD&D for these technologies is in general not warranted but in many cases institution barriers remain. Solar technologies included in both categories two and three require additional RD&D prior to their commercialization. The separation between the two categories is a function, in the panel's perception, of the time required to complete RD&D developments. This is not to say that a technology in category three cannot come-on-line sooner. However, for this to occur major technological developments must take place at a pace faster than presently envisioned (this could most notably occur for Photovoltaics).

Thus, the Panel found that most solar energy technologies are not ready for large scale commercial application today. However, their potential is great. It is estimated by the Impacts Panel that in the maximum practical case 18 quads of conventional energy could be displaced by 2000 if an aggressive RD&D program and appropriate incentives are executed.

To achieve this solar contribution the following RD&D program actions are recommended:

Near term:

- Passive solar heating and cooling technologies should be aggressively pursued in coordination with national conservation programs.

- Increased RD&D on lighter weight, more efficient collectors must be conducted if solar space heating and cooling is to receive widespread use. Active space heating system technologies are not cost competitive in comparison to most alternative fuel sources (electricity and oil) in most areas of the country.

- Direct combustion and methane recovery from biomass should be emphasized.

- DOE and Federal Power Generating Agencies should pursue an agressive program of windpower research, development, and demonstration where such activities hold promise.

Table 1

Federal Role in Accelerating or Implementing Solar Technology

	Federal Actions Other than RD&D		Federal RD&D		
	Would Accelerate	Necessary to Accelerate	Would Accelerate	Necessary To Accelerate	Necessary To Implement
Economic & Technical Status:					
1. Available Today					
Passive Heating	X				
Direct Combustion	X				
Low Head Hydropower	X				
Hot Water Heating	X				
Animal Wastes	X				
2. Near Term					
Active Solar Heating & Advanced Passive Heating		X	X———	X	
Agricultural & Industrial Process Heat		X	X———	X	
Wind Power		X	X———	X	
3. Long Term					
Total Energy Systems		X		X	
Photovoltaics		X		X	
Solar Thermal		X		X	
Solar Cooling		X		X ———	X
Biomass (Except Direct Combustion and Animal Wastes)				X ———	X
4. Post 2000					
Ocean Thermal Conversion					X
Solar Space Satellite					X

- Federal RD&D programs must focus more sharply on the opportunities for the use of solar energy by industry and agriculture to provide process heat.

- Increased emphasis should be given on selected field tests to prove the feasibility of a concept and to test promising systems, prior to large-scale demonstration programs. These latter programs do not supply the variety of data on regional, economic, or technical performance necessary for product improvement and systems development.

- Improved demonstration programs are required that include non-RD&D incentives (education, marketing, and standards development activities) to provide the information necessary to convince potential installers, purchasers, and users of the long-term dependability, performance, and economics of the products being demonstrated.

- More RD&D emphasis upon non-silicon photovoltaics technologies.

Long Term (beyond 1990)

- More RD&D emphasis on high-temperature collectors for improved thermal efficiency and low-cost storage for solar systems.

- More RD&D emphasis on hybrid, combined, or supplementary systems, particularly for retrofit applications, that will facilitate integrating solar energy into the existing national energy supply system.

- Increased emphasis on fundamental basic and applied solar energy research.

- Greater attention to the development of economically competing biomass conversion technologies.

III. Rationale for the Recommended Strategy

The Panel believes that an integrated RD&D strategy should consider the relative priority of each technological area given its likely contribution in augmenting energy supply. This assessment cannot be made and has not been made by the RD&D Panel in isolation since it includes considerations such as the competitive nature of alternate energy sources, national security concerns, and relative emphasis on centralized and decentralized energy systems. Another consideration of overriding importance which the Panel considered in the evaluation of its perferred RD&D strategy involved the potential substitution of solar for liquids.

The nation's energy supply problem is multi-faceted. Major questions must be resolved regarding the future role of electricity. But, in configuring research strategies for inexhaustible energy sources, critical judgment must be exercised to ensure that the most immediate energy requirements are distinguished from less critical and longer term requirements.

The overall energy system in the U.S. is most immediately being stressed by declining gas and oil supplies. Most fuel conversions are presently occuring (at substantial cost) as curtailed industrial gas loads are shifted to imported oil. Imported gas is expensive and has significant security and balance of payment drawbacks. The domestic and the international economic consequences of high imports and large currency drains are increasingly severe. The liquid fuels problem appears even more menacing in the long term because the development of alternatives for the transport sector will be extremely difficult. The imbalanced world money flow and the prospect of further disruptions threaten the interdependent world economic system that has evolved over the last several decades.

The Panel believes that the severity and the immediacy of the fluid hydrocarbons (oil and gas) shortage should be recognized in developing RD&D strategy for solar energy. The current Federal solar strategy is implicitly oriented toward the development of alternative means of generating electricity, which will only indirectly address the fluid fuel gap. The Panel in its recommended strategy has attempted to enhance solar RD&D activities with direct relevance to the replacement of oil and gas. As a result, solar electric applications are reduced in priority from DOE's existing planning. Biomass fuels and other solar technologies targeted to the large uses of oil and gas in the industrial sector are given increasing emphasis. The Panel believes that this basic re-orientation will enhance both the size and nature of the contribution that solar energy can make to the nation through the year 2000.

IV. Criteria for Option Selection

Before presenting the options themselves, it is important to describe the criteria employed by the Panel. They are as follows:

- The option merits Presidential consideration (i.e. the strategy differs considerably from the course presently being pursued).

- The stragegy is likely to lead to an augmentation of U.S. energy supply in a specific market sector.

- The strategy would contribute to the development of an economically viable product which will enhance the nation's welfare.

- The option allows leverage, such as cost-sharing, to enhance the benefit to the public obtained from Federal investments.

V. Options and Budgetary Implications

The attached appendix outlines in detail the RD&D options which the Panel considered likely to speed the contribution of each solar technology to total energy supply. It presents two options for each technology which are characterized as follows:

1. Moderate Option: Pursuit of those research elements and technologies which have the greatest promise of accelerating solar energy supply while attempting to follow the guidance that the DPR ". . . is not intended to commit the Administration to larger solar budget expenditures."

2. High Option: A more aggressive, high cost and higher benefit option, pursuing more intensive programs on the most promising technologies, parallel development in some technological areas, and more rapid movement to develop potential markets and support industrial capabilities.

The RD&D Panel has selected the recommended RD&D strategy from among the two options, as shown in Table 2. The budget required to support this recommended course of action would increase the DOE solar budget by 50 percent over the fiscal year 1979 request. Elements of the budget are listed in Table 3.

The guidance to the RD&D Panel was that significant budget increases were not to be assumed for the DPR. The moderate option was originally intended by the Panel to be a hold-the-line budget (roughly equal to FY 79) -- analyzing solely program priorities. The Panel was unable to fully comply with this desire. Although there was considerable analysis performed to reorient priorities within existing budget levels, and/or in some cases reduce total levels, budget levels for some solar technologies were so low relative to their potential that the Panel felt obliged to increase the funding, knowing the aggregate level in the moderate option would be violated. In addition, the Panel was aware that in a few key program areas large demonstration efforts had been undertaken in previous years and to completely eliminate these programs or to drastically reduce them might do irreparable harm to the highly-fragmented and infant solar industry.

Given this setting, the RD&D Panel selected its recommended options as follows:

A. Department of Energy

1. Heating and Cooling Demonstrations (DPR option - $38 million in FY 80)

Rationale: The reduced level reflects that past active heating programs have demonstrated the adequacy or inadequacy of the technology and that a large Federal buy program, plus financial incentives, are incorporated into the NEA to maintain industry momentum. It is time to

Table 2

Recommended Solar RD&D Strategy

Technology	Option Recommended
o Heating & Cooling	
- Demonstration	Moderate
- R&D	High
o Agricultural and Industrial Process Heat	High
o Solar Thermal	Moderate
o Photovoltaics	Moderate
o Wind Energy	High
o Ocean Thermal	Moderate
o Biomass	Moderate
o Small Scale Hydropower	No RD&D recommended
o Support to Lesser Developed Countries	High
o Solar Powered Satellite	Continue planned effort

Table 3

Comparison Between Existing DOE and Recommended Domestic Policy Review Budgets for RD&D*
(BA $ in millions)

	DOE Requested FY-79	DPR Mod FY-80	DPR Acc FY-80	DPR Recommended FY-80
A. Technology:				
Solar Heating & Cooling	84.2	107.0	160.0	138.0
-Demonstration Programs	39.1	38.0	60.0	38.0
-Heating and Cooling R&D	45.1	69.0	100.0	100.0
(Agricultural and Industrial Process Heat)	(11.0)	(22.0)	(30.0)	(30.0)
Solar Electric Applications	301.9	391.0	529.0	417.0
-Solar Thermal	100.0	137.0	181.0	137.0
-Photovoltaics	108.0	140.0	203.0	140.0
-Wind Energy	60.7	74.0	100.0	100.0
-Ocean Thermal	33.2	40.0	45.0	40.0
Fuels from Biomass	36.9	70.0	100.0	70.0
International LDC RD&D[1/]	-	8.0	14.0	14.0
Hydroelectric	28.0	-	-	-
SPS	4.6	3.4	3.4	3.4
Heat Engines[2/]	-	-	-	-
Storage[2/]	-	-	-	-
Technology Support	16.5	64.0[3/]	64.0[3/]	64.0[3/]
TOTAL	472.1	646.4	870.4	706.4

1/ Incremental to present level of funding.

2/ Increased funding in these areas would emanate from transfers from those programs most involved with their operations as indicated in the panels technical evaluations.

3/ DOE planning figure for FY'80- not evaluated by the panel.

*Funding for commercialization and other non-RD&D solar activities are not included in this table.

move from the Model T to the Model A. The Panel believes that increasing emphasis should be placed on R&D to develop a new generation of low-cost/high-efficiency collectors. It should be also recognized that active solar cooling technologies in almost all applications are uneconomic. Therefore, outside of a very limited field testing program in the commercial sector demonstrations should be curtailed. Also, increased emphasis should be directed toward the demonstration of simple passive systems for residential/commercial use.

2. Heating and Cooling R&D (DPR option - $70 million in FY 80)

Rationale: The rationale as stated in item one above applies. In addition, it is important to recognize that a variety of RD&D heating and cooling concepts are available now for accelerated investigation.

3. Agriculture and Industrial Process Heat (DPR Option - $30 million in FY 80)

Rationale: This strategy significantly increases RD&D on agricultural and industrial high temperature collectors in a market that represents 40 percent of present U.S. energy demand (this is also coupled with increased emphasis within the solar thermal program for strictly high-temperature industrial uses).

4. Solar Thermal (DPR option - $137 million in FY 80)

Rationale: The funding level increases by 37 percent from the DOE-FY 79 level. In addition, program priorities are significantly altered by the Panel to reflect increased emphasis on:

a) RD&D on small dispersed energy systems
b) major R&D to apply high-temperature technology to energy-intensive industrial processes
c) defer central power tower (electric) repowering demonstrations until Barstow pilot plant has provided enough operating experience (continue construction on Barstow)
d) undertake appropriate market and systems analyses to ascertain market potential and applications for this technology.

5. Photovoltaics (DRP option - $140 million in FY 80)

Rationale: This budgetary level reflects an increase of $35 million above the FY 79 DOE-requested level. The Panel believes that the strategy to be pursued in this area should be one that (a) does not commit itself to a Federal market-pull strategy based on single-cell silicon at this time, (b) increases RD&D funding on non-silicon photovoltaics technologies which, because of the wide spectrum of candidates, hold significant prospect for cost reductions, (c) maintains a demonstration effort at a level to avoid adverse effects upon industry momentum, (d) proceeds, at a reasonable level of program effort, to investigate silicon technologies currently under development, and (e) develops in much greater detail knowledge of balance of system costs, in order to assess market competitiveness more fully.

6. Wind Energy (DPR option - $100 million in FY 80)

Rationale: The Panel believes that wind energy can provide a significant source of energy supply by 2000. As such, the strategy recommended by the Panel involves a 70 percent increase in the FY 79 budget level. Further, this level should be maintained or slightly increased through the early 1980s, at which time appropriate financial incentives could accelerate market introduction. The Panel believes that the emphasis in the program should be on:

a) parallel wind machine demonstration efforts to accelerate market acceptance (including wind turbines)
b) wind energy assessments (identifying the most favorable and reliable wind sites)
c) accelerated demonstration of the windfarm concept and its interaction on a utility grid
d) investigation of combining solar thermal and hydro-electric with wind

7. Ocean Thermal (DPR option - $40 million in FY 80)

Rationale: The Panel concurs with the presently conceived DOE strategy for this technology. This technology will not significantly augment energy supply before 2000. This statement is reflected by the number of unanswered economic, technical, scientific, and environmental uncertainties and risks which surround the technology.

8. Biomass (DPR option - $70 million in FY80)

Rationale: This program area is consistently presented as one that can contribute significant amounts of energy by 2000. The Panel concurs and our moderate option reflects a 90 percent increase above FY 79 levels ($37 to $70 million). Outyear funding, in accordance with this strategy, would increase, but the FY 80 level reflects what the Panel believes to be the absorptive capacity of the program.

9. Small-Scale Hydroelectric (no funding for RD&D)

Rationale: To understand the Panel's rationale fully, the technical evaluation must be examined. However, the Panel believes that the following facts support this recommendation:

a) An economically viable, commercially available technology exists today

b) The market potential is relatively small and will be spread over a long time frame, inhibiting new American manufacturers from committing the investment capital to supply the domestic market

c) The major perceived barriers to utilization of this technology are institutional and regulatory in nature.

10. Solar Space Satellites (DPR option - $3.4 million in FY 80)

Rationale: The Panel supports the originally conceived conceptual study. A re-assessment of the prospects of this energy source should take place, as scheduled, in June 1980. In any event, this proposed technology could not contribute significantly to U.S. energy supply before 2000. Thus, there is no DPR option for SPS.

11. International RD&D for LDCs (DPR option - $14 million in FY 80)

Rationale: The Panel believes that RD&D specifically designed to the needs and requirements of less-developed countries should be undertaken in a more vigorous manner by DOE (small-scale decentrailized, non-capital intensive technologies -- appropriate technologies which would also benefit U.S. citizens). This strategy must be pursued with A.I.D., World Bank, etc., if it is to be successful. This recommendation is consistent with the recent Economic Summit Conference and has been coordinated with the International DPR Panel.

B. Other Federal Agencies

The implications for solar research, development, and demonstration extend beyond the Department of Energy. The Departments of Agriculture, Interior, Housing and Urban Development as well as the Environmental Protection Agency and the National Oceanic and Atmospheric Administration have vital roles, to varying degrees, in the technical, economic, and environmental development of individual solar technologies. Table 4, which illustrates the budgets of these other agencies, indicates that funding of energy-related RD&D is at low levels which may inhibit positive contributions. The RD&D Panel believes that this deficiency should be corrected to allow for maximum participation and utilization of the talents each agency can, or rather, should bring to bear on accelerating solar energy development. The Panel recommends adoption of the moderate option illustrated in Table 4.

VI. Organizational Issues

Solar energy technologies are in their infancy when compared to other energy sources. Acceleration of technology development is essential to determine their competitiveness with other systems as well as to provide an additional set of options for the Nation to implement should they be warranted by overriding national security considerations. Accordingly,

TABLE 4

Other Federal Departments
Domestic Policy Review
Solar Research, Development and Demonstration
(BA $ in millions)

Department/Agency	Estimated FY-79	DPR Mod FY-80	DPR High FY-80
U.S. Department of Agriculture[1]	7.2	20.0	38.5
Department of Interior[2,6]	1.8	2.1	7.6
Department of Housing & Urban Development[3]	-	1.0	2.0
Environmental Protection Agency[4]	5.0	13.5	17.0
National Oceanic & Atmospheric Admin.[5]	-	.2	.5
TOTAL	13.5	36.8	64.6

1/ These funds include 0.5, for Agricultural and Industrial Process Heat in FY'79, the DPR Mod, and DPR High Columns. The remainder is Biomass activities -- see options Appendix attached for detailed budgetary breakout.

2/ The Department of Interior activities are related principally to the study of a windfarm site in Wyoming ($200,000), small scale hydro development (400,000), and weather modification (Colorado River - $500,000).

3/ The Department of Housing and Urban Development activities are funded by DOE and primarily involve the demonstration of hot water, space heating, and cooling systems--see hot water, space heating options paper appendix attached for budgetary details.

4/ Funding is primarily direct combustion of wastes as a fuel (demonstration plants)--see biomass options paper in attached Appendix for detail budgetary breakout.

5/ Proposed budgetary authority relates to offshore environmental aspects associated with OTEC.

6/ Does not include approximately $600,000 in DOE pass-through R&D funds for small scale hydro, nor the Corps of Engineers study for $2.25 million of large scale hydro capabilities, nor $0.6 million of TVA hydro research.

solar energy RD&D should be given the highest priority by Federal managers. Once given the priority, strong, centralized program direction and management is required. A manager must be responsible for achieving the goals and objectives of the program. He should participate in all of the decisions related to the program. This is not now, in all cases, true with regard to solar energy.

There are areas where coordination among the Federal agencies and within the Department of Energy can be improved. The programs appear to be artifically split within DOE to fit an organizational structure designed to develop and demonstrate the more mature nuclear and coal technologies.

In addition, the manpower and experience that other Federal agencies possess have not been brought to bear on energy matters. The all too frequent reply is that DOE "did not coordinate or inform us of its policies." This reply the Panel believes is certainly a phrase which has been overused in order to sidestep responsibility.

If solar energy is to be brought to a state of maturity on an accelerated basis, both a clear, precise, national strategy and sound management will be required. In other words, a coordinated Federal strategy must be developed which can interact with States, localities, consumers, and private sector interests to achieve a balanced national effort.

Appendix

Options
By
Technology

Heating and Hot Water Options

Moderate Option:

I. Relative Program Priorities

A. Increased RD&D to improve system cost-effectiveness. Demonstration of systems which are not cost-effective on the specific applications will not accelerate private utilization.

- Develop more cost-effective collectors by improving thermal performance and durability, i.e., evacuated tubular and lightweight plastic collectors.
- Improve system design concepts, performance analysis procedures, and packaged standardized systems.
- Improve system installation packaging and procedures to reduce costs, improve reliability, and increase the potential for retrofit applications.
- Develop appropriate technology systems for low and moderate income group utilization.
- Accelerate development of and design procedures for solar assisted heat pump systems.
- Develop seasonal storage systems to reduce backup requirements.

B. Change Emphasis of Current Demonstration Program to:

- Reduce the level of active system demonstrations intended primarily for market development and commercialization purposes. Continue demonstrations of innovative projects and systems where there are clear opportunities for additional data and exposure. (Note, however, that the current demonstration program should not be reduced in scale until the NEA is approved or other incentives have been made available, since the current demonstration activity provides a significant part of the solar market.)

- Concentrate on data collection, and dissemination of analysis from present and near-term demonstration projects and from selected projects outside the demonstration program to accumulate the information necessary to promote confidence among installers, purchasers, and users. Specifically, evaluate system performance, reliability, economics, cost-effectiveness, and user-satisfaction.

- Increase RD&D on retrofitting systems in energy conserving buildings/residences.

- Fund demonstration projects based on total energy supply system costs--favoring low cost systems--rather than on incremental solar systems costs.

C. Develop, disseminate and demonstrate innovative passive and combined conservation/passive/active/residential and commercial designs.

D. Strengthen RD&D support and coordination with institutional and financial activities (i.e., train solar workers, develop consensus standards, develop effective warranty programs) to accelerate the use of hot water systems where they are now competitive, and heating systems as they become cost-effective.

II. Legislative and Budget Requirements

No additional legislation appears necessary if Public Law 93-409 is extended for an additional 3 years, provided the extension authorizes these continuing activities. Total budget levels are estimated to stay about the FY 1979 level for hot water and heating, as the demonstration program is reduced, but allocations for new system development should increase (see budget table 1).

III. Staffing

The proposed initiatives do not mandate increased staffing. Ongoing activites have been held back, however, by severely limited program staffs in several agencies, requiring extensive contractor assistance, and by inadequate program budgets.

IV. Impacts

Projections for 2000 range to a considerable degree; 1.0 to 3.0 quads is a realistic projection, but many variables can affect this number in either direction.

TABLE 1

Solar Hot Water, Heating, and Cooling Budget

	FY 1978 (actual)	FY 1979 (requested)	FY 1980 DPR Mod.	FY 1980 DPR High
1. Heating and Cooling Demonstrations	64.4	39.1	36.0	60.0
- Residential[1]	(26.0)	(14.6)	(12.0)	(25.0)
- Commercial[2]	(38.4)	(24.5)	(24.0)	(35.0)
2. Heating and Cooling R&D[3]	19.2	34.1	47.0	70.0
- Development of Demonstrations[4]	(11.0)	(12.0)	(13.0)	(13.0)
- R&D	(8.2)	(22.1)	(34.0)	(57.0)

Notes: [1] Funding transferred to HUD; provides for actual demonstration funding, operation of the National Solar Heating and Cooling Information Center, studies of market development issues, data management activities at NBS, and development of standards and performance criteria.

[2] Commercial demonstrations in DOE include actual demonstration activities, the operation of the data network, funding for management support contractor, and similar items.

[3] Excludes Agricultural and Industrial Process Heat RD&D which in FY 1977, 1978 and 1979 amounted to $10.3, 11.0 and 14.5 million, respectively.

[4] Managed by NASA Marshall Space Flight Center.

TABLE 2

Solar Hot Water, Passive and Active Heating, and Cooling Budget
($ Millions--Budget Authority*)

			FY 1980	
Activity	FY 1978 (actual)	FY 1979 Pres. Request	DPR Mod.	DPR High
Solar Hot Water	11.1	9.2	7.0	10.0
(demonstrations)	(4.7)	(8.0)	(3.0)	(5.0)
Passive Solar	6.8	10.6	16.0	25.0
(demonstrations)	(4.2)	(3.1)	(7.5)	(15.0)
Solar Cooling	37.3	29.3	30.0	50.0
(demonstrations)	(26.3)	(10.5)	(10.5)	(15.0)
Active Heating	44.2	24.1	30.0[1]	45.0[1]
(demonstrations)	(30.6)	(13.5)	(15.0)	(25.0)

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*Excludes NEA provision for $100 million in Federal heating and cooling demonstrations.

[1] Includes either one or two cost shared R&D pilot production facilities for evacuated tube.

High Option:

I. Relative Program Priorities

A. The high option increases emphasis on RD&D programs to develop more rapidly solar heating and hot water concepts included in the moderate option, specifically programs designed to:

- Develop and evaluate economic solar thermal/photovoltaic systems for residences and commercial buildings.
- Evaluate and develop concepts for community or district heating and hot water applications.

B. Conduct demonstrations of the new cost-effective systems and projects.

II. Legislative and Budget Requirements

No additional legislation appears necessary if Public Law 93-409 is extended for an additional 3 years, provided the extension authorizes these continuing activities. Budget levels will increase as additional systems and projects enter the redirected demonstration program (see table--high DPR option).

III. Staffing

Same as moderate option.

IV. Impacts

Same as moderate option, but with higher probability of achievement.

Solar Space Cooling Options

Moderate Option: (approximately the same level as requested by President in FY 1979).

I. Relative Program Priorities

Given the current state of the art and the technical concepts which have been identified, the principal emphasis in solar cooling should be on additional research, development and instrumented field testing.

II. Legislative and Budgetary Requirements

Authorization to continue the solar cooling research, development, and demonstration program through 1982 is proposed by a current amendment to Public Law 93-409. This or similar legislation is necessary to keep the program active.

III. Staffing

Additional staffing will be required to implement this option. This is important; ongoing program activities have been held back by severely limited program staffing requiring extensive contractor assistance.

IV. Impact

The energy savings (quad impact) from solar cooling will probably be relatively small, particularly in the residential sector, before 2000. If accelerated RD&D is successful in developing economically feasible solar cooling equipment, and particularly retrofit equipment, for the commercial/industrial sector, then energy savings by 1990 could amount to approximately .1 to .2 quads. By 2000 the combined effect could range between .4 and .7 quads for all sectors.

High Option:

I. Relative Program Priorities

This option encompasses all elements of the moderate option plus expanded emphasis in the following areas:

A. System Development Activities

- Expand R&D on more cost-effective components (high-temperature collectors, chillers, controls, constant temperature storage, etc.) and system packages.
- Increase passive cooling R&D and, in parallel with the solar heating program, look at combined passive-active solar cooling concepts identifying opportunities to design and test good passive cooling approaches.
- Also in parallel with the solar heating program, develop optimized heat pump systems which make effective and economical use of solar system components to improve performance in the cooling mode.
- Increase R&D into advanced cooling system concepts, especially chemical heat pumps.
- A field testing program to establish performance, reliability, and cost data on cooling system packages, to provide information needed to identify and develop cost-effective pre-engineered, prepackaged systems.

B. Demonstrations

- As cost-effective cooling system packages and approaches are identified for the commercial market, initiate appropriate limited number of demonstration projects.
- Given the current high cost of cooling systems for residential applications, no active solar cooling demonstrations are justifiable (excludes systems field testing).
- A limited number of passive cooling demonstration projects should be undertaken to verify new design concepts for utilization in the residential/commercial sectors.

C. Market Development Activities

- Disseminate information on passive designs for cooling in areas where they are applicable.
- Support development of appropriate standards and certification procedures for solar cooling components and systems.

II. Legislative and Budget Requirements

Authorization to continue the solar cooling research, development and demonstration program through 1982 is proposed by a current amendment to Public Law 93-409. This or similar legislation is necessary to keep the program active.

Additional funding on the order of $100 million is required to support this initiative over a 3-year time frame (see budget attached to heating options paper).

III. Staffing

Same as moderate option.

IV. Impacts

Same as the moderate option, but with a higher probability of achievement and within an earlier time frame.

Agricultural and Industrial Process Heat Options

I. Statement of Opportunity

There exists an opportunity to provide direct solar thermal process heat at temperatures which can significantly affect total United States process heat requirements in the mid and long term. While the following options deal with solar systems, it is stressed that they must be integrated as part of a strategy that includes aggressive energy conservation efforts.

A. Background

The Federal strategy has been to place priority on the application of state-of-the-art equipment rather than systems requiring significant R&D. It has been assumed that R&D in the Solar Heating and Cooling and Solar Thermal program would provide the necessary systems required for intermediate- and high-temperature applications in the mid to long term. Short-term emphasis has been on extrapolating solar hot water and heating technology for agricultural applications (generally temperatures below 212° F) and for demonstrations in industrial hot water and low pressure steam applications (generally, temperatures below 350° F). High capital cost relative to current levels of performance, together with rigid industrial capital investment criteria and short-term payback requirements, act as a disincentive to the use of solar systems in today's markets.

While the half of the potential solar industrial process heat market which requires temperatures above 350°F has started to receive increasing attention in the Federal program, the technology base for these systems is less well advanced, with prototype technical feasibility established only in experimental, limited field-test applications. The scope of these activities is considerably narrower than the scope of technical development required, the scale and diversity of process applications, and the complexity of the economic and other analyses required.

Moderate Option:

The purpose of this option is to maintain the momentum of current programs to reduce costs and increase performance of low and intermediate temperature systems and to retarget programs on higher temperature systems toward early midterm applications. The option would:

A. Continue current level funding RD&D for low and intermediate temperature systems with demonstration applications aimed at improved systems engineering, component cost reduction and improved durability, and the development of system and component performance standards and criteria.

B. In coordination with the Solar Thermal program, identify and initiate a coordinated RD&D program to provide for a carefully controlled, diverse development effort for high temperature systems (350°-550° F, and higher). Such a program would be aimed at establishing system design and an operational data base at a sufficient scale to support a midterm decision regarding the economic/market feasibility by manufacturers for these systems utilizing full or hybrid backup.

C. Review, identify, and prepare a program of agriculture/industry-related financial incentives and credits sufficient to support appropriate level capital investments in the 1985 time frame.

High Option:

This option is similar in outline to the base strategy, with the following exceptions:

The R&D development program for high temperature systems would be accelerated through 1982, and followed in mid-1983 by initiating a large-scale, cost-shared demonstration program involving initially 5 million square feet, with three to four doublings over the following 3 years. The demonstration program would be aimed at reducing system costs to a level sufficient to provide delivered energy costs in a range that is competitive with alternative fuels.

Secondly, industry-related financial incentives and credits would, ostensibly, be available during the same time frame.

II. Legislative and Budgetary Requirements

No legislative impact is foreseen. The estimated budgetary impacts of these options for both DOE and USDA follow.

DOE Current[*]
($ millions)

	(Actual) 1978	(Requested) 1979	Mod. Option 1980	High Option 1980
1) Prototype Systems Design & Field Tests	9.3	10.0	20.0	27.0
o Agricultural	(3.6)	(4.0)	(5.0)	(5.0)
o Industrial	(5.7)	(6.0)	(15.0)	(22.0)
2) Applications Analysis	0.5	0.5	1.0	1.0
3) Standards	0.5	0.5	1.0	2.0
Total	10.3	11.0	22.0	30.0

USDA Current
($ millions)

	(Actual) 1978	(Requested) 1979	Mod. Option 1980	High Option 1980
Agricultural Processes[**]	3.8 (3.5)	4.1 (3.8)	5.5 (5.0)	5.5 (5.0)

III. Energy Impact

The estimated mid- and long-term energy contribution for these options is estimated as follows (in quads):

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[*] The Solar Heating and Cooling Program adds $2.0 and $7.0 million, respectively, for A&IPH R&D. This funding is supported by the Panel.

[**] Includes passthrough funds shown for Agriculture in DOE budget (in parentheses).

	1985	2000
Moderate Option	0 - .05	1 - 2
Accelerated Option	0 - .1	2 - 3

Solar Thermal Options

Moderate Option:

I. Relative Program Priorities

A review of the solar thermal program and available reports and studies suggests that, except for trough collectors, the market-pull proposals (the repowering and large-scale dispersed cycle initiatives) be deferred until further component development has taken place and system operating data have been acquired from, for example, the Barstow facility. The proposals represent opportunities for early market penetration of innovative but untested technology, industry infrastructure development, and system cost reductions, but they should be carried out in an orderly way so that transfer of knowledge can occur between successive cycles. The specific reommended priority areas within the program are as follows:

A. Increase R&D to improve efficiency of receivers, collectors, heat transfer, storage, and small heat engine subsystems, and develop hybrid solar/fossil-fuel systems (both electric and thermal).

B. Complete the Barstow facility to obtain operating data. Phase large-scale repowering experiments to allow experience from the Barstow facility to be incorporated in the experiment design and to permit incorporating progress in R&D on materials, systems, components, and advanced and alternative concepts. Hardware purchases would be initiated after completed RD&D indicates the direction of efficient designs and the readiness of suitable components.

C. Complete detailed market analyses to ascertain the scope, viability, and utility participation in the repowering strategy, as well as the extent and nature of potential dispersed applications markets. The latter should be done in cooperation with the Agricultural and Industrial Process Heat program which addresses many of the same markets.

D. In coordination with the Agricultural and Industrial Process Heat program:

1. Continue expanded R&D on dispersed energy systems for local communities, farms, small businesses, industry, and decentralized utility load centers. Demonstrations should favor small-application experiments and industry incentives to encourage innovations, cost reductions, small business ventures, and solar industry development.

2. Initiate RD&D efforts in high-temperature technology for energy-intensive industrial process heat requirements, such as chemicals, synthetic fuels, feedstocks, and building materials.

II. Legislative and Budgetary Impact

No new legislation would be required. A budget increase relative to the FY 1979 program would be warranted. (See Table 1.)

III. Staffing

Staffing levels would increase with the size and scope of the overall program.

IV. Impacts

An addition of 0.2 to 1.0 quads of energy supply by the year 2000 plus facilitating the significant quad impacts cited in the Agricultural and Industrial Process Heat option paper.

High Option:

I. Relative Program Priorities

This option emphasizes fast deployment of near-term central power-tower technology and seeks cost reductions by mass production of current hardware. Parallel large-scale demonstrations would be instituted for the purpose of generating sufficient demand to encourage construction of mass-production facilities. A similar strategy would be pursued for dispersed repowering applications.

The objective of this option is to accelerate the rate of market penetration to make the earliest possible energy impact while still pressing for the development of the next generation solar thermal technology.

Development of advanced technology would continue at an accelerated pace to reduce systems costs through increased efficiency of components and to encourage the development of new concepts.

II. Legislative and Budgetary Requirements

Program budgetary requirements in FY 1980 would be about $181 million. (See Table 1--High DPR Option.)

III. Staffing

Staffing will increase with the size and scope of the program.

IV. Impact

This option could have an impact of 1 quad of energy supply by the year 2000 plus facilitating the significant quad impacts cited in the Agriculture and Industrial Process Heat option paper.

DOE Solar Thermal Budget

	Requested FY 1979	DPR Mod. FY 1980	DPR Acc. FY 1980
Dispersed Applications	28.0	34.2	52.8
- Total Energy Systems	(14.0)	(18.2)	(30.0)
- Small Power Systems	(14.0)	(16.0)	(22.8)
Large-Scale Applications	27.0	30.0	50.0
Advanced Thermal Technology R&D	14.0	30.0	35.0
Capital Equipment	3.0	3.9	3.9
Construction (Barstow)	28.0	39.0	39.0
Total	100.0	137.0	180.7

Photovoltaics Option

Moderate Option:

I. Relative Program Priorities

This option would rationalize or systematize RD&D searches for cost-effective photovoltaic energy system components, through concept R&D, process technology development, and systems engineering applications tests. The "market pull" approach would be deemphasized, and at least postponed until cost objectives for arrays and the balance of systems (BOS) are reached or pathways for reaching them in the near term are foreseen. The moderate option consists of the following key building blocks:

A. Continuation of high levels of support for advanced collector R&D concepts.

B. Expansion of process technology development for collectors to include qualified[1] advanced concepts emerging from the laboratories.

C. Expansion of innovative engineering approaches to balance of systems (BOS) costs.

D. Strengthening of systems tests, evaluations and engineering, mission analyses, standards, and information exchange.

E. Continuation of low-to-moderate levels of systems applications demonstrations[2] primarily to obtain performance, economic and institutional data and to introduce photovoltaics to identified potential markets.

F. Limited process production experiments on a cost-shared basis with the private sector; including polysilicon processes (EPSDU's in the 100 Te/year size range), cell (or surface) production processes, and module production processes.

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[1] "Qualified" with regard to carefully developed and applied criteria (as yet nonexistent).

[2] The National Energy Act would require Federal photovoltaic purchases of $98 million over the 3-year period (FY 1979, 1980, 1981).

G. Detailed examination and evaluation of international, notably LDC, market potential.

H. Upgraded environmental research into potential impacts (both positive and negative) of a mature photovoltaics industry.

I. Exploration of "nonconventional" photovoltaic concepts, e.g., hybrids and photothermochemical systems.

II. Legislative and Budget Requirements

No new legislation would be required. This option would increase funding for advanced concept R&D and would require a budget about 30 percent larger than the revised FY 1979 budget level.

III. Staffing

Increasing the staff is warranted to improve the ongoing program management, particularly of the evaluations of energy system characteristics and to reduce the role of contractors for overall program, as contrasted to project, management.

IV. Impact

Studies indicate little, if any, meaningful energy impact by 1985. Estimates for the year 2000 vary from 0-5 quads with an average of 1 to 2 quads. Any quad impact must, of course, embody major commercialization of photovoltaics of which a necessary (though not sufficient) precursor is the meeting of cost goals and the availability of acceptable, reliable systems--the objectives of the RD&D program.

High Option:

I. Relative Program Priorities

This option seeks to accelerate Federal RD&D by forced development of collector process technology. A demonstration effort would be continued at a slightly higher level. Substantial RD&D increases are proposed in DOE preliminary FY 1980 planning for advanced collector R&D, and silicon production pilot plant construction would be increased.

New emphases recommended in the moderate option would also be reflected in this option. In the high option, the following would be added to the moderate option.

A. Immediate assessment of the status of existing advanced concepts and subsequent initiation of substantial technology development (e.g., in production processes) for the most promising two (or possibly more) concepts.

B. Accelerated installation of pilot production facilities.

II. Legislative and Budget Requirements

No new legislation would be required. A major budget increase, approximately a doubling of the revised FY 1979 levels, would be required over a sustained period of time as shown in the photovoltaics budget table.

III. Staffing

Additional staffing would be required, both to implement this option and to improve the management of ongoing programs.

IV. Impacts

Same as moderate option, but with higher probability of achievement.

DOE Photovoltaic Funding*

	1978 Actual	1979 President Request	Option 1 1980	Option 2 1980
Advanced R&D	8.7	35.0	47.0	60.0
o Collectors	(8.7)	(35.0)	(45.0)	(55.0)
o Nonconventional	(0)	(0)	(2.0)	(5.0)
Technology Development	36.0	40.8	59.0	92.0
o Flat Plate Processes	(32.7)	(27.0)	(33.0)	(50.0)
o Concentrating Collectors	(3.3)	(13.8)	(17.0)	(20.0)
o Advanced Processes	(0)	(0)	(0)	(10.0)
o Silicon Production	(0)	(0)	(9.0)[1]	(12.0)
System Support Engineering (including BOS)	9.5[2]	9.3[2]	15.5[4]	25.0[2]
Tests and Applications[3]	19.2	16.6	12.5[4]	20.0
Missions and Standards	3.3	3.6	5.0	5.0
Environmental	0.4[3]	2.7[3]	1.0	1.0
Total	77.1	108.0	140.0	203.0

[*] All number B.A. (Budget Authority) in millions for programs administered by Assistant Secretary for Energy Technology.

[1] Includes silicon production process <u>pilot</u> facilities on a cost-shared basis (100 tons/year).

[2] BOS engineering evaluations and technology development included. Storage program funding of $0.75 million included in $3.5 million BOS work in FY 1978, 1979 and 1980. Option 1 provides $5 million increase for BOS technology development and Option 2 provides $10 million.

[3] Includes $0.15 million from EPA and $2.3 million from DOE/CS - no CS funding in FY'80 options.

[4] $98 million for Federal purchases of photovoltaics is required in the NEA (over a 3-year period). Additional purchases of photovoltaic systems for testing and system engineering purposes should be financed through this mechanism, the so-called "FPUP."

Biomass Options

I. Relative Program Priorities

A sound strategy for Federal biomass RD&D must actively involve all existing programs in developing priorities, planning work, and implementing research. The management mechanism linking DOE with other agencies' biomass RD&D should be strengthened. Greater use should be made of centers of biomass-related energy RD&D, technological expertise, legislative authority, and pragmatic opportunities that exist primarily in USDA and EPA. The efforts of all Federal programs must be drawn together to implement a national strategy for the development of biomass. Further, within the various agencies, particulary DOE, there is a need to clarify and define management responsiblity for biomass programs.

Moderate Option:

A. Concentrate development and demonstration efforts to exploit the most promising near-term energy yield. Near-term potential processes to be emphasized should include demonstration of direct burning for industrial process heat, and development of better systems and equipment for collection of forest and agricultural residues. Emphasis should also be placed on development and demonstration of effective end use of products from municipal, animal wastes, forestry, and agricultural residues. RD&D programs to demonstrate vehicle use of fermentation-derived gasohol should be supported where they can contribute to improving process efficiency and economics.

B. Institute a balanced program of applied research to support development of technologies having intermediate and long-term potential. Applied research should cover screening of candidate biomass species for various regions of the country, parallel development of harvesting collection, and storage equipment and processes most suitable for various combinations of biomass source and end use, and overall system analysis of the proposed combinations needed. Applied reseach should emphasize as well the study of a variety of biochemical and thermochemical conversion processes yielding alternative fuels and chemical feedstocks, research and development of more efficient separation and purification processes of product fuels and chemical feedstocks.

C. Support a limited number of innovative projects, beyond the structured research program, that may be proposed by states, individuals, and organizations.

D. Expand agricultural and forestry statistical data to provide and maintain up-to-date site- and application-specific information on land, residue, crop, and timber availability for commercial and farm users in their planning and design processes.

E. Initiate a comprehensive commercialization program for near-term potential processes.

High Option:

Expand the moderate option to include the following:

A. Additional near-term demonstrations of small and medium biomass-fired process heat burners and electric generating plants through cost-shared funding.

B. Multiple demonstration farms representing differing species and geographical areas.

C. Development of production and collection equipment for biomass species.

D. Accelerated work on marine biomass production and collection.

II. Legislative and Budgetary Requirements

New legislation is not required to implement this option. Budgetary requirements, starting in FY 1980, would be increased with like funding levels for subsequent years (see following tables).

III. Staffing

Increase the professional and nonprofessional program staff to levels appropriate to the size of the Federal program, and avoid the use of contractural personnel for program management purposes.

IV. Impacts

The more than 1.3 quads of current biomass use may be increased in the moderate option by 0.3-1.0 quads by 1985, and by 3.0 quads by 2000. The high option could increase the year 2000 level to 7.0 quads.

FY 1980 Budget for Biomass Options
(millions of dollars)

DOE Resources, $ millions

	Current 1978	Estimated 1979	Moderate Option 1980	High Option 1980
Direct Combustion	2.0*	2.2*	7.0	16
Anaerobic Digestion	1.8	4.0	8.0	12
Fermentation	2.5	5.5	7.0	12
Thermochemical Conversion	6.5	9.5	26.0	30
Production and Harvest	6.2	9.7	19.0	24
Basic Research	0.4		2.0	4.0
Innovative Programs	0		1.0	2.0
Other	5.0	7.0	0	0
Total	24.4	38.1	70.0	100.0

*Includes 1.2 in Power Systems Divisions

EPA Resources, $ millions

	Current 1978	Estimated 1979	Moderate Option 1980	High Option 1980
Waste Collection & Processing	1.0	1.0	3.5	3.5
Direct Combustion	1.6	1.6	3.1	5.6
Anaerobic Digestion	0.4	0.4	0.5	0.5
Thermochemical	0.3	0.3	2.0	4.5
Pyrolysis	0.9	0.9	0.9	2.0
Environmental Assessment & Control	0.7	0.8	1.0	1.0
Total	4.9	5.0	13.3	17.1

FY 1980 Budget for Biomass Options
(millions of dollars)

USDA Resources, $ millions

	Current[1] 1978	Estimated[2] 1979	Moderate Option[2] 1980	High Option[2] 1980
Biomass Inventory in plants	0	0	1.0	2.0
Production and harvest, agriculture	0.7 (0.1)	2.8	3.0	7.0
Production and harvest, forest	0.5 (1.0)	0.5	2.5	9.0
Production and harvest, aquatic	0.1	0.1	.5	4.0
Residue collecting and processing, agriculture	0.1	0.1	3.5	5.0
Residue collecting and processing, forestry	0.1	0.1	4.0	4.0
Fermentation and other biochemical processes	2.0	2.1	3.0	5.0
Basic Research	0.5[3]	1.2	2.0	2.0
Total	4.0	6.7	19.5	38.0

[1] Figure in parenthesis indicates additional funding through DOE reimbursements.

[2] Passthrough DOE funding recommended by DPR not shown.

[3] Estimated from prorating resources on photosynthetic efficiency program.

Ocean Energy Conversion Options

OTEC systems are in the component design and evaluation phase; all other ocean energy conversion systems are in the exploratory development/ concept evaluation phase. Concerning OTEC, a number of technical problems must be solved. and design and engineering approaches to their solution must be found which are economically feasible. Current assessments of the cost of OTEC systems are highly uncertain because complete systems have not been designed and because fundamental design approaches have not been demonstrated. Continued component development should lead to less uncertain economic estimates. However, the economic viability of OTEC systems will not be established without the construction and deployment of an experimental facility (about 10MW) that may lead to resolution of OTEC's technical uncertainties.

Moderate Option

I. Relative Program Priorities

A. OTEC

- Adopt a low-risk, serial development schedule leading to 10 MWe OTEC experiments. Continue to narrow the economic uncertainties associated with component performance. Initiate conceptual design work for the 10 MWe experiment in FY 1980. Following thorough evaluation of OTEC-1 results, a decision to proceed to the construction phase could be made in FY 1982, with operation scheduled to begin in FY 1986.

- Modestly advance exploratory development efforts on alternative OTEC systems such as open cycle, hybrid systems, and foam and mist.

- Increase substantially efforts to assess the technical and economic feasibility and potential environmental impact of deploying full scale (200-400 MWe) OTEC systems.

B. Other Ocean Systems

- Expand the collaboration on the wave energy electric option recently begun under the auspices of the International Energy Agency.

- Fund at a low level thorough assessments of the resources. conceptual designs, and critical research (e.g., membrane technology for salinity gradient conversion) for the extraction of ocean energy accessible to United States coastlines and islands in the form of waves, ocean currents, salinity gradients, and tides.

II. Legislative and Budget Requirements

New legislation would not be required nor would there be significant budgetary impacts (see budget table for figures).

III. Staffing

If the current management approach of substantial Federal involvement in design selection and system configuration is to continue, increased staffing will be required.

IV. Impact

A commercial OTEC system serving island economies could be operational by 1995. OTEC plants serving the United States mainland would likely be operational after the year 2000.

High Option:

I. Relative Program Priorities

Adopt a parallel development schedule for 10 MWe experiments. The design basis for the 10 MWe system would be the results of shore-based component tests and the early results of OTEC-1. If these results are judged favorable. preliminary design could begin in late FY 1980 followed by detailed design and construction in FY 1981. Operations would begin in FY 1984. If this option is chosen, clear go/no-go decision points should be established before proceeding with either preliminary design or construction. The program should assure that the data required for such decisions will be available. Other items of the moderate risk option remain unchanged.

II. Legislative and Budget Requirements

New legislation would not be required. For FY 1980, the total budget for this option is increased slightly to fund preliminary design work. Significant budgetary impacts would occur after FY 1981 since a 10 MWe experiment will require a capital outlay of approximately $100 million spread over 3 to 4 years.

DOE Budget*
($ millions)

	FY 1978	FY 1979	FY 1980 (DPR-Mod)	FY 1980 (DPR-High)
OTEC	35.3	32.5	35.0	40.0
Other (Waves, currents, etc.)	0.6	0.7	5.0	5.0
TOTAL	35.9	33.5	40.0	45.0

*It should be noted that NOAA has a high priority interest in this program area and their participation should be expanded.

III. Staffing

Same as the moderate option, except in early 1980's staffing requirements rise if it is decided to proceed with the 10 MWe experiment.

IV. Impact

Commercial OTEC systems serving island economies could be operational during the 1990's. Although commercial systems serving the United States mainland could be operational by 2000, a significant impact is not expected until after 2000.

Small-Scale Hydropower Option

(Only one option)

I. Relative Program Priorities

A. Federal and state assistance to develop hydropower should be offered to the owners of SSH sites. This assistance should be general in nature. Furthermore, consideration should be given to the removal of duties on foreign machinery if it is determined that this action would appreciably enhance market penetration.

B. Strong attention should be given to removal of institutional, regulatory, and environmental constraints.

C. Funding currently planned for demonstration activities is not critical and, therefore should be eliminated. Funding for basic R&D is not vital to the resolution of the key difficulties facing this technology.

II. Legislative and Budgetary Requirements

Minimal Federal, but some state, legislative changes would be needed to exempt small-scale hydropower from general hydropower provisions appropriate only to large-scale developments. No specific RD&D budgetary appropriations are required.

III. Staffing

The RD&D Panel believes that the DOE RD&D support staff in this technological area is sufficient.

IV. Impact

The RD&D Panel estimates the impact of this option would be about 5 to 10 GW (0.2 to 0.4 quad) by 2000.

Heat Engine Option

(Only one option)

I. Relative Program Priorities

- Speed the development of solar-powered heat engines using proven engine concepts by development of specific devices, such as small generators and total energy systems, that include a heat engine. Considerable engineering is required to tailor a proven engine design to specific application and this should be done in the appropriate solar energy programs.
- Accelerate the development of advanced heat engines (for example, closed-cycle Brayton and Stirling engines which might be powered by solar energy or fossil fuels), in a coordinated program directed specifically at developing engine components and materials that are needed to make reliable high efficiency heat engines available.

II. Legislative and Budgetary Requirements

No additional legislation appears necessary. Increased budget would not be required in FY 1980 for advanced heat engine development. However, in the outyears, budgetary levels should be expected to rise considerably.

III. Staffing

No staffing impacts are associated with this option.

IV. Impacts

Heat engines are components of larger solar energy systems. Early availability of low-cost and high-performance devices could accelerate the use of solar for electrical generation, pumping, or industrial and agricultural uses.

Windpower Options

Moderate Option:

I. Relative Program Priorities

A. Improve assessment of the accessible national windpower resource and its regional distribution.

B. Develop commercialization plans based on substantial use of windpower as soon as practicable.

C. Develop a wider range of wind energy options in both large and small systems.

D. Give more emphasis on systems costs associated with the use of windpower on the grid.

II. Legislative and Budgetary Requirements

No new legislation is required by this option. A small increase in the DOE budget would be required for wind assessments in 1979 and a somewhat larger one in FY 1980 and FY 1981 to support parallel systems.

III. Staffing

Additional staff will be required by this option to augment what appears to be an undermanned staff for managing ongoing programs.

IV. Impacts

Approximately 0.5 to 1.0 quads/year of energy from fossil fuels could be displaced by the year 2000. Significant added impact could be expected to come from integration with hydrostorage.

High Option:

I. Relative Program Priorities

This option expands the moderate strategy to include:

- Additional wind energy systems demonstrations in remote non-network utilities, irrigation pumping, agricultural, rural, residential, and industrial applications, and appropriate technology settings.
- Simultaneously develop a wider range of wind machine designs (for example, vertical-axis machines) and address a wider range of specific applications.
- Establish by 1980 a commercialization program including financial and other non-RD&D incentives.
- Initiate the active involvement of Federal power agencies in the demonstration and commercialization of windpower. This should include detailed wind siting and economic and environmental assessments leading to the cost-shared development of multiunit wind farms.
- Identify private and public utilities that may be interested in or are highly suitable candidates for windpower. Initiate detailed siting, economic and environmental studies leading to cost-shared demonstration programs.

II. Legislative and Budgetary Requirements

It is estimated that the budget would increase to about $100 million in FY 1980, with further increases anticipated until the early- to mid-1980's, when financial incentives will be more appropriate to accelerate market introduction (see table attached). Depending upon the financial incentives adopted, legislation may be required. Legislation may also be required to allow the Federal Power Agencies to actively participate in the demonstration/commercialization of windpower.

III. Staffing

Significant additional staffing would be required to implement this option.

IV. Impact

Additions to the primary energy supply of up to 2 quads/year by the year 2000.

DOE Wind Energy Program
($ millions)

Program Element	Actual FY 1978	Requested FY 1979	DPR Mod. FY 1980	DRP High FY 1980
Program Development and Technology (Wind Assessment)	9.3	10.7	15.0 (1.0)	25.0 (8.0)
Small WECS	8.5	11.6	12.0	15.0
Intermediate WECS	3.3	4.1	8.0	15.0
Large WECS	18.2	30.3	30.0	30.0
Systems Demos and Studies	2.0	4.0	9.0	15.0
Total	41.3	60.7	74.0	100.0

Energy Storage Option

(Only one option)

I. Relative Program Priorities

Short duration energy storage is needed with solar energy devices whether they are used for electric power generation, space conditioning, water pumping, or industrial processes. There will always be a need for buffering storage to smooth transients caused by passing clouds and weather; and maintain systems controllability and reliability. Some facilities may require more storage (several hours) to facilitate startup and other normal systems transitions. These requirements are dictated primarily by the nature of the solar devices themselves rather than by the nature of the energy load being served. Short duration storage, however, could meet the needs of solar devices installed for intermittent or "fuel saving" operation assuming storage systems are matched to specific end uses.

High performance energy storage is not on the critical path for the use of solar energy in the near term, but it will be essential as the nation places increasing reliance on solar energy. As solar energy use becomes more extensive and diverse, the need to decouple the intermittent solar source from an independently varying load can become paramount.

Additional storage becomes necessary, but its nature and quality will depend on a number of complex factors such as backup fuel price and availability, the mix of solar and conventionally fueled devices, the coincidence of sunlight with the daily requirement for energy, and the seasonal relationship between solar intensity and heat or power demanded. Depending on the application, storage will be dedicated to the solar components of a system or shared with backup and complementary energy sources. It could store heat or electricity for intermediate to long time periods, store heat at high or low temperatures, or, in the case of total energy (cogeneration) systems, be cascaded over a range of storage times and temperatures.

The current storage programs within DOE are an important element in developing solar technology, but they need increased focus on concepts tailored to solar applications. Specific areas of increased RD&D funding for solar storage technologies are:

- Thermochemical technologies for systems requiring extended duration storage.

- Early assembly and examination of a family of storage technologies to match the specific solar end uses for the agricultural and industrial process heat markets.

- Accelerated development and field testing of chemical heat pumps for utilization as a cooling, heating, and storage technique.

II. Legislative and Budgetary Requirements

No additional legislation appears necessary. Increased budgetary emphasis for basic R&D within existing program budgetary levels is recommended in FY 1980. However, over the ensuing 5-year period additional funding beyond present levels would be necessary to implement this option.

III. Staffing

No staffing impacts are associated with this option.

IV. Impacts

Storage's contribution to energy supply derives from the fact that it constitutes a component of a larger energy system. Early availability of low-cost and high-performance storage could accelerate the use of solar supply sources.

TAB A

Technology Evaluation: Solar Space and Water Heating

I. Current Engineering/Scientific Status

It is generally agreed that the use of solar thermal energy to heat building space and provide hot water is the solar technology most nearly ready for widespread commercial application. Encouraged by the Federal solar program, a rapidly growing industry is now offering a number of different solar systems on the open market at this time.

However, this industry is not yet mature, and a number of problems must be addressed in order to utilize solar heating fully as a major national energy source.

A. Public Interest: Why Heat with Solar Energy?

The rapid growth of the solar heating and hot water industry reflects a parallel increase in the public awareness of solar heating. Some of the public perceptions and technical facts leading to this awareness are the following:

- Solar energy is inexhaustible and free.
- As a low-density energy source, it is particularly useful for small, individually controlled applications.
- The technology is simple and harmless to the environment.
- Solar heating dates back many years, and a technical information base is developing from the program and from the private sector.
- Analytical procedures exist to predict the performance of solar heating systems; these procedures now include the analysis of passive solar heating systems, which still require validation.
- An industry infrastructure has emerged since 1974, supporting an active industry association.
- Conventional space and water heating costs have risen to the point that many homes have winter energy costs as large as mortgage payments.

- Newspapers and magazines are routinely carrying articles on solar energy, and the National Solar Heating and Cooling Information Center is providing additional information to hundreds of thousands of people.

B. Solar Heating and Hot Water Systems: How They Work

A solar heating or hot water system is simple in concept: a collector receives and absorbs solar radiation, converting its energy to heat; a transfer fluid (such as water or air) picks up this heat and transfers it to storage or to the point of use; the storage subsystem retains the heat energy for use when there is no sunlight or when the demand for energy is greater than that being provided by direct sunlight; a distribution subsystem (normally part of the conventional heating or hot water system) distributes the energy to the point of use; and the control subsystem coordinates and controls the entire operation.

These functions are required whether the system is "active" (requiring outside energy operating through special equipment to transfer energy), "passive" (utilizing natural energy flows to transfer energy), or "hybrid" (involving a combination of the two).

1. Active Systems

Active solar heating and hot water systems are generally characterized by the use of specialized components to perform the functions of a solar system; typically, they are as follows:

- The collector usually consists of a metal absorber plate with a special surface coating, mounted in an insulated enclosure protected by one or more transparent covers to reduce convective losses.

- The transfer fluid may be either a liquid (water with or without additives, or silicone, or hydrocarbon oil, for example) or a gas (air is most common).

- The type of collector and transfer fluid determines the storage subsystem to be used. Liquid systems usually employ large insulated storage tanks, sometimes with heat exchangers to minimize the amount of fluids needed or to reduce toxicity hazards.

Air systems usually use rock-bin storage subsystems, but interest is growing in the use of phase-change salts to reduce storage volume and provide precise storage temperature controls.

- The distribution subsystem most commonly utilizes the conventional heating or hot water system, often with heat exchangers to transfer the heat energy to the distribution medium.

- The control subsystem for an active solar system usually consists of sensors measuring collector and storage temperatures, appropriate processing and switching elements, and in some cases microprocessors to provide specific control functions.

The output of an active system generally is hot air or hot water at temperatures between 120°F and 200°F, although some systems operate at lower temperatures.

The optimum size for an active solar heating or hot water system depends upon both technical and economic factors. Technical factors include the energy demand, insolation levels, system efficiency, and lifetime, and maintenance requirments. Economic factors include system installation and operating costs, interest, competing conventional energy costs, and similar items.

2. Passive Systems

Passive systems are generally defined as systems that do not use electrical or mechanical energy to circulate or transfer the collected solar energy. In practice, this definition can be stretched to permit the use of low-horsepower fans to assist in distributing the collected energy.

Most passive systems involve elements of the building structure to perform the system functions:

- Solar energy is received through transparent areas such as south-facing windows or greenhouses and collected as it impinges on walls, floor slabs and other elements of the building mass. The increase in temperature of this building mass provides the storage.

- The collected and stored thermal energy is transferred by conduction and/or radiation to the building space or by convection of air heated by the warm storage mass. This flow of energy distributes the heat to the building areas, occasionally helped by low-power fans.

- Control of a passive system involves shading the receiving/collecting area when solar energy is not needed, insulating the receiving area when the net energy flow would be outward, and modulating the energy flow within the building to keep internal temperatures within comfort limits.

These control functions may involve drapes, removable panels, dampers, transfer fans, and similar devices. The control complexity can increase as the design attempts to minimize temperature swings in the building space. Typically, a conventional heating system may vary ± 3°F from the base thermostat setting; many passive homes today operate on a ± 10°F swing. The use of phase-change materials as passive storage devices can provide a much closer temperature control.

Architectural techniques to maximize winter solar gain and minimize summer solar gain have been known for many years. However, designers have paid little attention to these techniques in recent years due to the low cost of energy needed to provide an acceptable indoor climate.

With the rapid increases in energy costs and the high price of active solar systems, passive solar energy concepts are receiving renewed attention, for several reasons: (a) because they use the building structure, they usually cost less; (b) they generally are mechanically simple and require little maintenance; (c) it is easier to provide a 'partial passive' project which provides energy savings but at lower costs; (d) there is less need for specialized materials and equipment; and (e) passive designs may be more esthetically acceptable than some of the current active system designs.

Also, analytical techniques to predict the effective contribution of a passive system to building energy demands are now available, and attention is growing on the use of joint passive-active systems which can utilize the active system to minimize the temperature swings of many passive systems.

3. Hybrid Systems

In many applications, the most appropriate solution may be a system that permits some energy transfer through natural means and uses outside energy for other energy flows. Such systems are called "hybrid" systems; they can be analyzed through a combination of active and passive analysis methods.

C. System Applications: How They Are Used

The type of system selected for a particular application will depend upon the requirements of that application, but some general guidelines apply to all applications. In general, no solar energy system should be considered without first analyzing the energy demand and the methods used to reduce this demand. Energy conservation analysis is the first step in designing a solar system.

1. Energy Conservation

It has been estimated that a given investment in energy conservation in a building built before 1970 will save three times the energy that can be provided by an equivalent investment in a solar energy system. This situation leads to two conclusions: First, in designing a new solar building, start with energy conservation features. Second, do not consider installing a solar heating system in an existing building without first determining what energy conservation features can be provided.

For longer-range planning, under provisions of Title III, Public Law 94-385, HUD and DOE are developing thermal performance standards for all new buildings to be implemented in the 1982 to 1985 time frame. As buildings of greater energy efficiency are built, the investment and size of solar heating systems can be reduced and be more cost effective.

2. Domestic Hot Water Systems

Solar domestic hot water systems are economically feasible now in many parts of the country in competition with resistance electric water heaters, in part because they have a useful output throughout the entire year. Also, since their efficiency is not significantly affected by the presence or absence of energy conservation in the basic building, they can be effective in retrofit applications. If an active solar heating system is installed, addition of a domestic hot water system is a relatively simple matter.

3. Heating Systems in New Construction

Designs for new building with solar heating systems should consider energy conservation first and then look at both passive and active solar systems. The final selection will depend upon many factors, both technical and economic.

4. Heating Systems in Existing Construction (Retrofit)

While the size of the stock of existing buildings make an attractive target for the use of solar heating, the actual applicability of solar heating to an existing building will depend upon whether the building has been fitted with effective energy conservation measures, whether it is correctly oriented with respect to the sun (or whether there is adequate area for a ground-mount collector), and whether existing vegetation or other buildings could shade the collector area during significant parts of the day.

The cost of installing retrofit solar systems can be considerably higher than the cost of installing the same system in a new building because each building is unique. "Packaged" systems can help overcome this problem, just as similarly packaged systems helped speed commercialization of residential air conditioners.

5. Appropriate Technology

The term "appropriate technology" is used to describe those approaches that are less expensive and less sophisticated but can make a contribution in reducing energy demand or providing additional energy in certain low-cost housing applications. Some passive solar approaches, the use of "direct gain" solar systems (primarily passive solar approaches that provide no significant storages mass but can reduce daytime demand for conventional energy), and simple active systems fall into this category. Appropriate technology also addresses applications that can be installed by the homeowner.

II. Economics and the Market

Solar heating and hot water systems can be characterized in general as one-time investments with a long-period payback from reduced operating energy requirements. Annual maintenance and operating costs will be relatively minor with quality systems. The generally high first cost of most active systems has proven to be an important barrier to the rapid development of a solar heating and hot water system market, partly because of the importance of price competition in the building market. The effect of the high initial costs can be reduced in two ways, by directly reducing system costs and by encouraging economic decisions to be based on the "life-cycle" cost, which reflects the energy savings to be obtained from the system. Acceptance of the life-cycle cost approach depends on the development of recognized procedures to analyze these costs.

A. Economic Analysis Procedures

While commercial and industrial building owners and many apartment owners take operating energy costs into consideration in estimating project feasibility, this approach is not common in the single-family market. Analyzing the impact of savings from a solar energy system involves consideration of many variables, including system installation and operating costs, current and projected prices of conventional energy and of money, system performance estimates, and similar items.

A number of computer modeling procedures are now available to carry out these analyses. Acceptance by the building industry and its financial sources is essential to such analyses having an impact on the solar market.

Recently, practical and objective system evaluation procedures have been developed for passive solar energy systems, permitting similar economic feasibility studies for life-cycle costs and benefits of passive installations.

B. Current System Costs

Accurate data on installed solar system costs is limited, partly because of a relatively small sample and partly because many builders do not keep accurate project cost information. Based on industry comments and the Federal demonstration program, however, the cost ranges are as follows:

1. Active Systems

A recent DOE study estimated active system costs varying from \$25/ft^2 to \$40/ft^2 of collector area; systems in the first three cycles of the HUD residential demonstration program had an average installed cost of \$32.77/ft^2 collector area.

2. Passive Systems

Estimating passive system costs is more difficult, since many of the building elements involved in receiving, collecting, storing, distributing, and controlling the energy flow are parts of the building structure.

In general, incremental costs for the limited number of passive products in the Federal residential demonstration program have run from about $5000 to about $8000 for custom-designed houses of 1500 to 2000 ft^2. Independent analysis of potential passive design techniques indicate costs of $2000 to $3000 for a passive system. By comparison, active system costs for the same size home have run from about $8000 to about $12000.

3. Cost Parameters

The traditional way to compare the cost of solar installations has been to report the cost of the installation in terms of collector area, as reported above. This is a useful way to compare general cost ranges, but it is misleading when used to compare alternatives for given installation, since it does not reflect system effectiveness.

Two alternative measurements are being used in the Federal program. One measures the system cost in terms of energy delivered over its lifetime--"dollars per million Btu delivered" over the total system operating life. This provides a comparison of system effectiveness and cost. The second method reports the system cost in terms of energy delivered to and used by the building in a design year--"dollars per million Btu used" in one year. This provides a figure of merit with respect to a specific installation, useful in comparing alternatives but not necessarily giving a full picture of the cost savings. Each approach has its merits; both are relatively easy to determine. A system designed to use the collectors throughout the year, as in a solar heating and cooling system, can reduce the cost/energy unit.

D. Solar Energy Installations in the United States

The number of solar installations now operating in the United States is not known. The National Solar Heating and Cooling Information Center has estimated that approximately 40,000 to 50,000 installations currently exist but points out that these estimates are based on fragmentary data.

The Federal demonstration program currently includes some 160 operating projects involving over 1,400 residential dwelling units and more than 50 commercial/industrial installations. It has been estimated that over 17,000 residential dwelling units and about 400 commercial/industrial projects will be involved in the 5-year demonstration program authorized by Public Law 93-409.

Serving this market is an industry consisting of several thousand manufacturing, distribution, and installation firms, ranging from some of America's largest industrial giants to small, local plumbing and heating contractors. The growth of the industry is shown by membership in the Solar Energy Industries Association; first organized in 1974, it now reports a membership of almost 1,000 firms from all parts of the industry.

III. Federal Strategy and Goals

Direct Federal support for solar heating and cooling began under the National Science Foundation (NSF) in 1971, with limited funding for the first 3 years. In FY 1974, the NSF solar budget was $6,200,000 to provide support for the Phase 0 studies and for several test installations.

The current Federal program was authorized by Public Law 93-409, which directed HUD and NASA to establish a 5-year program. Enacted September 3, 1974, this legislation was followed by legislation creating ERDA and assigning overall responsibility for solar energy to the new agency. Early in 1975, a formal program plan for the solar heating and cooling program was adopted and published; as stated in the current version of the plan, the goal is:

> "... to assist in the early establishment of a viable solar industry for the design, manufacturing, distribution, sales, installation, and maintenance of solar heating and cooling systems."

The program strategy consists of the following elements:

- Research and technology development of new and advanced system approaches and subsystems or components to reduce costs, improve reliability, and provide solutions to problems;
- Engineering development aimed at bringing system, subsystems, and components to a marketable stage for utilization;
- Demonstration of solar heating and cooling in commercial and residential buildings, using available systems installed in both new and existing buildings and the associated collection, evaluation, and dissemination of data and the development of standards and performance criteria;

- Market development to assure that an institutional framework exists for widespread use of solar energy, including technology transfer, environmental, and resources assessment, and studies of barriers and incentives.

Appendix A lists the participants in the Federal program, describes the current status of that program, and reports other Federal solar activities.

IV. Advanced Concepts and Development Opportunities

The technical basis for solar heating and domestic water heating is fairly well known and accepted. However, the foregoing discussion has indicated that problems still exist in system costs, system quality control, and overall system performance.

An analysis of baseline flat-plate collector costs made 2 years ago by Arthur D. Little, Inc., reported that approximately 10 percent of the price was due to fabrication labor, that the materials were generally carried at their commodity price levels, and that the only area for significant price reductions was in the "entrepreneurial" costs of overhead and profit. This analysis indicates that volume production will have only a limited effect on prices.

More recently, some manufacturers have indicated that material price increases and increasing competition have reduced their profit and that they do not expect prices to come down further.

The potential for reducing collector prices, therefore, is dependent largely upon the development of new collector designs that use less expensive or lesser amounts of materials more efficiently.

Specifically, current or potential RD&D opportunities include the following:

A. Improving Collector Performance and Reducing Costs

Only limited improvements appear possible in current flat-plate collector designs. However, new collector concepts such as evacuated tubular collectors designed for volume production and plastic collectors promise to reduce collector prices and improve collector performance. The evacuated tubular collectors also provide efficient high temperature performance useful in solar cooling and industrial process heat applications.

Current collector prices run generally in the order of $\$20/ft^2$ to $\$30/ft^2$. Prices as low as $\$5/ft^2$ for the evacuated tube collectors have been forecast in volume production. Some of these designs are now reaching the marketplace, and prices could be significantly lower in 2 to 5 years.

B. Improving System Design and Performance

A collection of good components does not necessarily result in a good system. The installation cost of a solar system is often the single most expensive part of the project, involving as it does field labor rates and dependence upon building configuration and weather. Components must be matched, system operating logic must fit the capabilities of the various components, and problems of quality installation must be resolved if the solar system is to be economical and efficient. System engineering development can provide a significant improvement in efficiency and better cost performance.

Improvments are also needed in system analysis and design procedures, particularly for passive solar applications. While current passive analysis methods have made an improvement in the understanding of passive system performance, further significant improvements are possible.

C. Central or District Heating

A few demonstration projects have looked at the feasibility and cost of solar systems designed to provide heat or hot water to a number of buildings in a given locality. The potential of reducing the size and cost of the solar investment per unit by combining the units into a common system is under study. Technical problems include location of a collector field, insulating the distribution system, providing adequate storage and controls, and allocating and metering the collected energy.

A longer-term application of this approach includes the concept of a "solar total energy" installation combining electrical generation with heating and cooling.

D. Seasonal Storage

Current design approaches generally optimize a solar system for 1 to 3 days of storage. Such a system cannot handle peak energy demands economically, and a backup system must be provided. Seasonal or longer-duration storage capability would permit a greater seasonal solar participation.

For single-family dwellings, the economics of seasonal storage appear marginal at the present time, although added experience is being developed through the ACES project in Tennessee. For larger buildings or community or district heating systems, the prospects of seasonal storage are more promising, with considerable interest at this time in the use of natural confined aquifers for energy storage (either solar heated or winter chilled water).

A joint DOE-Canadian single-family residence project is underway in Canada, several larger projects are under consideration by the DOE Division of Energy Storage Systems, and a number of European single and district heating studies are being monitored by DOE.

An alternative thermochemical method using the heat of dilution of sulfuric acid is being developed by DOE for production where suitable aquifers are not available.

E. Solar Assisted Heat Pumps

Hardware development efforts currently under way combine new heat pump concepts with solar heating, cooling, and hot water systems. These promise significantly more cost effective systems. Advantages of the new systems include maximizing solar input, cost competitiveness with existing systems, assisting in utility load balance, and providing a balanced heating and cooling system.

F. Chemical Heat Pumps and Storage

Chemical heat pumps based on thermally driven reversable chemical reactions are being developed, on a limited scale of effort, for solar heating and cooling of large and small buildings. These systems are absorption chillers or solar-assisted heat pumps. The predicted economic performance of these systems is quite attractive, with a coefficient of performance of 1.6 in the heating mode, using current or near-term evacuated tube or simple concentrating collectors. Because the systems include heating, cooling, and storage in a single subsystem, they should offer significant savings when ready for the marketplace.

G. Solar Heating/Electric Systems

Preliminary considerations of combining solar heating systems with other solar technologies indicate that there may be significant economic and operational benefits from such applications. A limited R&D effort is now underway to examine combine photovoltaic-solar heating systems, and other combinations, such as wind energy-solar heating, have been proposed. The rate at which such combinations will be developed will depend in part on the rate at which the various technologies are brought to commercial readiness.

H. Relating Conservation, Passive, and Active Design

While considerable studies have been made of energy conservation approaches, active solar systems are fairly well understood, and passive systems are now being demonstrated to a limited extent, there remains a significant opportunity to develop market-acceptable system concepts that make the most effective use of all three approaches to reducing the need for conventional energy.

I. Market Development

A number of issues impacting the development of a solar market have been identified in the literature and are under consideration by other panels. Most of these are under active study in the Federal solar program:

- Sun access--the right to unobscured sunlight from over a neighbor's property.
- Solar financial analysis--developing and marketing methods of analyzing the life-cycle costs of solar installations.
- Codes and regulations--the existance of or need for building code model language and regulation guidelines that can encourage solar installations (and identifying existing situations that discourage installations).
- Standards and criteria--the development of consensus standards, certification methods and other assurances of quality for the industry and its customers.
- Information dissemination--getting the solar word out to the public and the industry.
- Training and technology transfer--helping to create an industry infrastruture based on the latest proven technology.

V. Technology Evaluation

A. The State of the Technology

At the gross level of whether solar heating and domestic hot water systems "work", the technology is now "available". However, this does not mean that RD&D or further system development is not necessary or that subsides will not be needed to promote market acceptance. The foregoing discussion indicates that significant opportunities exist for improvement in the technology to raise performance and lower costs, particularly for solar systems to be installed in existing buildings (retrofit). At the same time, market experience in the Federal demonstration program and in the commercial market shows that current first costs are so high that they reduce market interest.

In the residential market, this problem of first costs is made more severe by the high cost of housing and the fact that any major increase in price due to the solar system in many instances becomes an imposing barrier.

B. Alternative Paths

The effectiveness of current solar systems is limited because of their cost and application. Future Federal actions are needed to aid market development, but without improvements in system engineering and reduction in system costs, they will have only a limited impact on the marketplace and on energy consumption. The market would continue to be limited to areas with high conventional energy costs (these areas would change as fuel price policies change) and applications where the demand is for a reasonably long portion of the year.

Thus, the panel believes that the direction of the program outlined in section IV appears to provide the most effective way to expedite the use of solar heating. However, it is apparent that the prioritites within the program need to be reevaluated. Specifically, the panel wishes to express the following observations and recommendations:

- o greater emphasis needs to be given to passive designs and techniques as this technology, in most forms, is competitive.
- o at this time, most active systems are not cost effective without subsidies.

- hot water systems are competitive against electricity in most regions of the country, but the market will not grow appreciably without the proposed NEA incentives.
- R&D on existing low temperature flat-plate collectors should be cut back and innovative designs which show promise of reduced prices, such as lightweight plastics and evacuated tube collectors, should be stressed.
- R&D on chemical heat pumps should be accelerated.
- greater R&D emphasis upon hybrid systems should be undertaken.
- the space heating demonstration program should be significantly reduced until new lower cost innovative systems are available.
- system design concepts need to be improved to enhance probability of lowering total costs (especially retrofits).

C. Organization Management Assessment

While general coordination within the various participants in the solar heating and cooling program has been good, program activities have been handicapped by severely limited program staffs in several agencies, requiring extensive contractor assistance, and by inadequate program budgets.

Coordination between solar energy activities and conservation activities, on the other hand, has been less effective, except in the area of energy storage, where there is active communication between these areas.

The effectiveness of the solar heating and cooling demonstration program in helping establish a viable solar industry has been the subject of discussion by this panel, as well as having been one of the items discussed in the DPR public meetings. A definitive resolution of the question of managerial effectiveness is beyond the time and manpower resources of the panel.

However, the panel believes that the goal of demonstrating technical feasibility has been achieved. The more difficult goal of demonstrating cost competitiveness remains to be achieved. It is important to note that the methods to achieve these cost reductions are not readily apparent in the Federal program.

D. Incentive Mechanisms

Incentives can take several forms. Financial incentives that reduce the system costs or provide lower-interest loans to the buyers and capital investment assistance to newer firms are two examples of the possible forms of incentives. The panel notes, however, that study of possible Federal financial incentives to the buyers, in the summer of 1977, indicated that, in most cases, an effective front-end incentive would have to be at least 30 percent of the system cost for hot water installations and that loan rates of 6 to 8 percent for the balance would be necessary.

E. Energy Impacts

Estimates of the energy impact of the use of solar energy for space and water heating have varied widely. It is likely that 1985 impacts will be relative low but that impacts by the end of the century could be on the order of 1 to 3 quads.

APPENDIX A

Program Review of Solar Heating and Cooling

I. Program Description

A. Authority

The current Federal solar heating and cooling program was authorized by the Solar Heating and Cooling Demonstration Act of 1974, Public Law 93-409; through subsequent legislation ERDA, and later, DOE, received the management responsibility for this program.

B. Purpose and Goals

As stated in the latest edition of the National Program for Solar Heating and Cooling of Buildings (DOE/CS-0007), the overall goal of the program is:

> "... to assist in the early establishment of a viable solar industry for the design, manufacture, distribution, sales, installation, and maintenance of solar heating and cooling systems."

A number of objectives have been identified as important in achieving this goals; these include:

- o Conduct of a directed research and technology development program for substantially reducing solar heating and cooling system costs and improving system performance;
- o Operation of an information system to collect, store, evaluate, and disseminate user-oriented technical, environmental, and socioeconomic data relating to solar energy utilization;
- o Demonstration of the feasibility of solar heating technology in new and existing residential and commercial buildings by 1977;
- o Demonstration of the feasibility of solar heating and cooling in new and existing residential and commercial buildings by the end of 1979 (draft legislation will

extend this to 1982), with special emphasis on the development of low cost systems for retrofit installations;

- Development of solar energy system performance standards and criteria for the production and installation of solar energy systems, subsystems and components, with appropriate provisions for consumer protection;
- Identification and promulgation of the necessary legislation, codes, and incentives to mitigate or eliminate existing legal or institutional restrictions which may discourage the development of solar energy;
- Accelerate the development of a solar hot water industry and market, through a concentrated demonstration activity;
- Promote the utilization of solar heating and cooling applications by all Government agencies;
- Conduct rigorous economic and technical assessment of solar energy systems to identify potential markets and to evaluate Federal efforts to accelerate market penetration;
- Develop design guidelines for solar heating and cooling systems, subsystems, and components;
- Assure early availability of accredited private sector testing facilities; and
- Assist in the development of site and structural design criteria of high utilitarian and aesthetic value.

C. Program Statements

In addition to the National Program Plan, cited above, several subordinate documents have been developed. Key among these are:

o DOE/CS-0008	National Program Plan for Research and Development in Solar Heating and Cooling
o DOE/CS-____	National Passive Solar Heating and Cooling Program (in draft)
o DOE/CS-____	National Solar Heating and Cooling Retrofit Program (in development)

D. Assumptions

Assumptions as stated in Public Law 93-409 are as follows:

- Solar hot water and heating technology is ready for commercialization.
- Solar cooling technology requires additional research and development prior to commercial market development.
- A Federal program to assist in the development of technology and standards, provide visibility, and assist in reducing costs and improving performance could accelerate the use of solar energy for heating and cooling buildings.

E. Consistency of Federal Program Activities

While coordination of the various Federal activities and agencies involved in the solar heating and cooling program is quite good, there are areas which could profit by closer coordination, for example, the building energy conservation and solar heating and cooling programs. In addition, a number of other agencies are funding solar activities within their own areas of activity; a list of some of these programs is provided below. Closer coordination could make these programs more effective and more supportive of the National plan.

F. Federal and Non-Federal Program Participants

Agencies involved in the solar heating and cooling program include:

o DOE	Responsible for overall program management, demonstrations in commercial applications, research and development, technology transfer, and market development.
o HUD	Responsible for residential demonstrations, standards and criteria, market studies in the residential market, and information dissemination to the building industry.
o NBS	Support DOE and HUD in standards, and support HUD in data collection and evaluation.
o DOD	Manage demonstrations in Defense facilities.

- GSA Manage demonstrations in GSA facilities.
- HEW Manage demonstrations in HEW/health care facilities.

Non-Federal organizations involved in the program include:

- Planning Research Company: DOE management support contractor.
- Boeing Aerospace Company: HUD management support contractor.
- Franklin Institute Research Laboratories: HUD information dissemination program contractor; manages National Solar Heating and Cooling Information Center for DOE and HUD.
- National Laboratories (Argonne, LBL, LLL, INEL, Sandia, LASL, BNL): Conduct R&D and provide management support to DOE R&D program.
- IBM: Manage instrumented data collection network and system operations.
- Dubin-Bloome Associates: Technical support to HUD program.
- Real Estate Research Corporation: Market research support to HUD program.
- AIA Research Corporation: Technical/architectural support to DOE passive program and HUD demonstration program.
- Solar Energy Research Institute: Providing support to DOE and HUD in various activities.

In addition to the DOE demonstration program, which directly involves HUD, HEW, and NBS, among other agencies, a number of Federal organizations have undertaken solar projects of interest to their constituencies or in support of their own programs. Some of these programs include:

- Department of Agriculture
  - Developed building designs and utility systems to reduce costs of housing for low-income rural families.

  - Conducting studies of residential environmental control utilizing solar collectors and greenhouses; a number of such studies are underway.

- General Services Administration

  - Conducting solar feasibility studies for all new GSA building projects.

  - Five solar feasibility projects are under construction or in operation in various areas of the country to test various approaches to solar energy utilization.

  - Five additional solar buildings are being designed, nine more are planned, and ten feasibility studies are in progress.

- Environmental Protection Agency

  - Prepared a report on environmental research needs in solar energy.

  - Carried out preliminary environmental assessments of solar energy systems.

  - Surveyed EPA installations for potential solar applications.

- Department of the Interior

  - Five solar facilities projects (including three passive projects) are in progress.

  - The National Park Service has a program which includes 8 solar thermal installations and 12 solar photovoltaic installations.

  - The Fish and Wildlife Service has 4 solar heating projects under construction, 13 more in planning or design.

- Community Service Administration

  - Supporting the National Center for Appropriate Technology, which is performing research in passive and energy conservation approaches, providing information and advisory services on appropriate technology, and supporting low-income demonstration projects.

- CSA has also supported some community-based energy projects.

o <u>Department of Commerce</u>

- The Economic Development Administration funded the development of standard collegiate-level curricula for solar design and solar installation courses, and has supported the development of a solar air-conditioned factory in Puerto Rico.

- The National Oceanographic and Atmospheric Administration is maintaining a solar/weather data network, and is studing the influence of climate on housing design.

- The National Bureau of Standards is actively supporting the DOE and HUD solar demonstration and standards programs.

o <u>Department of Housing and Urban Development</u>

- Issued standards and instructions permitting the inclusion of solar heating and hot water systems in housing projects financed with HUD/FHA insured mortgages.

- Issued instructions permitting Title I lenders to include property improvements loans for solar energy installations in their insured load portfolios.

o <u>Department of Defense</u>

- Installed solar energy installations in a number of DOD installations outside the DOE-funded demonstration program.

o <u>Department of Health, Education, and Welfare</u>

- As part of the Federal program, installed five solar installations in health care facilities, and about to issue another RFP for additional projects.

G. Private Sector Organizations Interacting with the Federal Program

A number of private sector organizations are involved in activities that impact, or are impacted by, the Federal Solar heating and cooling program. These fall into two primary categories, industry organizations and standards organizations:

- Industry Organizations
  - Solar Energy Industries Association
  - Solar Energy Research and Education Foundation
  - Air Conditioning and Refrigeration Institute Sheet Metal Contractors National Association
  - American Institute of Architects
  - National Association of Home Builders
- Standards and Codes Organization
  - American National Standards Institute
  - American Society of Heating, Refrigerating and Air Conditioning Engineers.
  - American Society for Testing and Materials
  - American Society for Mechanical Engineers
  - Institute of Electrical and Electronic Engineers
  - Underwriters Laboratories
  - International Association of Plumbing and Mechancial Officials
  - Building Officials Conference of America
  - Southern Building Code Congress
  - International Conference of Building Officials

- National Conference of States on Building Codes and Standards
- National Institute of Building Sciences
- American Insurance Association

H. Federal Budget

The heating and cooling budget, beginning with the establishment of ERDA, is as follows (not including funding from agencies other than ERDA/DOE):

Program FY:	1975	TQ+1976	1977	1978	1979 (requested)
	Millions of Dollars				
Residential Demo:	0.9	7.0	23.8	26.0	14.6
Commercial Demo:	5.6	20.9	38.2	38.4	24.5
Development for Demo:	0.9	11.3	12.0	11.0	12.0
Research & Development:	3.5	7.5	14.9	18.5	22.1
TOTALS	10.9	46.7	86.9	93.9	73.2

I. Impact on Comeptition in the Energy Industry

The Federal solar heating and cooling program has been encouraging the rapid development of the solar industry, which has grown from a few firms in 1974 to several thousand firms listed as manufacturing or installing solar energy systems at the present time.

Activities in the heating and cooling program which support competition and market development include:

- Identification of potential barriers to market development and development of ways to overcome these barriers.
- Support for the development of standards and model codes to provide a standard of quality for the industry.
- Documentation of technical and market response to demonstration projects providing information needed for industrial development.

- Research and development of new or improved products and analysis procedures.
- Widespread information dissemination to the industry and to the public making potential customers aware of solar energy.

J. Evaluation Criteria

Factors which can be used to judge the effectiveness of the Federal program include:

- Ratio of private to Federally-sponsored solar installations.
- Improvement in product performance and reliability, and reduction of product costs.
- Effectiveness of the information dissemination program in reaching the intended audience.
- Development and promulgation of performance criteria and standards.
- Development of legislative recommendations to overcome or mitigate the effect of identified barriers and constraints.
- Identification of incentives which can encourage the rapid development of a solar market, and steps to implement these incentives.

The growth of the solar industry can be measured by the growth of the principal industry organization, the Solar Energy Industries Association (SEIA). However, while the Federal program has assistance the SEIA growth, it cannot take credit for this growth.

II. Current Status

A. Accomplishments to Date

The current status of the heating and cooling program is reported in the latest version of the National Program for Solar Heating and Cooling of Buildings, DOE/CS-0007, April 1978, and the National Program Plan for Research and Development in Solar Heating and Cooling, DOE/CS-0008.

Briefly, three cycles of commercial demonstration projects and four cycles of residential demonstration projects have been funded; Interim Performance Criteria have been published for both commercial and residential applications, and HUD has promulgated a Supplement to its Minimum Property Standards for solar heating and hot water systems; a number of market studies have been conducted, including formal reports to the Congress on Federal financial incentives and several mathematical analysis models to assess economic feasibility; the R&D program has initiated over 250 separate projects; and the National Solar Heating and Cooling Information Center has responded to over 300,000 inquiries since October 1976.

B. Barriers to Goal Achievement

A number of factors are impacting the establishment of a solar heating and cooling industry and market; these include:

- High first cost of solar system, and a "first cost mentality" in the building industry and among its customers.
- Wide variation in product quality, and the lack of consensus standards to control quality.
- Need for more accurate and useful system performance models, validated by actual field data. Without these, it is difficult for the customer to know what he is buying.
- Need for customer confidence in product quality, reliability, and economic performance.

III. New Factors

A. New Assumptions

- Manufacturing costs of active solar systems probably will not come down significantly, although installed system costs can be reduced through better system packaging and improved installation procedures.
- Passive solar energy systems provide a significant opportunity for reduced costs and increased energy savings.
- Cooling systems require a substantial amount of R&D to reduce costs and improve performance.

- Close interaction of conservation, passive, and active system concepts is appropriate path for the future.
- System reliability is a major problem.

B. New Opportunities

- Increase R&D on passive analysis, storage, controls, and modeling.
- Increase R&D on solar cooling components and systems to improve performance and to develop standardized systems.
- Develop compact storage systems.
- Develop packaged domestic hot water and heating systems to minimize field costs, improve product quality, and simplify retrofit applications.
- Provide Government support of training programs to increase the number of qualified installations, operation, maintenance, and service technicians.

TAB B

Technology Evaluation: Solar Space Cooling

I. Current Engineering/Scientific Status

A. Background

The primary Federal legislation on solar space conditioning is Public Law 93-409. This act, and most discussions within Government and industry circles have linked solar space and water heating with solar space cooling, but there is a significant difference in the state of equipment development and market readiness between the two technologies. This difference was recognized in the public law by specifying a 3-year period of demonstrations for solar heating and water heating and a 5-year development and demonstration program for solar space cooling. In response to recent testimony on the actual state of the technology at this time, the House of Representatives is considering an amendment to Public Law 93-409 that would extend the cooling authorization for an additional 3 years, through 1982.

The term "solar space cooling" currently embraces three different technical approaches: active systems, passive systems, and heat pumps using solar system components for more efficient and economical performance in the cooling mode.

B. Active Solar Cooling Systems

Active systems involve the use of solar thermal collectors to convert solar radiation to heat, which then can be used to operate thermally driven equipment such as absorption systems, heat-engine-driven vapor compressors, or desiccant cooling units. (Specific consideration of photovoltaic arrays generating electricity to drive cooling equipment is beyond the scope of this assessment.)

At this time, only absorption systems using lithium bromide and water as the absorbent/refrigerant fluid are commercially available for the residential market. Absorption cooling is not a new concept; many commercial establishments have used steam-driven absorption cooling systems for a number of years. The principal historical residential applications of absorption systems were gas-fired refrigerators and gas-fired air-conditioners.

Absorption systems designed specifically for solar applications are now available in 3 and 25 ton capacities. Technically, these systems have three limitations. First, system capacities drop significantly when input water temperatures fall below 195°F. This characteristic necessitates the use of either very efficient flat-plate collectors or concentrating collectors for providing sufficiently high input temperatures. Second, the lithium-bromide absorbant requires water cooling to prevent crystallization in the absorber, hence cooling towers are required for heat rejection, adding both cost and increased maintenance requirements. (This is not a major problem for large commercial, industrial or multifamily residential applications.) Third, absorption cooling systems cannot efficiently use electricity as the auxiliary energy source.

C. Passive Cooling Systems

Passive cooling systems are those that utilize "natural" energy flows to and from the environment in order to condition a space. As such, they are not truly solar cooling methods; they are generally incorporated in buildings in conjunction with passive solar heating features. The principle behind passive cooling is to minimize building heat gains and to maximize heat flows from the conditioned space to the environment, i.e., the atmosphere, sky, and ground.

Passive cooling can occur by direct or indirect modes:

- <u>Direct cooling</u> occurs when the interior surfaces and contents of the space are exposed directly to the environmental energy sink.
- <u>Indirect cooling</u> occurs when the space is cooled by heat transfer to storage or to a heat exchange surface, which is in turn cooled by exposure to the environmental energy sink.

The primary mechanisms of passive cooling are:

- Evaporative cooling of air delivered to the space or to storage;
- Radiative heat transfer to the night sky;
- Conduction heat transfer to the earth by a circulating fluid, for example, by air ducts buried underground;
- Cooling of the structure or of storage by circulation of cool night air.

The effectiveness of passive cooling methods is highly dependent on local climatic conditions, and in humid or cloudy areas active solar cooling methods are usually more appropriate.

D. Cooling with Solar-Assisted Heat Pumps

By "heat pump", we mean a vapor-compression system that can be operated in either a heating or cooling mode. In the heating mode, it transfers, or pumps, heat from the outside air into the building; in the cooling mode, it transfers building heat to the outside air or to another external heat sink. The heating performance of a heat pump at low outside air temperatures can be improved by using solar heat to replace the outside air as the heat source for the heat pump.

In the cooling mode, the collector subsystem of such a solar assisted heat pump system is not used. However, the storage capacity of the solar system can help improve the cooling efficiency of the heat pump. In one approach, the heat pump is operated at night when air temperatures are lower than during the day. In this approach, the storage system becomes "cold storage" and then can accept heat from the living space during the day.

An alternative approach involves operating the heat pump during the day, rejecting heat to the storage subsystem, which in turn is maintained at a temperature below daytime ambient by cooling it with nighttime outside air (a low temperature heat sink).

II. Economics

A. The Economic Problem

The problem of high first costs in active solar heating systems is even more of a problem for active solar cooling systems. There are two reasons why this is the case.

First, the equipment package is more complex. The cooling equipment is not in volume production and involves a complicated technology. High temperature collectors are necessary for good system performance, and ancillary items such as cooling towers are currently necessary for good system operation. All of these add to system installation and operating costs.

Second, the annual operating cycle for most residential solar cooling systems is limited to a small part of the year. Only in south

Florida or in the warmer areas of the southwest will the cooling period extend for more than 4 months. As a result, the high installation cost can only be written off over a limited part of the year. Commercial and industrial installations with high internal heat loads often will have a much longer annual operating cycle, improving the system economics. For this reason, wherever heating loads exist, residential solar cooling systems should always be constructed as combined heating and cooling systems.

A good overall system design making maximum use of collectors and other principal system components can reduce this cost impact (for example, in combined heating and cooling systems involving solar-assisted heat pumps designed as an integrated package). Such systems will most readily compete in south Florida and the Southwest, where in addition to the longer cooling season, high summer insolation improves collector performance for high temperature applications.

B. Current System Costs

The only current cost information for residential absorption system derives from the limited number of Federal demonstration projects and quoted prices for the one system in the marketplace. While system costs are dependent on system size and the cooling load handled, the installed cost of an average 3 ton residential active solar cooling system ranges from $25,000 to $30,000. This is about 15 times the cost of a conventional residential air conditioning system of the same capacity (installed). Costs for commercial size active solar cooling systems have run on the order of $10,000 per ton of cooling, compared with conventional system costs of approximately $1500 per ton.

Because of these high costs, only a few solar cooling demonstration projects have been funded. In addition, the high costs of active solar cooling systems have increased interest in both passive cooling designs and in the use of solar-assisted heat pumps in the cooling mode.

C. Industry Structure

Solar space cooling is one aspect of the overall activity of space conditioning by means of solar energy. It is likely that the solar cooling industry will evolve as part of a solar heating and cooling industry, along the lines of the conventional industry, as outlined in the technology evaluation of solar space and water heating.

III. Federal Goals and Objectives

The technology assessment of solar space and water heating outlines the background and legistative authorization of the current National program for Solar Heating and Cooling of buildings. To a great extent, the activities in this program apply equally to solar space cooling.

However, as noted above, the state-of-the-art-in solar cooling and the current costs of active solar cooling equipment are such that this technology is not ready for the marketplace. The principal Federal activities, therefore, are directed to research and system development leading to improvement of the equipment, cost reduction, and eventual market penetration. As a result, interest in passive cooling and solar-assisted heat pumps has increased significantly, and several projects are directed to the improvement of analysis techniques and development of marketable designs and products.

(Appendix A of the Technology Evaluation: Solar Space and Water Heating contains more detail about the Federal Solar Heating and Cooling program.)

IV. Advanced Concepts and Development Opportunities

Current solar cooling R&D activities include improving the high temperature performance of collectors, improving the performance of lithium-bromide absorption systems, developing solar-driven heat engine vapor-compression cooling systems, and chemical heat pumps.

A. Improved Collectors

Current absorption cycle cooling systems require input energy at 195°F or higher for full capacity, while solar heat engine performance is significantly improved by high input temperatures. Very few flat-plate collectors can provide this temperature except under limited conditions. Several technical approaches are being investigated to provide alternative types or improved versions of collectors:

- o Improved flat-plat collector designs and materials, including new selective surfaces, which more efficiently collect and retain solar energy;
- o Development and improvement of evacuated tubular collectors that provide more efficient operation at high temperatures, and, as noted in the solar heating technology assessment,

give promise of future prices significantly below those of flat-plate collectors.

- Development and improvement of concentrating collectors to achieve significantly higher temperatures and reduce costs.

B. Alternative Cooling Technologies

As noted above, only lithium-bromide absorption machines are currently available commercially to provide direct "solar cooling." However, several other technical approaches to solar cooling exist; all are currently under investigation:

- Engineering improvements in the lithium-bromide cycle are reducing the input temperature requirements.
- A number of studies of alternative absorbent/refrigerant fluid combinations are underway. For example, the water/ammonia cycle is being studied, since this combination can be operated with air cooling rather than requiring a water-cooling tower.
- Heat engines (such as those operating on the Rankine cycle) can be used to drive vapor-compression equipment for cooling. The efficiency of these engines increases with increasing temperature, and current research and system development work is addressing matched collector-heat engine packages. Air-cooled designs are receiving development priority for residential systems (design capacity below 25 tons).
- Systems involving desiccants for dehumidification are also under study for small and midrange system capacities. The desiccant material reduces humidity (and therefore the latent portion of the cooling load), and solar energy at a relatively low temperature is then used to regenerate the desiccant material.
- Solar-assisted heat pumps can be used to provide more cost-effective space cooling, as outlined above. These systems are designed to utlize the storage and control sub-systems of the total solar-assisted heat pump system to improve the cooling performance of the heat pump and thereby reduce the cost of providing space cooling. Since all of the foregoing solar cooling technologies are still

quite expensive and many are still in development, the solar-assisted heat pump system provides the only near-term active cooling approach utilizing the solar investment. Since the system, in the heating mode, utilizes relatively low temperatures, collectors can be relatively low-cost, low-performance units; the high performance collectors required in active solar cooling technologies are not necessary.

- Investigations of the potential for combining solar cooling and photovoltaic technology are underway.

C. Development of Integrated Systems

As noted in connection with heating and hot water systems, good components do not necessarily make a good system. In addition to the potential benefits of developing the various alternative cooling technologies noted above, there is significant potential in improving the overall system design. This involves several technical actions:

- Design and assembly of promising integrated systems;
- Field tests in actual applications to allow collection of realistic performance data necessary to obtain improved designs and to support subsequent commercialization activities;
- Demonstration projects using market-ready equipment to support market acceptance activities.

D. Commercial Retrofit Applications

It was noted earlier that absorption cooling is a common way to provide air-conditioning in commercial and some industrial applications. Most of the current equipment is driven by steam from a boiler used primarily to provide winter heating or some form of process heat.

Studies are underway to determine the potential benefits that could come from installing solar input systems as an alternative to steam systems in these commercial installations, using "future-generation," high-temperature collectors and high-temperature storage systems.

E. Seasonal Storage

Seasonal storage is of only limited interest in most single-family residential cooling applications, since the peak insolation occurs during the period of greatest cooling demand. However, in larger buildings with high internal heat loads, which require cooling for long periods of the year, the ability to store chilled water obtained during colder winter periods can reduce the size of cooling equipment necessary to handle peak summer cooling loads.

As noted in the technology evaluation for solar space and hot water heating, the principal interest at this time is in the use of natural confined aquifers for energy storage (a test installation is under consideration for J. F. Kennedy Airport, New York), the ACES project in Tennessee, and thermochemical storage.

F. Chemical Heat Pumps and Storage

As discussed in the technology evaluation for solar space and hot water heating, chemical heat pumps based on thermally driven reversible chemical reactions are being developed for both heating and cooling applications.

The relatively high efficiencies in the heating mode and the minimal additional cost to include cooling make these systems attractive for areas where both heating and cooling loads are important. They could offer significant system savings when ready for the marketplace.

V. Technology Evaluation

A. The State of the Technology

Although active solar cooling systems are now available in the marketplace, the price of these systems is considerably higher than can be justified by their energy savings. In addition to the absorption equipment now available, a number of other technical approaches are under development.

Space cooling can also be provided through passive means, and the theory of this approach is well understood. New studies of passive design methods and analysis procedures are establishing a base of information which can be used to provide for more effective passive cooling designs in new buildings.

Solar-assisted heat pump systems designed for improved cooling performance appear to provide the most attractive, near-term cooling package for most locations. Additional RD&D will be of value in the development of systems making use of the storage and control sub-systems to provide more cost-effective space cooling.

B. Alternative Paths

The principal alternatives to be considered are the three approaches to space cooling--active solar systems, passive designs, and solar-assisted heat pumps. Within each of these technical approaches, it is necessary to perform additional RD&D before commercialization.

- Active Solar Cooling

  Costs prohibit any near-term market for active solar cooling systems on the residential sector and severely limits the attractiveness of these systems for industry. More efficient systems are needed, a major RD&D priority.

- Passive Cooling

  Passive cooling approaches can and should be considered in all new building designs, just as passive heating and energy conservation features should be considered. Improved analysis and design procedures and an extensive information program are required.

- Heat Pumps

  Since passive cooling designs are climate- and geography-limited, buildings in many areas of the country may require additional cooling. Solar-assisted heat pump systems provide promising near-term cooling technology for residential applications, providing cooling at operating costs below that of commercial air-conditioning equipment.

RD&D activities are indicated for improved system designs, development of heat pump equipment compatible with solar system performance requirements, and for procedures for measuring system performance. Heat pump system demonstrations are lacking as are follow-on plans for new generations of equipment as they become available.

Given the present state of development and the resulting economics of the various cooling technologies, the RD&D panel believes that any large scale demonstration effort for the residential sector is unwarrented at this time. As for the commercial sector, the panel believes that in a few applications cooling technologies may be economic and a limited, specifically targeted field testing, instrumented demonstration effort should be continued to further investigate these applications.

Active solar cooling systems will be needed in areas where the cooling load is high, where local climate conditions preclude extensive passive cooling designs, and where even the reduced electric energy required for heat pump applications is too expensive.

C. Organizational/Management Assessment

The Federal solar program organization managing the solar cooling program is the same one that handles solar heating and hot water, and the comments on management assessment in the technology evaluation on solar space and water heating also apply to solar cooling.

D. Incentive Mechanisms

Serious consideration of financial incentives for active solar system installations is premature until system cost effectiveness has been improved significantly. Financial incentives for solar heat pump and passive solar applications may encourage some additional use of these systems, primarily in the commercial sector. Promotion of these passive systems through incentive mechanisms to develop passive solar applications will be difficult.

TAB C

Technology Evaluation: Agricultural and Industrial Process Heat Applications

I. Current Engineering and Scientific Status

A. General

Agricultural and industrial process heat applications use a broad range of solar collection systems to produce hot air, hot water, and steam within three primary temperature ranges (Low: less than 212°F; Intermediate: 212 to 350°F; and High: greater than 350°F) to support farm and industrial operations. Heat from these collection systems is injected into the process directly or through heat exchangers, with or without storage or conventional backup systems, depending on the system design and application. R&D support for these applications is drawn, in part, from technology development programs discussed under the Solar Heating, Solar Cooling, and Solar Thermal technology evaluation elsewhere in this document, as well as the applications program itself.

Much of the technology and many of the system components for agricultural and industrial applications in-place today are technical adaptations of those used for solar heating and cooling of buildings, particularly for low- and intermediate-temperature systems. These systems include collectors; heat-transfer fluids; heat-exchangers; and storage, distribution and control subsystems and are described in the technology evaluation of solar space cooling. As experiments and demonstrations move to higher temperatures, the applications draw more heavily on troughs and other collectors in the solar thermal technology area.

There are significant differences between agricultural and industrial systems:

- Industrial process systems are usually very large and consume substantial amounts of energy. The actual energy uses and the range of temperatures involved are substantially more diverse than in building applications and require specific process design. Further, industrial process heat loads are, in general, predictable and relatively constant, which means that collectors can be three times more effective than in a space heating role.

- Agricultural solar energy systems will in most cases be operated and maintained, and in some cases built, by the farmer requiring readily maintainable, although not unsophisticated, systems and components. Further, the adaptability of such systems for more than one on-site application is an important economic consideration.

- Industry, although it usually uses life-cycle costing techniques, traditionally requires a payback period of less than three years for capital process improvements.

- Because of high reliability requirements, near-term industrial applications require some level of back-up capability and use minimum storage so that hybrid systems will be the rule. Over a longer time span, however, additional storage will become desirable to reduce reliance on the back-up fuel sources, usually oil and gas.

B. Agricultural

Direct solar heat can provide about 10 percent of the total energy consumption by the U.S. food system. Seventy-five percent of the energy consumed in the U.S. food system is consumed in off-farm activities, such as transportation, food processing, and marketing. An additional 15 percent is consumed by on-farm activities for which there is little or no potential for direct process heat application, such as for transportation.

Current applications include grain drying, crop drying, food processing, and space shelter heating. The temperature requirements for applications are moderate, with temperatures generally below 212°F. For example, applications of space heating for poultry shelters and greenhouses generally requires temperatures of less than 50°F above the ambient temperature. These requirements can be met by currently available, lower cost, simple collectors and/or passive designs.

C. Industrial

Current studies have indicated that approximately 3 percent of industrial process energy is used at temperatures of less then 212°F, that 32 percent is used at temperatures between 212°F and 350°F, and that 65 percent is used at temperatures greater than 350°F. The temperature requirements through 212°F can be met by flat-plate collectors. Temperatures between 212 and 350°F require high performance evacuated tube and simple concentrating systems. The higher temperature requirements must be met by using more complex concentrating collectors.

The technology for the 350 to 550°F temperature range is not well advanced; with technical feasibility of components, subsystems, and systems having been demonstrated only in prototype. While data from short-term operations have led to design improvements, a long-term base has been sufficiently developed to identify the need for rigorous R&D in relevant subcomponent areas, including structures, coatings, reflectors, and controls, as well as systems engineering for low cost manufacturing, assembly, and installation.

There is a continuing and important dialogue regarding the role of thermal storage in these systems. For the near to mid term, it may be desirable to provide short duration (up to 1 hour) buffering storage to smooth input transients caused by passing clouds and to maintain system controllability and reliability. In some cases, more storage (2-3 hours) may be desirable to facilitate start-up and other normal system transitions. More storage would be desirable if moderately priced back-up fuels were not available, or not in assured supply. The level of storage in a specific application is a complex function of the cost of the storage subsystem, specific system application and complexity, effects of storage on system efficiency, as well as the cost and availability of alternate fuels.

Current R&D is concentrated on sensible and latent heat technologies for relatively short duration storage, while thermochemical technologies are being investigated for extended duration storage needs.

II. Economics

A. General

The economics of agricultural and industrial solar process heat applications depend on system capital costs, load profile, climate, efficiencies, durabilities, interest rates, taxes, economics of scale, and costs of alternative energy sources and their corresponding escalation rates.

At present, solar water, heat, and steam systems represent capital intensive investments, with long term payback. This characteristic is the primary constraint on the near-term market development of these technologies.

Most of the current analyses utilize life cycle costing methodologies by evaluating the impact of the first cost over the projected operational life of the system. Installation system costs are most frequently compared on the basis of cost per square foot of collector.

This level of comparison is useful only when system efficiences are known. Recent analyses are evaluating system performance on the basis of investment in terms of the useful energy delivered to the application, usually in dollars per million Btu for the design year. This type of analysis allows a direct comparison with unit costs of conventional energy requirements. Estimated capital costs in dollars per million Btu are indicated in Figure I.

B. Low and Intermediate Temperature Systems

Current system costs vary depending on type of system and type of application. However, current studies indicate that these applications cost less than current solar heating and cooling systems due to simplified system installation requirements and, in the case of lower temperatures, simplified collector components. In all cases, the system costs are currently driven by costs of the collector subsystem and by system installation.

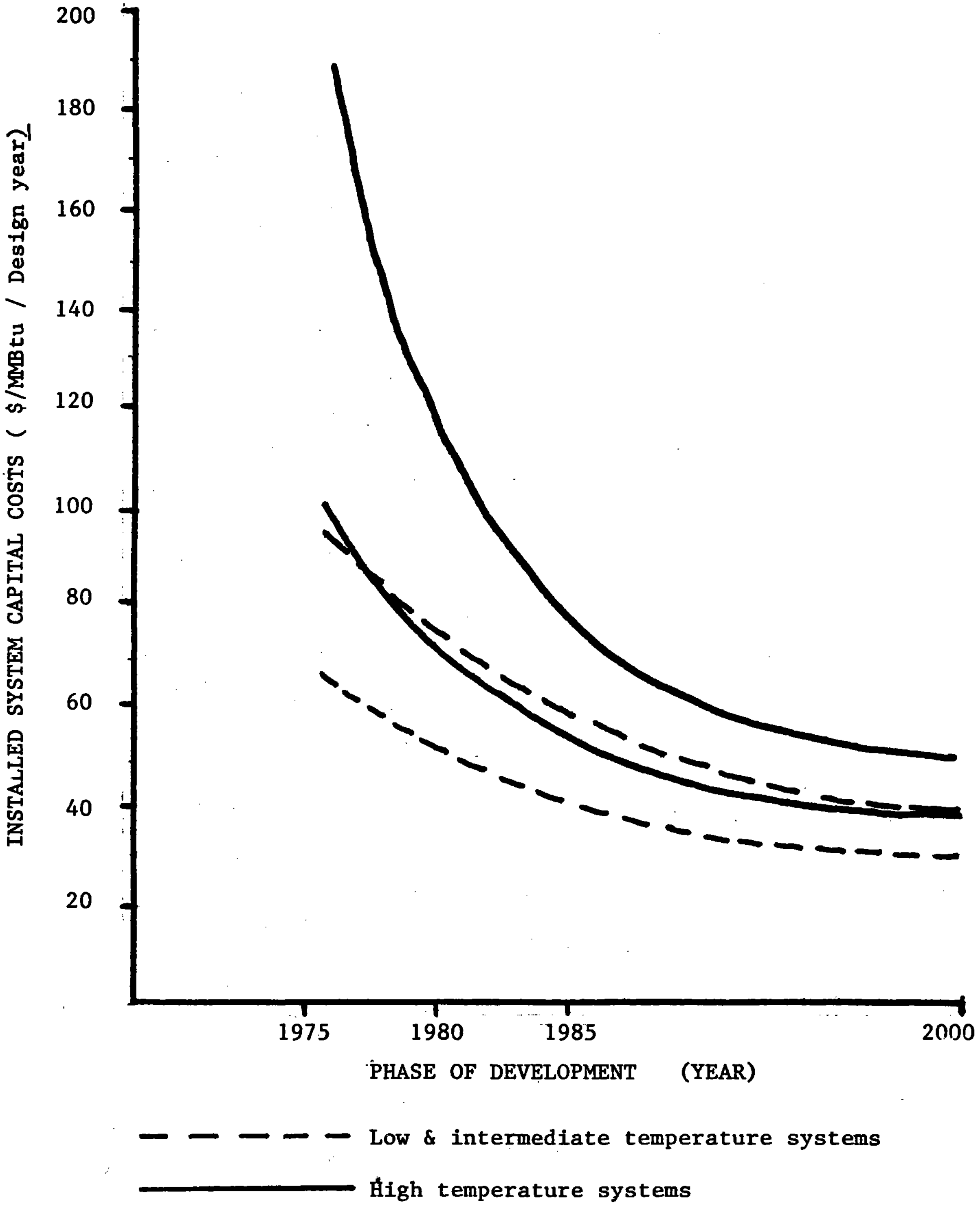
There is currently considerable debate over future system costs, given continuing R&D, increased development, and the potential impact of the considerably larger market. It appears that system costs within the lower temperature ranges, those systems utilizing flat-plate collectors, are not significantly sensitive to volume production. For temperatures above 212°F and below 350°F, development of the evacuated tube and simplified concentrating collectors appear to hold promise for reduced collector costs and improved system performance.

C. High Temperature Systems

The technological base for the high temperature concentrating systems is much less developed than for the low- and intermediate-temperature systems. System costs are projected on the basis of early prototype demonstrations. Insofar as these systems have potential applications only in the widely diverse industrial market, economic analyses must include consideration of the capital costs associated with large-scale land acquisition and preparation, the long-term cost projections for alternative energy sources (particularly coal), and the impact of Federal tax incentives.

Given the early stage of development and the diversity of impacting economic factors, current studies vary substantially on the near- and long-term system costs. Accordingly, there is considerable disagreement on the economies of scale attainable with mass production. In any case, development of these systems will necessarily aim at a major reduction in collector, system, installation, and operation and maintenance costs.

Figure 1


INSTALLED SYSTEM CAPITAL COSTS ($/MMBtu / Design year)
200
180
160
140
120
100
80
60
40
20
1975
1980
1985
2000
PHASE OF DEVELOPMENT (YEAR)
Low & intermediate temperature systems
High temperature systems

III. Current Federal Program

The 1977 and 1978 combined Department of Energy and Department of Agriculture budgets for agricultural and industrial process heat applications were $9 million and $10.8 million respectively. The general program strategy for both industry and agriculture has been to place priority on the application of those system designs that were based on state-of-the art components (predominently low temperature, flat-plate collectors) rather than utilizing systems whose components required significant research and development efforts. It has been assumed that Federal R&D expenditures within other programs, notably those in solar heating and cooling and solar thermal electric technologies, would provide the necessary systems R&D required for intermediate and high-temperature applications in the mid to long term.

The Department of Agriculture manages a series of cost-shared demonstrations, experiments, and prototype systems development projects for the Department of Energy. The program now consists of approximately 50 projects under a variety of climatic conditions. These projects include agricultural food processing, grain drying and the heating of livestock shelters and greenhouses.

The Department of Energy is sponsoring a series of projects to demonstrate the industrial application of state-of-art solar systems within the widely diverse industrial processes. Four of these systems have become operational, and seven are under construction and will become operational within a year. Four high temperature projects are to be initiated in 1978 and three to six large-scale demonstration projects in 1979.

Increased effort is only beginning to be directed toward high-temperature collectors. Although complex and not well developed, such efforts are considered important to furthering agricultural and industrial uses because the potential market increases greatly as the temperature capability of the solar system increases.

The long-term prospects for solar process heat are dependent on RD&D program efforts, because in the long term, use will be determined primarily by solar system cost and particularly by collector costs. To reduce these costs, the Federal program should support more fundamental research and development that can eventually lead to significantly improved, lower cost collector systems. (A more detailed description of the Federal program is given in Appendix A.)

IV. Advanced Concepts

The technology base for low and intermediate temperature systems is fairly well established. Current research and development activities have been aimed at improving the collector and component and total system performance. Areas where improvements should be made include collector performance; system design, particularly controls, and operating logic and system installation.

For high-temperature industrial process heat applications, the concentrating collector systems in the Solar Thermal program are presently considered to be the most likely technology for industrial process heat applications requiring temperatures to 550°F, and beyond, for both direct heat and pre-heat applications.

V. Technology Evaluation

A. Ability of the Technology to Supply Energy Without Further Federal R&D

It is necessary in assessing the agricultural and industrial process heat technology to separate the low and intermediate temperature applications and the high temperature applications because of the wide variation in level of technological development, the scale and diversity of process applications, and the complexity of the associated economic analyses.

- Low and Intermediate Temperature Systems: The technology base for these systems is well established in large measure because the technology and system components are generic adaptions of the solar hot water, heating, and cooling technologies. Since these system applications require full back-up systems for high reliability and total end-use energy requirements and since the performance limits of the collector component are fairly well known, additional RD&D efforts may hold limited promise.

  Nonetheless, agricultural applications, including crop drying, grain drying, and space heating for greenhouses and livestock shelters (operating predominantly as fuel savers) will benefit from current level support aimed at cost reductions through continued systems engineering.

  For industrial applications, the technology is available and some hot water systems can be economical for the near term. However, severe capital investment criteria act as barriers to commercialization.

Current technology, therefore, is presently capable of providing process heat within these temperature ranges. Given potential system applications with sufficient justification for economic viability, continued demonstration efforts are warranted.

- High-Temperature Systems: The technology base for these systems is less well advanced, with proto-type technical feasibility established only in experimental, limited-field-test applications. While development of high-temperature industrial direct-heat applications is tentative, the magnitude of these energy requirements is such that the potential application, if successful, is very large.

  High-temperature applications are proven technically feasible. Their use in industry will be strongly influenced by the following considerations:

  a. Sensitivity to R&D efforts

  b. Relative to economic projections, the current data base is small and surrounded by considerable disagreement relating to economics.

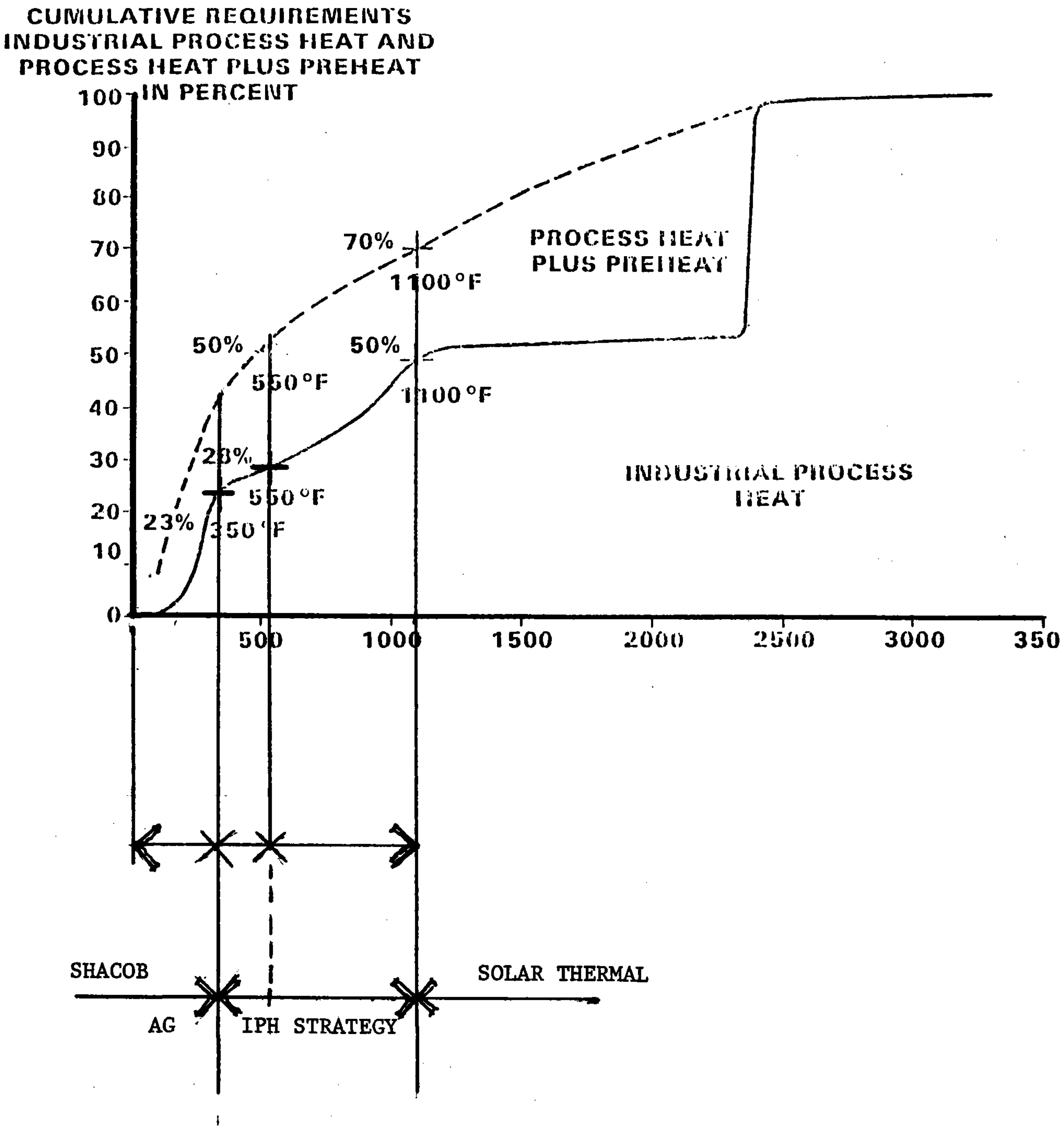
  c. Institutional barriers associated with rigid industry capital investment criteria and short-term payback requirements, as well as fuel cost write-offs act as a disincentive to the use of solar systems.

The Federal program strategies for agricultural and industrial process heat applications, therefore, must be built around a balanced understanding of the wide variation in the level of technical development of these diverse system applications and the evolutionary relationship this "technology" maintains with the solar heating and cooling of buildings (SHACOB) and solar thermal technologies.

Figure II shows this relationship as a continuum of technology applications broken by a gap in the 350-550°F temperature range.

Any Federal strategy must contain a coordinated approach to these related technologies. Program decisions should be guided by assessments of market potential by temperature range and specific applications, and should seek to encourage application of the best technology within the available spectrum. This means that the commonality of agricultural and industrial market

Figure II


CUMULATIVE REQUIREMENTS
INDUSTRIAL PROCESS HEAT AND
PROCESS HEAT PLUS PREHEAT
IN PERCENT
100
90
80
70
60
50
40
30
20
10
0
500
1000
1500
2000
2500
3000
350
70%
1100°F
PROCESS HEAT
PLUS PREHEAT
50%
550°F
50%
1100°F
28%
550°F
23%
350°F
INDUSTRIAL PROCESS
HEAT
SHACOB
SOLAR THERMAL
AG
IPH STRATEGY

studies needs to be recognized, and exploited, across the three DOE solar program areas.

The panel's observations are:

- Low and Intermediate Temperature Systems: Current-level RD&D funding should support demonstration applications aimed at cost reductions through simplified component and system designs and installations, the development of multiple-use applications utilizing energy-conservation/waste-heat recovery options, and relatively hard-line manufacturer-based systems performance standards and criteria for widespread regional dissemination.

  Further, given the experience and expertise for agricultural production and processing technology that exists within the Department of Agriculture, any strategy should provide for a significantly increased management and technical role of that Department for agricultural solar technologies.

- High Temperature Systems: Technology could be developed to apply to an increased segment of the total process-heat market beyond that previously pursued. Coupled with the high temperature (between 550° and 1200°F) process-heat applications identified in the solar thermal technology, a substantially augmented R&D effort would yield a significant opportunity for mid-term applications in industrial process heat (Figure II).

Accordingly, the panel feels a strategy with vigorous R&D efforts for the following would be effective:

A. Component Technology

1. Materials (high temperature)
   - High durability
   - High performance coating
2. Reflectors/Coatings
3. Controllers
   - Microprocessors
   - Solar Trackers

B. System Engineering

1. Installation and Integration

   - o Durability

   - o Low cost

2. Operations and Maintenance Data

3. Large-Scale Manufacturing Techniques

C. Market Penetration

1. Extended analysis of specific processes for temperature-matched applications in industry with the highest potential for solar penetration

D. Non-RD&D Incentives

Given the current high capital costs associated with these system applications and the rigid capital investment criteria utilized within industry, any Federal strategy must include a well-developed and carefully timed program of financial incentives supported by the Federal Government and State and local governments. The key factor in developing the government program is the impact on the timing of their activities with the needs of solar equipment manufacturers and the state of readiness of the potential market.

E. Energy Impact

There are a number of studies and reports regarding agricultural and industrial process heat applications that project estimated market potential and penetration impacts, with each based on its own set of assumptions regarding collector costs, installation and O&M costs, alternative fuel costs, type and location of application, and the relative impact of various financial and tax incentives. While there is a wide variation in the projected quad contribution for A&IPH applications, there is fairly uniform agreement that the size of the potential market is substantial. A rough estimate of energy contribution, would yield contributions in the range of 1.0 to 2.0 quads in the year 2000.

APPENDIX A

PROGRAM REVIEW OF AGRICULTURAL AND INDUSTRIAL PROCESS HEAT APPLICATIONS

Program Description

The Department of Energy, under the Assistant Secretary for Conservation and Solar Applications, and with management support from USDA, has an established program for agricultural and industrial process heat to develop the potential for the replacement of fossil fuel energy (oil, natural gas, LPG, and coal) with solar energy in applications requiring direct heat.

For agricultural applications the specific program objectives are to:

- Encourage the adoption of near-term solar technology which can provide substantial heat input to crop drying, grain drying, food processing and the heating of livestock shelter and greenhouses, by demonstrating the technical and economic advantages of available equipment and systems,

- Stimulate further research and development of improved component and system design,

- Insure the ability of industry to provide and maintain acceptable levels of cost, reliability and availability of agricultural heating systems,

- Identify existing or potential applications for agricultural heating, including multiple uses of solar for on-site applications.

For industrial applications, the specific program objectives are:

- Develop, test, and demonstrate solar industrial process heat systems in order to identify systems exhibiting potential for providing process heat, and to identify problems and barriers to development,

- Encourage development of systems capable of advancing solar process heat system performance and temperature range,

- Through demonstration and testing indicate the economic and technical advantages of applying solar process heat systems to their industrial requirements,

- Encourage the identification and adoption of financial investment incentives by the Federal sector,
- Assess the potential for application of solar energy to industrial process heat and identify those processes and locations where solar energy can provide a significant amount of process heat requirements.

Assumptions

The initial program strategy for both industry and agriculture, was to stress priority to the application of those system designs that were based on state-of-the-art components (predominantly low- and near-term intermediate) temperature systems, rather than utilizing systems whose components required significant research and development efforts. The substantial Federal RD&D expenditures within other programs, notably the solar heating and cooling and solar thermal electric technologies, were expected to provide the necessary systems development required for the IPH system adaptations for the mid-long term, intermediate and high-temperature applications.

Thus, the primary assumptions associated with the development of this program have been that:

- Within the low and intermediate temperature applications there is an established technology available for immediate and near term demonstration, and that these applications are dependent upon the development of solar heating and cooling.
- For high temperature applications, the technology is less well advanced, and that the required research and development would most likely come from the solar thermal program being developed within the Solar Technology program under DOE's Assistant Secretary for Energy Technology.
- Thermal storage is a technical issue for low and intermediate applications, but that it is at least problematic for high temperature applications. Since these applications need a high degree of system reliability, requiring full or hybrid back-up, the optimized solar application will provide only a portion of the total requirements.
- The high capital costs for these applications will strongly mandate a broad Federal program of financial and investment incentives.

Consistency

This program in general is consistent with other Federal programs, in part because of the technology upon which it is based. As in the solar heating and cooling program, it is important that this program consider energy conservation and both active and passive solar systems simultaneously.

Federal and Non-Federal Participants

The Department of Energy, Assistant Secretary for Conservation and Solar Applications (CS) has been assigned the Federal responsibility for the management of this program. Further, the Department has delegated the management of agricultural aspects of the program to the Department of Agriculture, with monitoring of progress by the Department of Energy personnel.

The non-federal participants, working under Federal contracts or grants, are the same as those identified in the Solar Heating and Cooling Program Review, with most activity occurring in the Department of Energy managed commercial demonstration program and the R&D program.

Federal Budget*
(in millions of dollars)

	FY 75	FY 76	FY 77	FY 78	FY 79
AG/DOE	1.5	2.4	2.6	3.6	4.0
AG/USDA			0.3	0.3	0.3
IND/DOE	0.1	3.2	5.9	6.7	10.2
TOTAL	1.5	5.6	8.8	10.6	14.5

Impact on Competition in Industry

Current applications cover both large and small users and draw equipment and support services from sources that vary from on-farm manufacture and installation to large corporations. R&D efforts are required to further develop the high temperature technology before any widespread industrial utilization will occur.

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* Includes non-RD&D activities of $3.5 million.

Evaluation Criteria

The primary evaluation criteria for A&IPH applications are:

- Reduction in system and component costs,
- Effectiveness in demonstrating low and intermediate temperature applications,
- Level of technical development for high temperature systems,
- Rate of development of industry based system performance standards,
- Removal of financial/investment barriers.

Current Status

Accomplishments: Exposure of agricultural applications to the agricultural community has been initiated through cost-shared demonstration in the heating of commercial greenhouses and the heating of livestock shelters. The Department of Agriculture is managing a series of experiments and prototype systems development. The program now consists of approximately 50 projects under a variety of climatic conditions. These projects include agricultural food processing, grain drying, crop drying and space heating.

The Department of Energy is sponsoring a series of projects to demonstrate the industrial applications of state-of-the-art solar systems within the widely divergent industrial processes. Four of these systems have become operational, and seven are under construction and will become operational within a year. Four high temperature projects are to be initiated in 1978 and three to six large scale demonstration projects in 1979.[3]

Figure A-I briefly summarizes current milestones in the Federal program.

Barriers

The low level of technological development (RD&D) for high temperature components and systems, those for 350°F to 550°F and higher temperatures, has led to the exclusion of a large portion of the process heat market where direct applications might be considered, thus reducing significantly the range of economic alternatives.

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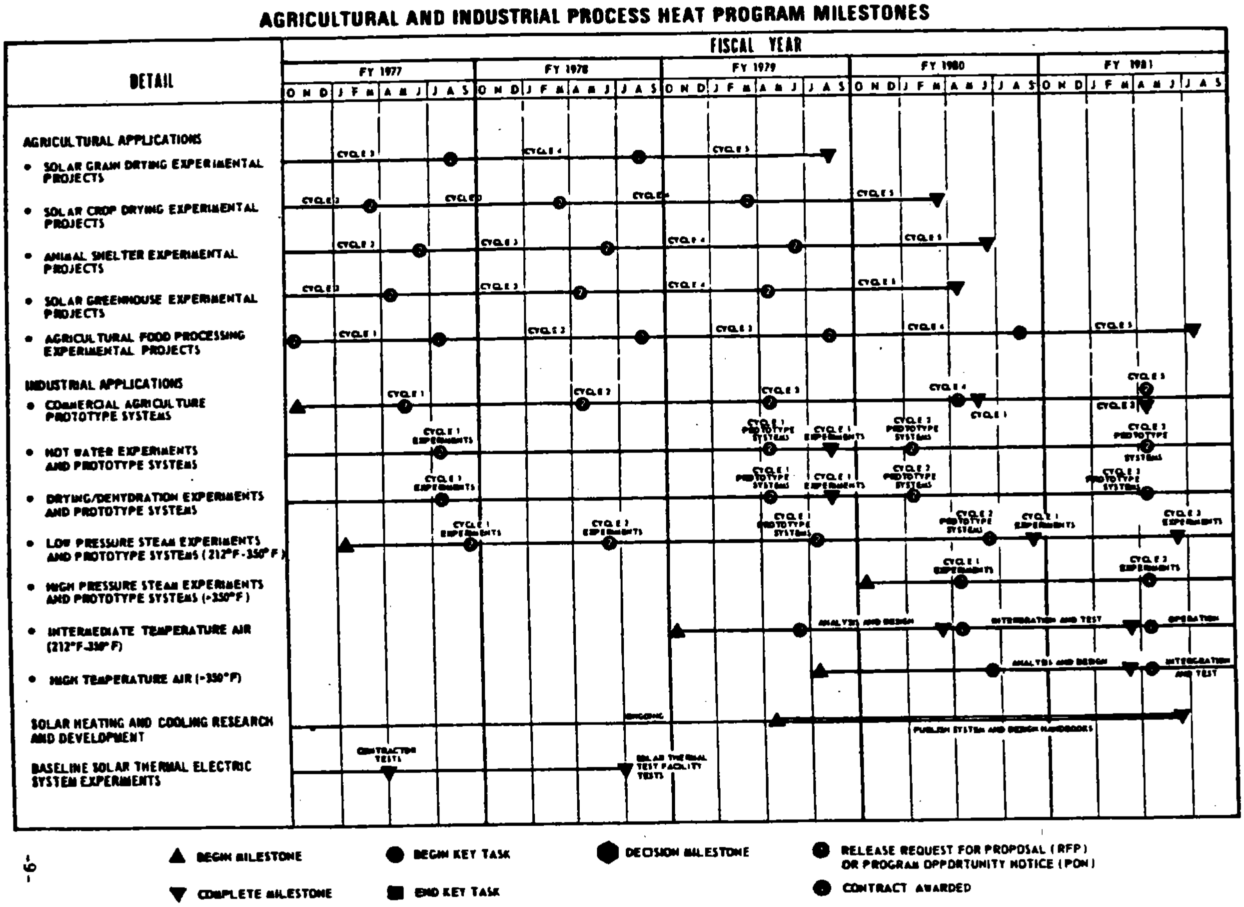
[3] For detailed project summaries, see Solar Energy for Agricultural and Industrial Process Heat, ERDA 77-72.

Figure A-I

Timetable



Further, the high capital costs associated with these systems is counter to the industrial practice that uses life cycle costing, but requires a very short payback (3 years or less) and a high internal rate of return for capital investments.

Federal Tax Policy that allows writing off fuel expenses while treating solar equipment as a capital investment, acts as a major disincentive to solar investments for these applications.

New Factors

Inasmuch as high temperature solar technology is not dependent upon solar heating and cooling progress, and given the early indication of technical feasibility for such applications identified within the solar thermal power program, it would appear that additional R&D could be applied to develop a substantially greater segment of the total process heat sector than previously addressed. It is apparent that the high temperature technology must develop a system design background specifically related to direct use of solar thermal energy in industrial processes. Minor modifications of system concepts "borrowed" from other programs is inappropriate. With the inclusion of high temperature demand which can be attributed to pre-heating, this program shows a significant opportunity for mid-term applications in industrial process heat.

R&D for expanded IPH applications would also address the need for increased manpower at DOE within this area and for strong, less fragmented direction across this, the Solar Thermal, and Solar Heating and Cooling Programs.

TAB D

Solar Thermal Power Systems Technology Evaluation

I. Technology and Applications

A. Introduction

Solar thermal power systems can provide high-temperature (160° to 1400°C), environmentally clean, inexhaustible heat to conserve scarce resources in a wide variety of applications. These systems can produce thermal, electrical, or mechanical energy, or a combination of these for total energy systems (cogeneration). Potential applications include utility, institutional, agricultural, and industrial processes such as primary metals industries, synthetics, and manufacturing.

B. Current Technology Status

Solar thermal technology includes a variety of systems generally grouped as central receivers, line-focusing distributed receivers, and point-focusing distributed receivers. To some extent, each type of system has a requirement to store heat for later use.

1. Central Receivers

The central receiver system uses a large field of mirrors (heliostats) to focus direct sunlight on a centrally located mirror atop a high tower. At the receiver, a boiler transfers heat to the working fluid (e.g., water/steam, air, or liquid sodium) used to run a power-conversion subsystem (e.g., a gas turbine) near the tower which produces electricity. Thermal energy storage could be used to smooth operational transients and to match incoming solar energy with end-use demand cycles.

Alternately, a fossil fuel boiler could be used to smooth the transients in a repowered or hybrid system. A repowered system is one that adds solar thermal collectors to use in an existing fossil-fired powered plant, with the fossil-fired boiler as a back-up system. Hybrid systems represent new plants designed to optimize the solar/fossil-fuel mix. Repowered and hybrid systems have minimal thermal storage and use solar energy in a fuel-saver mode only.

Present central receiver designs can achieve working fluid temperatures of over 500°C. Advanced concepts are under investigation to achieve temperatures on the order of 1100°C. These higher temperatures lead to higher thermal efficiency, which, in turn, implies lower system costs.

Much work is being done in the area of heliostats, the most expensive part of the central receiver system. One of the major technical efforts proposed is the development of mass-production techniques for these items. This is based on the belief that because of both the large quantity (15,000 to 20,000 for a 100 MWe plant) and the uniformity of heliostats needed for utility power systems, mass production can reduce their cost.

Central receiver system experience includes construction of the 5 MW (thermal) Solar Thermal Test Facility in Albuquerque, New Mexico, which is nearing completion, and the detailed design of the 10 MWe central receiver pilot plant now under way. The pilot plant will be the first complete central receiver plant to operate in the R&D program. It will use a water/steam central receiver, thermal storage, and a water/steam Rankine-cycle turbine,and is scheduled to begin operation in a utility grid in Barstow, California in late 1981.

2. Line-Focusing Distribution Receivers

Typical distributed receiver systems involve the following major subsystems: a number of individual concentrator/receiver modules, thermal transport, thermal storage, and a power conversion subsystem (if conversion from thermal to electrical or mechanical energy is required). Sunlight can be concentrated by several types of line-focusing collectors, including fixed V-troughs, one-axis tracking parabolic troughs, and variable slats, all of which include receivers where solar radiation is transformed into thermal energy (200° to 375°C). The heat is then transported by a working fluid through a pipe network to a central location for direct utilization as thermal energy, to charge storage, for conversion to electrical or mechanical energy, or a combination of these. The capacity of the storage depends on the extent to which the system will be required to operate in a stand-alone mode.

Line-focusing systems are a relatively advanced solar thermal option, particularly for the parabolic trough. A shallow-well irrigation-pumping experiment using parabolic troughs has been operational in Willard, New Mexico, since FY 77. A total energy system in Ft. Hood, Texas, and a deep-well irrigation-pumping system, both using parabolic troughs, are scheduled for completion in FY 80 and FY 79, respectively.

The mid-temperature (200° to 340°C) Solar Thermal Test Facility in Albuquerque is operational. Tests have been made on both collector modules and collector systems functioning as a total energy system generating thermal and electrical energy. A mid- to high-temperature (325° to 550°C) test facility is planned at the Solar Energy Research Institute in Golden, Colorado.

The major remaining issues are associated with cost reductions, including development of low-cost collectors and lower cost thermal transport subsystems. R&D is under way in absorber and concentrator coatings to produce higher temperature, more efficient, and more durable subsystems.

3. Point-focusing Distributed Receivers

Point-focusing distributed receivers can supply high-temperature heat (375° to 1100°C) to a central or distributed electric generating system. A typical modular electric system consists of a field of parabolic-dish concentrators, each with a small receiver or heat engine/alternator located at the focal point of the dish. Electricity can be produced by an alternator at the focal point or by a generator coupled directly to each dish/receiver module. Point-focusing systems produce from 5 to 50 kW of electric power, depending on size and design.

Alternatively, thermal energy can be generated at the dish collector and a high-temperature thermal transport system used to carry the heat to a central location. There, the heat is turned into electricity, used directly as high-temperature process heat, or used in a combined system (cogeneration). A thermal storage subsystem may be used.

Small, externally fired heat engines such as open-cycle Brayton, closed-cycle Brayton, and Stirling will be tested for mounting at the focal point. A high-temperature test site is being planned at the Edwards Test Station in California for dish-mounted heat engine systems.

First-generation (400°C) parabolic dishes with thermal transport, central power conversion, and storage subsystems are to be used in the first large-scale industrial total-energy experiment held at Shenandoah, Georgia, producing electricity, process heat, heating, and cooling. It is scheduled for completion late in FY 80.

Modular dish-electric systems are less developed than the other systems mentioned above. Systems using Brayton-cycle engines are planned for testing in the early 1980's. The Stirling engine with its potentially high efficiency (40 to 50 percent), has been selected for the first Small Power System Engineering Experiment scheduled for operational testing in FY 82 and completion in FY 83. Accelerated technical development is needed in the areas of mass production of dish collectors, high-temperature thermal transport, high-efficiency heat engines, and advanced receiver and concentrator coatings. Investigations are already under way in these areas.

4. Storage of Solar Thermal Energy

Almost any solar thermal facility requires short-duration buffering storage to smooth input fluctuations caused by passing clouds, and somewhat longer storage (on the order of 2 to 3 hours) may be required to assist in start-up and other normal system operations. Longer term storage would become important for increased use of dispensed applications, especially where there is a need to minimize use of a back-up fuel. Larger amounts of storage capacity might be required for utility applications, depending on the penetration of solar thermal plants into that market and on the mix of solar, hybrid, and conventional power plants in the utility system affected.

Current R&D concentrates on sensible and latent-heat storage technologies for short-duration storage. Thermochemical technologies are being investigated for storage over extended periods.

II. Economics

Although solar thermal systems have proven their feasibility and no scientific breakthroughs are needed for their deployment, substantial cost reductions must be realized before solar thermal systems become competitive with conventional power sources. The principal issues and uncertainties for solar thermal technologies are therefore economic, and their ultimate success or failure hinges on attaining major reductions in collector costs through a combination of marketing efforts (volume production) and improvements in performance of the systems. Collector costs are dominant in solar thermal systems.

A. Capital Cost Estimates

Solar thermal cost goals (1978) are discussed in terms of current collector subsystem costs and cost goals. It is presumed that current DOE goals are an accurate reflection of what competitive solar thermal systems should cost.

1. Central Receiver System

The DOE 1985 cost goals for central receiver systems are \$1600/kWe for storage-coupled systems and \$1300/kWe for repowered systems. The respective 1990 goals are \$1200 per kWe and \$1000/kWe. METREK[1] estimates range from \$1200 per kWe to \$2300/kWe in 1990, the lower end of the range corresponding to fossil/solar hybrid plants and the upper to storage-coupled plants.

The corresponding 1990 heliostat cost goal is \$108/m^2. Actual costs in the second heliostat buy for the Solar Thermal Test Facility (1977) were four times that level. Projected costs for the Barstow pilot plant heliostat buy (1980) are two and a half times the cost goal.

2. Line-Focusing Systems

The 1990 cost goals for line-focusing systems are \$1000/kWe for remote (e.g., irrigation) applications and small-community electric systems and \$2000/kWe for total-energy systems. A JPL report [2] concludes that by the year 2000 costs for a one-axis variable slat system would fall in the range of \$3100/kWe to \$3700/kWe.

Cost goals for parabolic trough collectors are \$91/m^2 (installed) in 1990. First-generation (200°C) troughs cost about twice that figure (1976) for the collectors purchased for the Willard, New Mexico, experiment. Second-generation (300°C) parabolic troughs were purchased for eight times that figure for the Mid-Temperature Solar System Test Facility (1976) and are projected to cost about two and a half times that goal for the deep-well irrigation and first total-energy system buys (1979).

3. Point-Focusing Systems

The 1985 cost goals for point-focusing distributed receiver systems are \$600 to \$1000/kWe. Corresponding parabolic-dish 1990 cost goals are \$86 to \$108/m^2. The JPL[2] estimates that in the year 2000 parabolic-dish systems using Stirling will cost \$2100 to \$2300/kWe, with dish costs roughly corresponding to DOE goals.

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[1] Solar Energy: A Comparative Analysis to the Year 2000, MITRE Corporation, METREK Division (March 1978)

[2] Projection of Distributed-Collector Solar Thermal Electric Power Plant Economics to Years 1990-2000, JPL (Dec. 1977) (These estimates may be high, more useful for comparing distributed collector systems than as absolute cost estimates.)

The cost of the first dishes purchased for the Mid-Temperature Solar System Test Facility (1978) was about forty times the goal. The projected cost of parabolic dishes purchased for the industrial total-energy experiment (1980) buy is about four times the cost goal.

Commercially produced parabolic-dish/steam-engine systems currently sell for \$4200/kWe, with a corresponding collector cost of $\$1100/m^2$. These costs, four times the goals, are for a system that is manufactured by hand without the use of mass-production techniques and facilities. Major cost reductions are believed to be possible through improving subsystem efficiency and by mass production of small heat engines (when they become available) and concentrator subsystems.

B. Levelized Energy Cost Estimates

If the capital cost goals are attained, solar thermal power will provide energy costing between 40 and 60 mills/kWh. This estimate includes all capital costs, interest, fixed and recurring costs such as operation and maintenance. The energy costs are roughly competitive with conventional electric generating costs forecasted for the period 1985 to 1990. However, it appears that other market barriers may limit the level of market penetration within this time frame without major government incentives.

Comparative energy costs were calculated by JPL for several solar thermal systems using relatively high capital costs[2]. The energy cost of a central receiver system was estimated to range from 127 to 172 mills/kWh, from 107 to 113 mills/kWh for a parabolic-dish system with Stirling engines, and from 147 to 174 mills/kWh for parabolic dish systems with central steam-Rankine conversion. Although high, these estimates allow internally consistent comparisons of the relative energy costs of alternate solar thermal systems.

Table 1 shows a comparison of conventional and central receiver systems provided by Sandia Laboratory[3], in which heliostat costs are lower than the DOE program goals.

The study says that, if heliostat costs can be reduced to below the program goals, solar thermal energy may be cost-competitive for peaking- and intermediate-load applications, even at the relatively low capital cost levels shown for coal and nuclear plants, assuming fuel costs rise rapidly. However, it also remains to be seen whether solar thermal can achieve the relatively high capacity factor (47 percent) given the optimistic capital cost estimate.

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[3] Sandia Labratories, Livermore, California (July 1978)

Table 1: Comparison of Levelized Busbar Costs[a]/

	Capital Cost ($/kWe)	Fuel Cost ($/MMBtu)	Energy Cost Case 1	Energy Cost Case 2
Coal	550	1.00	40	33
Nuclear	790	0.40	36	34
Combined Cycle (oil)	250	2.60	75	42
Combustion Turbine (oil)	120	2.60	102	54
Solar Central Receiver	1600	--	58	58

a/Assumptions:
1. Case 1: Fuel escalation 4-6% above inflation.
2. Case 2: Fuel escalation same as inflation.
3. Heliostat cost \$75/m^{2}solar plant.
4. 47% capacity factor solar plant.
5. 15% fixed charge rate, in 1977 dollars.

C. Market Potential

In the near term, solar thermal central receiver and distributed receiver systems may be applied to the repowering of industrial and utility power plants, leading to the substitution of solar heat for oil and gas in a number of plants. The size of this market has been estimated as high as 10,500 MWe[4].

There is also early market potential for the powering, or repowering, of dispersed on-site applications. Both electrical and thermal energy can be produced by solar thermal systems to substitute directly for or augment the combustion of petroleum or natural gas. An assessment of the potential of these applications is needed. Market studies throughout the solar thermal area are incomplete and are not coordinated with analyses conducted by the agricultural and industrial process heat program, which is directed at the same markets.

In the intermediate time frame, modular point-focusing distributed receiver systems using small heat engines hold promise if the anticipated economies of scale and improved efficiencies for dispersed applications to localized utilities, small communities, rural areas, and industry are achieved. Hybrid fossil/solar thermal systems could provide a high-efficiency, baseload option for electrical generation.

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[4] Public Service of New Mexico, presentation at the Central Power Systems Semi-Annual Review (March 1978)

For both the large and the small power systems, the long-term market penetration rate would be dependent on technology development of the solar, storage, and power-conversion systems needed, costs of competing systems, and collector cost reductions achieved after the initial near-term market penetration, as well as other factors.

III. Solar Thermal Federal Program

The current Federal RD&D program is aimed at the electrical utilities market located in the Southwest and parts of the Southeast, with secondary but increasing emphasis on dispersed applications. The overall objective of the solar thermal program is to establish the technical readiness of cost-competitive solar thermal power systems for both dispersed and utility energy production applications. The initial commercial implementation objectives are the early 1980's for dispersed applications and the mid-1980's for utility applications.

The key issues confronting the solar thermal program are the balance between utility and other applications and whether the Federal Government should invest heavily in near-term demonstration projects using existing technology.

The current program plan calls for a number of major projects to be carried on in parallel. In the central applications area, these include a storage-coupled pilot plant (at Barstow, Calif.), a repowering demonstration plant, and a hybrid experiment sponsored jointly by the Electric Power Research Institute and the Department of Energy. In the dispersed applications area, these include total-energy system experiments (industrial, military, and institutional projects), three irrigation experiments, and three small community (electric only) experiments. These experiments touch a number of potential applications for near- and mid-term markets.

The DOE solar thermal program also includes a repowering initiative for central power systems and a dispersed initiative designed to lower the cost of distributed receiver systems through a series of competitive procurements; each successive cycle will encompass additional types of systems and applications. Both the repowering and dispersed system thrusts are market-pull strategies intended to accelerate the adoption of available technologies by driving down the costs of collector systems, through the development of a manufacturing infrastructure supplying a limited, government-funded early market.

The projects which are being conducted include initial systems operation in specific market sectors to bring to light technical, institutional, operational, and other barriers that might arise when these systems are commercialized and to establish the operational properties of the designs being tested. The tight scheduling may limit the transfer of knowledge between succeeding experiments.

An advanced technology component of the program conducts R&D on a number of advanced concepts utilizing higher temperatures, higher efficiency engines, and other improvements, with a goal of supporting applications by providing systems with enhanced performance. It is also investigating a number of market sectors with long-term potential, such as fuels and chemical processes.

The solar thermal program is not in conflict with any other Federal programs. Areas of coordination include advanced engine development by DOE Transportation Energy Conversion (TEC) and the Division of Power Systems (DPS), storage system development by DOE Division of Storage Technology (STOR), materials and chemical process research under the Office of Energy Research, and coating materials R&D under DOE Conservation and Solar Applications (CSA). Coordination will be needed in the development of advanced solar thermal systems for high-temperature process heat applications.

Participants in the Federal program include large corporations (e.g., McDonnell-Douglas and General Electric), small firms (Sanders and Bi-Phase), major laboratories (Sandia and JPL), universities (University of Minnesota and Georgia Institute of Technology), consulting firms (e.g., MITRE), and utilities (Southern California Edison and Public Service of New Mexico).

The total FY 78 budget is $104.1 million, and the total FY 79 budget is $100 million. About one-third of this is for the construction of the Barstow facility. Preliminary budget planning for FY 80 through FY 83 shows considerable budgetary growth, primarily to incorporate the repowering and dispersed cycles thrusts. As in FY 79, about 70 to 80 percent of the budget would be for central receiver electric generating technology. (A more detailed description of the Federal program is given in Appendix A.)

IV. Advanced Technology

A. Central Receivers

The advanced technology effort for central receiver systems concentrates on performance improvements in two major areas: heat engines, and advanced central receivers. The benefit of increased performance and efficiency is to reduce the size of the heliostat field required to reflect a given amount of energy to the receiver. This, in turn, is expected to yield system cost reductions on the order of 25 to 50 percent. The advanced engines under study for central receiver include open- and closed-cycle Brayton and advanced steam-Rankine cycles. Advanced receivers (e.g., liquid metal, molten salt, thermochemical, hot air) capable of achieving the higher temperatures needed by the advanced heat engines are also under development. Many parallel efforts are under way in the receiver R&D investigations.

B. Distributed Receivers

Additional advanced R&D is needed on system cost reductions through increased performance and lower materials and fabrication costs, as well as in Stirling engines and bi-phase turbines which can be more efficient at higher temperatures but which require greater accuracy in the parabolic dish. Research and development is required toward selection of materials (light-weight, low-cost structural glass, polymeric materials, supporting framework, etc.). The integration of the distributed receiver with industrial batch processes needs further study.

C. Other Areas

Other areas of R&D include absorber and reflector coating investigations, heat transport fluids studies, and new applications for solar thermal systems. Current investigations in the latter area are concentrated on the fuels and chemicals industries. It is also the panel′s view that much more emphasis upon systems studies and industrial market analyses should be undertaken by the program to clarify many unresolved economic issues.

V. Technology Evaluation

A. Ability of Solar Thermal Power to be Commercialized Without Further RD&D

Solar thermal technologies would not make any significant market penetrations before the year 2000 without Federal RD&D. Most industrial firms would not continue investmenting R&D funds and venture capital at the present rate without continuing Federal support for such a high risk technology.

B. Federal RD&D Opportunities

RD&D could enhance market acceptance through several approaches:

- The rate of engineering development can be accelerated to improve system and subsystem designs, reduce weight, improve efficiency, increase durability, and to advance through several generations of technology before full-scale deployment and commercialization of solar thermal systems is attempted.

- Industrial innovation can be encouraged and fostered by proper Federal incentives to apply advanced technology, capabilities, and proprietary concepts to solar thermal development.

- System cost reductions can also be sought in standardization, quality control, and installation.

However, Federal incentives and RD&D programs for reducing costs by mass production must be carefully timed to prevent deployment of unsuitable technology. Federal efforts should first attempt to achieve maximum cost reductions via accelerated engineering deployment to improve performance, by encouraging industrial innovation, and by advanced technology. The rate of technology development should be accelerated to advance through as many generations of technology as feasible before major attempts are made to deploy or commercialize solar thermal technology. This approach will be more cost-effective and is more likely to obtain goals of large energy impacts within this century.

C. Non-RD&D Incentives

These could include incentives to either the supply or the demand sectors, including grants, accelerated depreciation, rapid amortization, tax credits, or numerous other options. The major question here would be how to achieve the solar thermal objectives at minimum cost to the Federal Government.

The following analytical efforts would suport non-RD&D incentives:

(1) Venture analysis to estimate industry's response to various initiatives the Government might take, and to assess the cost and benefits of each

(2) Market analyses and data

(3) Studies of the process of technology transfer from Federal programs to the private sector

(4) More definitive engineering cost studies

(5) Technology assessments to compare solar thermal and conventional energy systems in terms of costs and impacts

D. Institutional Constraints

There are a number of questions remaining to be answered in this area. For dispersed systems, one of the anticipated problems involes the on-site solar thermal user and the local utility, which might be the alternative power source. Would the solar thermal end-user be forced to pay for the additional capacity the utility has to keep on-line for on-site users or would he be charged standard commercial rates? Could he sell excess energy back to the utility?

Central applications constraints will involve the public utility commissions and possible questions concerning land use. It is anticipated that these problems will surface in current large-scale experiments.

E. Energy Impacts

The near-term (1985) DOE cost goals for central receiver electric power plants are $1300/kW for repowering applications and $1600/kW for storage-coupled applications. The attainment of these capital cost goals depends on the rate of engineering development and innovation, the realization of economies from mass production, and accumulating production experience. It appears that costs could be reduced from present levels to meet DOE program goals, but only through concentrated technical improvements and market development. The energy cost for the $1600/kW storage-coupled plant would be 58 mills/kWh, which compares favorably with oil but is 50 to75 percent more expensive than coal or nuclear power.

A rough estimate of the total market potential of central power tower solar thermal electric is 0.2 to 0.5 quads by 2000. The solar contribution resulting from industrial and agricultural process heat applications could be larger by several quads, but the uncertainties here are greater (addressed more fully in AIPH Technical Evaluation). Modular systems might have an impact in this market, as well as in total-energy systems supplying heating, cooling, and electricity to large building complexes, but a numerical estimate of quad penetration would be extremely uncertain. More definitive market-penetration studies based on accurate engineering and life-cycle cost estimates are needed.

APPENDIX A

Program Review of Solar Thermal

I. Program Description

The objective of the solar thermal power program is the widespread commercial implementation of solar thermal power systems for electric utilities and for dispersed applications requiring high temperature process heat alone, or in conjunction with on-site generation of electricity (cogeneration).

The DOE, Assistant Secretary for Energy Technology is responsible for the Federal Solar Thermal Power Systems Program. The utility (central power) systems program has the role of developing large (50 to 300 MWe) solar power plants for electric utility networks. The dispersed power systems program develops solar power plants of lesser capacity which are characterized by close geographic proximity with the point of energy use for industrial or community use. The advanced technology program has the role of providing the advanced technology that will be required for the evolution of economically viable central and dispersed power systems. The goals, purposes, assumptions, and participants in solar thermal programs are outlined below.

The Federal budget for solar thermal has been increasing during the past few years. The FY 79 budget is $100 million, of which $69 million is for RD&D operations and $30 million is for capital equipment and the construction of the Barstow 10 MWe central receiver pilot plant. DOE funding for these programs is shown in Table 1 below. The budget shown indicates that present priority has been given to central utility application and central receiver technology. The dispersed power program has been primarily oriented toward development of mid-temperature, line-focusing technology for total energy and irrigation applications.

Table 1: DOE SOLAR THERMAL PROGRAM BUDGET (MILLIONS $)

Activity	FY 78	FY 79
Dispersed Power Applications		
o Total Energy Systems	17.2	14.0
o Small Power and Irrigation Applications	10.9	14.0

Table 1 (continued)

	FY 78	FY 79
Central Power Applications		
o Large-Scale Systems	10.0	16.9
o Central Receiver Subsystems	11.8	10.1
Advanced Thermal Technology	10.2	14.0
TOTAL Operating	60.1	69.0
Capital Equipment	3.0	3.0
Construction (Barstow)	41.0	28.0
TOTAL (millions)	104.1	100.0

A. Central Power Program

1. Purpose and Goals

The overall objective of the Solar Thermal Central Power Program is to establish the technical readiness of cost-competitive central receiver power systems for utility applications. In the 1985 to 1990 time frame, the intent is to repower peaking and intermediate loads in electric utility systems now burning oil and natural gas. In the long term--1990 onward--high temperature solar energy collector technology is expected to evolve toward higher capacity factor systems and ultimately to emerge as an alternative to coal and nuclear plants for baseload power generation. In addition, the central receiver technology may be adaptable to serve non-electric processes requiring very high temperatures.

The principal strategy for reaching these goals is the creation of a heliostat mass production capability in the private sector through a market-pull strategy. A Federally sponsored program of retro-fitting gas- and oil-fired electric plants, known as the repowering program, has been proposed to create the needed initial demand for heliostats.

2. Assumption

The development and commercialization of solar thermal central power systems would directly reduce the national consumption of exhaustible fuels such as oil and natural gas, since 70 percent of the electricity presently being generated in the Southwest is produced from the burning of these fuels. It is also assumed that mass production will result in a significant drop in the price of heliostats, the main solar plant subsystem cost item.

3. Federal and Non-Federal Participants

The solar thermal central power program is directed by the DOE Power Systems Branch. Sandia Laboratories (Livermore) provides field program management for central receiver technology development and coordinates use of the Solar Central Power Test Facility in Albuquerque. The Aerospace Corporation, Jet Propulsion Laboratory, and SERI give technical support to DOE. Competitive solicitations in private industry provide the majority of development efforts for the Central Power Program.

B. Dispersed Power Program

Several projects have been undertaken in the Dispersed Power Program including total energy, irrigation, and small power systems including development of both line-focusing and point-focusing distributed receiver systems.

1. Purpose and Goals

Solar total energy (cogeneration) power systems development is to provide electrical generation and low temperature heat for space heating, air conditioning, and hot water largely using line-focusing technology. The small power and irrigation applications have two principal targets: electricity generation for irrigation and for small solar electric power systems such as rural communities, farms, municipal customers, and small industrial users served by local utilities. The point-focusing distributed receiver project supports development of point-focusing distributed receiver technology for small power systems applications. Line-focusing and central receiver systems projects apply to dispersed power requirements for both total energy and small power systems.

2. Assumptions

Fossil fuels for local generation and heating systems will be saved by the use of solar energy. The efficiency of the solar power system will be enhanced by use of the waste heat from power generation. Small power systems exhibit an attractive near- to mid-term economic potential because more than 60 percent of the nation's population resides in communities below 25,000. Engineering development and mass production of distributed receiver hardware will substantially reduce costs.

3. Federal and Non-Federal Participants

The solar thermal dispersed power program is directed by the DOE Dispersed Power Systems Branch. Sandia Laboratories (Albuquerque) provides field program management for irrigation, total energy, and line-focusing distributed receiver technology development. The NASA Jet Propulsion Laboratory provides program management for small power systems and point-focusing distributed receiver technology development. The Aerospace Corporation and Oak Ridge National Laboratory provides applications analysis support. Competitive solicitations with private industry provide the majority of development efforts for the dispersed power program.

C. Advanced Technology Programs

1. Purpose and Goal

The goal of the advanced thermal power technology program is to accelerate the reduction of the cost of solar thermal energy by improving system performance and applying advanced technology.

2. Assumptions

Solar thermal power is technically feasible but substantial cost reductions are needed to allow it to compete with conventional energy sources on a national basis. Major cost reductions can be achieved by improving system, subsystem, and component performance and by accelerating the development of advanced technology and materials.

3. Federal and Non-Federal Participants

The responsibility for the advanced technology program resides with the Advanced Thermal Power Technology Branch. SERI provides overall technology assessment and supporting technology, NASA/JPL is responsible for advanced dispersed power systems development. Sandia-Livermore is responsible for advanced central power systems.

II. Current Status

A. Accomplishments to Date

Prototype receivers, heliostats, and energy storage systems have been designed, built, and successfully tested by several contract teams. A 1 MW receiver was tested in a solar facility in Odeillo, France. Technology was selected for incorporation into a 10 MWe power plant to be built in Barstow, California, the first complete central receiver system to be constructed in the U.S. Bids for the pilot plant have been received and contracts will be awarded in September, 1978. Conceptual designs have been developed for 100 MWe commercial size power plants using water/steam central receivers. Alternate central receiver designs using sodium, molten salt, and air as the heat transport fluid are nearing completion. Second generation heliostat designs have been completed and contractors project quantity production costs will be in the range of the DOE cost goal.

A 5 MWt Solar Thermal Test Facility (STTF) is nearing completion in Albuquerque, New Mexico. The facility has 222 full-size heliostats and 28,000 heliostat hours of operation have been recorded.

A Mid-temperature Solar System Test Facility (MSSTF) is currently operational and presently consists of a Systems Test Facility (STF) and a Collector Module Test Facility (CMTF). This is the only government-owned facility capable of testing distributed solar collectors and related components in the 300°C range.

A High Temperature Test Facility (HTTF) is under development by the Jet Propulsion Laboratory at Edwards Test Station in California.

Design or construction of total energy systems for Ft. Hood, Texas, and a knitwear mill in Shenandoah, Georgia, shallow irrigation pumping experiments in New Mexico, and a deep well experiment in Arizona, are under way. These applications primarily utilize line-focusing distributed receiver technology with 1-axis tracking to develop intermediate temperatures.

The point-focusing distributed receiver technology program has requested and receive proposals for concentrators, receivers, and engines. Parabolic-dish collectors with 2-axis tracking are used to develop high temperatures and greater energy conversion efficiency. Evaluations are in progress and negotiations started on six receiver contracts. Three concentrator contracts and four engine contracts are scheduled for negotiation.

The small power systems project has awarded three contracts for the systems design and engineering of Engineering Experiment Number One (EE-1), a small community power plant.

The advanced technology program has selected the parabolic dish/ Stirling engine configuration for the first advanced dispersed power system. Conceptual designs in progress involve determining functional requirements and evaluations of materials and processes for high temperature (800°C) operations. Contractors have been selected for advanced engines and liquid metal energy transport and storage. Analyses have identified high temperature heat receivers and high efficiency small heat engines for dispersed power applications to offer significant economic gains. Studies have identified potential commercial uses of solar thermal power in the fuels and chemicals industry. An Advanced Component Test Facility was completed at the Georgia Institute of Technology and is being prepared for the testing of a large 1100°C heat receiver. In the materials and coatings supporting technology program, research on durable absorber coatings is in progress, and high temperature ceramic receivers, heat pipes, and chemical decomposition receivers are under development.

B. Anticipated Accomplishments Timetable

Construction of the Barstow pilot plant is scheduled to be completed and initial operation to begin September, 1981. Test operations at the STTF will begin in September, 1978, with an Electric Power Research Institute (EPRI) funded Brayton cycle receiver. This will be followed in October, 1978, by the test of a water/steam cooled receiver panel representative of the Barstow pilot plant design. Second generation heliostats are to be designed, built, and tested by mid-1980.

A repowering program is planned to begin in FY 79. Other new projects include support of a joint EPRI/DOE central receiver experiment using an advanced heat engine, evaluations of alternative central receiver concepts, hybrid systems (solar with other fuels) and advanced receiver and heliostat designs.

Prototype tests of novel irrigation pumping concepts will be initiated in FY 79. The shallow well experiment will be expanded to provide increased power for center pivot point irrigators. The deep well experiment is to begin operations in April, 1979. The Shenandoah total energy system should be completed and operational by June, 1980.

Preliminary design of point-focusing distributed receiver subsystems will be completed in mid-FY 79, followed by the design phase with fabrication scheduled in FY 82. Tests on various items will start in FY 79, to be completed by FY 83.

Engineering experiments being developed by the small power systems projects include a small community and military applications. The small community engineering experiment (EE-1) will begin final design and construction in late FY 80 and operational testing in FY 82. Contracts for preliminary designs of a second engineering experiment will be awarded in FY 79 for planned operational testing in FY 83.

New advanced technology feasibility contracts will be let in FY 79 for solar hydrogen production, fuels and chemical uses, insulation studies, and Brayton and Stirling engine development. Chemical storage concept development is anticipated in FY 80, with advanced concepts available for testing in FY 83. The concept design of an advanced central power system is planned for FY 80. The advanced dispersed power dish/Stirling subsystem integrations experiment is planned for FY 83.

C. Barriers to Goal Achievements Including Unresolved Issues

The potential barriers to reaching the program goals are a) funding limitations, b) technical operational problems that have not been recognized or anticipated yet, and c) limited effectiveness of demonstrated projects using existing components in reaching these goals.

Major barriers to implementation are the lack of reliable economic and market potential data on the central receiver concept and the difficulty of predicting capital and fuel escalation rates. Substantial progress has been made in demonstrating the technical soundness of the concept through testing of prototype components. Operating experience will be obtained from the STTF and the Barstow pilot plant. Improvements have been and are being made in the technology which result in cost projections for solar thermal power plants which are in the economically interesting range. However, commercialization will not occur until potential investors are able to analyze cost and operating data to determine the suitability of the concept to their needs. The uncertainty in cost projections for the technology can be greatly reduced by the fabrication of hardware and the construction of plants. The repowering program and the associated market pull strategy (heliostats) are intended to achieve this goal.

III. New Factors - What Has Changed Since the Program Began

A. New Assumptions

The solar thermal program was initiated to provide systems for electric utility applications and for agricultural applications such as irrigation pumping. A new factor is the potential use of solar thermal systems for applications that use high temperature heat (e.g., fuels, chemicals, cement, kilns, gypsum board manufacturing, and glass making). It appears that a large market may exist for solar thermal systems in industries that manufacture or process materials in batches. Industries that could be shut down because of shortages of oil or gas may be more receptive to solar thermal systems than the utilities which have priorities on these fuels.

Another near-term market appears to be the production of synthetic products, fuels, and strategically essential chemicals using solar heat. In the long run, industrial processes may be developed to use solar heat for essential chemicals, synthetic products, fuels, and other important material production.

B. New Opportunities

Repowering of existing plants has been described by DOE as an opportunity to reduce utility consumption of oil and gas while developing an initial market for heliostats through volume purchases. High temperature process heat is also seen as a priority application for solar thermal technology.

TAB E

Technology Evaluation: Photovoltaics

I. Current Engineering/Scientific Status

Photovoltaics energy systems are comprised of insolation collection devices (arrays containing photovoltaic cells), mounting structures, power conditioners, system controls, and as needed, storage. Major RD&D efforts have been underway aimed at developing array and cell technologies, with an emphasis on silicon, for several years.

The status of photovoltaic collection devices ranges from "basic research" (e.g., certain thin film semiconductor and reradiating concepts) to commercial (i.e., "remote market"--flat plate single crystal arrays in systems designed for remote stand-alone applications). Major DOE program emphasis currently lies in the category of "Manufacturing Cost Reduction" ($36 million of $77 million in FY 1978), primarily for single crystal silicon cells and arrays. Legislation now before Congress is likely to shift the major emphasis onto system-level tests and demonstrations.

A necessary precursor to the development of major photovoltaic markets is achieving DOE cost-reduction goals for collector technologies, i.e., flat plate, thin film, or concentrators. Most analysts agree that array first costs of $0.50 per peak watt* or less are necessary to induce significant markets for photovoltaic systems and to produce quad-scale energy impacts.

Additionally, major questions regarding timely achievement of non-array or Balance of System (BOS) cost goals must be addressed, because they must be achieved in the same time period as array goals (in the mid to late 1980's to early 1990's). Balance of system components include the following: support structure, power conditioning, storage, controls, and installation.

Photovoltaic electricity systems will become cost competitive only if BOS costs are reduced substantially to $0.50-$1.00 per peak watt. Existing systems show BOS costs of $5-$15 or more per peak watt. Research in power conditioning and other BOS components receive limited emphasis in the present DOE program, and systematic storage research specific to photovoltaics applications began in late 1977.

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*All cost goals are stated in 1975 dollars unless otherwise noted.

Total energy concepts involving photovoltaics are in early stages of development, and consensus has not been reached regarding the likelihood of commercial systems. Total energy systems applying concentrators to increase solar intensity combine photovoltaic electricity production with heat production (up to at least intermediate temperatures). In concept, total energy systems can achieve greater overall energy recovery than single mode-systems at favorable costs.

Because of photovoltaic's inherent modularity at the cell level--cells may be assembled into modules, which in turn may be assembled into arrays of essentially any size or configuration--the array imposes essentially no physical limitation on the size or type of application. Some economies of scale have been identified in power conditioning components, but cost objectives may be difficult to meet for some photovoltaic applications. The criteria that define or limit the probable or possible applications for photovoltaics--institutional and economic issues aside--are, hence, for the most part those that apply to solar energy in general, and include:

a. Insolation availability
b. Deployment area availability
c. Load match
d. Materials limitations

Other constraints relate to the type of energy produced--electricity. For purposes of further discussion, it is appropriate to somewhat arbitrarily define four principal types of electrical power applications:[1]

a. Central power stations of 10 MWe or greater, feeding energy to electric utility grid.

b. Dispersed onsite applications of the intermediate 1-10 MWe size for commercial, industrial, institutional, agricultural, or small communities. Grid connection or backup (diesel motor generator, gas turbine) power facilities are assumed.

c. Dispersed sites as in "b", except in the under-1 MWe size for residential use. Grid connection is assumed.

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[1] This breakdown is taken from "A Review of the Photovoltaic and Solar Thermal R&D Programs," D. Israel, May 17, 1978.

d. Isolated or remote applications of up to several megawatts for sites without grid connections (although perhaps with motor-generator backups).

Specific Photovoltaic Technologies

There is currently a large number of photovoltaic devices (cells) under investigation at widely different levels of effort. Table 1 presents a partial listing along with measures or estimates of cell efficiencies.

Single-crystal (nonconcentrating) silicon is by far the most advanced cell in terms of experience. The small current commercial market for photovoltaic systems is today supplied exclusively with such cells. Major DOE program emphasis is being given to reducing the manufacturing costs associated with such cells, including alternative approaches to reduce single crystal ingot costs.

Cadmium sulfide thin film heterojunction cells rank next in terms of the historical research effort. Development of these cells for concentrators is the most recent area of effort. Neither thin film nor concentrating systems have captured any significant portion of the existing small market. Private investment in CdS production pilot plants has been made in the last year or two, although private investment in silicon technology remains at substantially higher levels.

While device and cell research and development have been the focus of attention to date (because of the recognized need to effect substantial cell cost reductions and/or improve efficiencies), utilization and market penetration by photovoltaics depends upon total system performance and characteristics. That is, decisions or choices among flat plate, thin film and concentrator cells must be made from the "top down," by determining what is required of the system by the application, what is required of the subsystems--of which the array is one--by the system, and finally what is required of the cell (or module). The recent application of this "systems engineering" approach has led to the publication of allowable BOS prices for major applications, as well as projections of what those prices are likely to be.[2] These results indicate that additional work is needed, especially in structures,

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[2] "Status of the DOE Photovoltaic Systems Engineering and Analysis Project," G. J. Jones and D. G. Schueler, Sandia Labs, presented at IEEE PV Specialists Conference, June 1978.

TABLE I

Photovoltaic Devices Currently Under Investigation

Device	Probable maximum achievable efficiency	Maximum measured efficiency*	Performance of commercial cells	Reference
Silicon devices				
Single crystal homojunction	20-22	19	10-15	(1,2)
Polycrystalline homojunction	?	7-14(?)	-	(4,5)
Amorphous Schottky with platinum	15	5.6	-	(6,7)
Thin films				
CdS/Cu_2S (chemical vapor deposit process) (heterojunction)	15	8.6	2-3	(8,9)
CdS/Cu_2S (spray process) (heterojunction)	8-10	5.6	-	(10)
(Cd/Zn)S/Cu_2S (heterojunction)	15	6.3	-	(9)
CdS/$CuInSe_2$ (single crystal) (heterojunction)	24	12	-	(11)
CdS/$CuInSe_2$ (thin film) (heterojunction)	15	6.9	-	(12)
GaAs (Schottky AMOS)	25-28	14	-	(1,13)
Single crystal Schottky with indium-tin oxide	20	12	-	(3)
Cells for use in concentrated sunlight				
Optimized silicon cell (single-crystal homojunction), 200 times concentration	22	18	12.5	(14,15,16)
Interdigitated back-contact silicon, single-crystal homojunction, 100 times concentration	26-27	15(20?)	-	(17)
Thermophotovoltaic	30-50	13	-	(18)
$Ga_xAl_{1-x}As$/GaAs (180 times)	25-26	24.5	-	(19)
$Ga_xAl_{1-x}As$/GaAs (1,700 times)		19	-	(20)
Multicolor cell (GaAs/Si/Ge)	40	-	-	(21)
Vertical multijunction (silicon)	30	9.6	-	(22)

*Techniques for reporting efficiencies differ. Wherever possible, efficiencies were chosen which assume air mass 1 and include losses due to reflection and contact shading.

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installation, and storage technologies, and in operation and maintenance practices. Additional uncertainties remain concerning storage versus sell-back to utilities (in grid-connected, onsite systems) and level of production effects upon the cost of power conditioning.

Different assessments have ascribed different levels of importance to the three classes (flat plate, thin film, concentrator) of array technology. DOE program assessments, for instance, conclude that reduction of manufacturing costs for flat plate silicon technology is currently the leading route to achieving cost-effective photovoltaic arrays. The recent Solar Working Group report,[3] concludes that thin film cell development deserves top R&D priority. A third view is presented in the OTA assessment,[4] which emphasizes the attractiveness of total energy or cogeneration systems (producing electrical and thermal outputs) which generally utilize concentrating arrays. It is worth noting that silicon-based cells (amorphous silicon films and silicon concentrator-optimized cells) are candidates for thin film and concentrator arrays as well as flat plate arrays. Most of the differences of opinion regarding the "best" array technology evolved from differing perceptions of the ability of the various technologies to meet the cost reduction goals and of the potential for viable markets. Regardless, the demonstration of \$0.50/watt cell production must be accomplished in the early 1980's if such technology is to be in place by the current program goal of 1986. Since only silicon-based technologies have been the subject of extensive DOE RD&D support, they alone appear at this time to have the potential to meet the 1986 goal.

II. Economics

A brief summary of current photovoltaics module prices is presented in Appendix A. Only silicon flat plate price data have any real validity since it is the only technology with any market volume.

Figure 1 superimposes price data upon the DOE program price reduction goals scenario. Most analysts agree that still further reductions in price (i.e., to \$0.10 - \$0.30 per peak watt) will be necessary to achieve central electric power station cost effectiveness.

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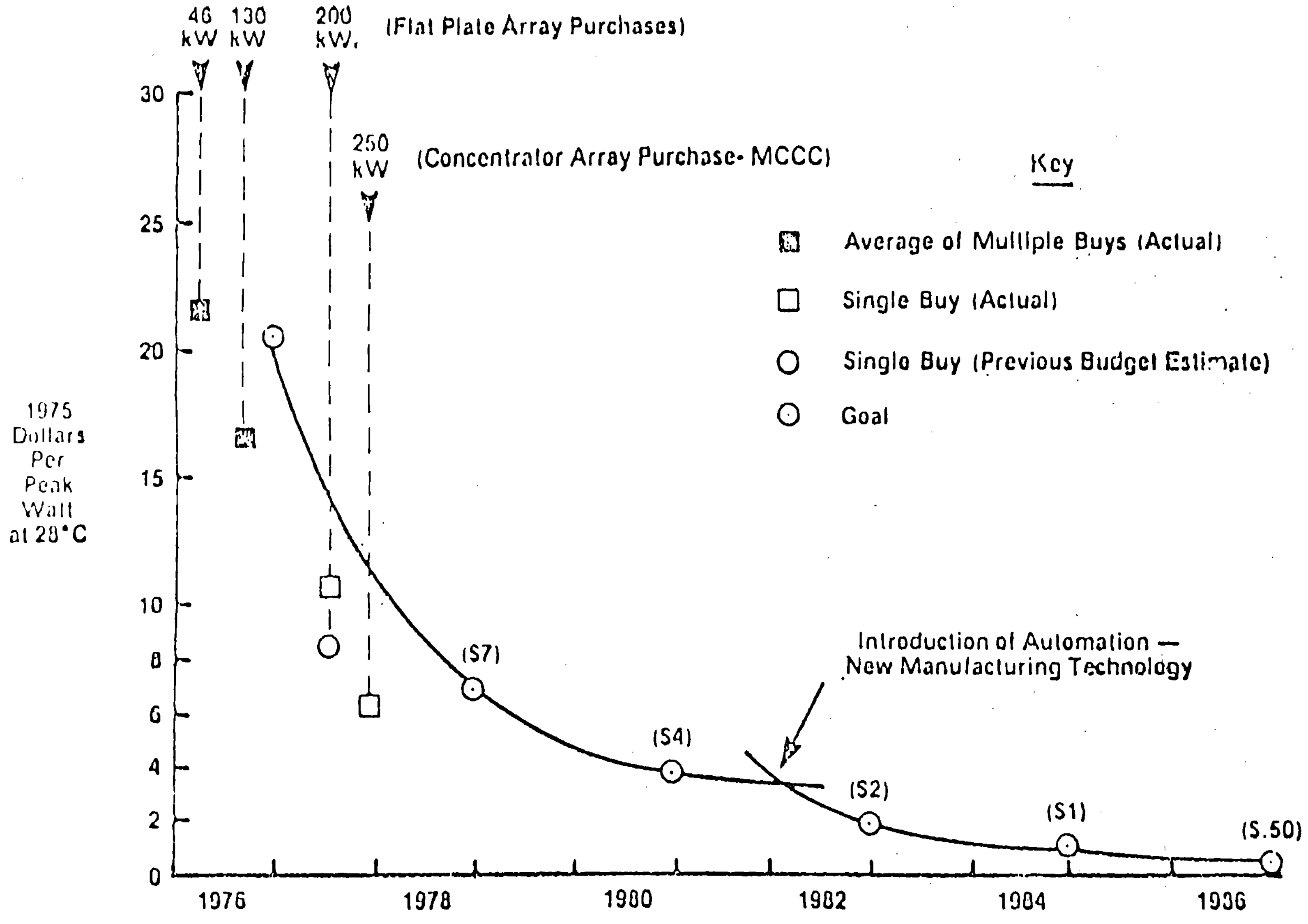
[3] Solar Energy Research and Development Program Balance, Solar Working Group, U.S. DOE; February 1978.

[4] Applications of Solar Technology to Today's Energy Needs, Office of Technology Assessment; June 1978.

FIGURE 1

Terrestrial Solar Array Price History/Goals



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It should be noted that the DOE goals scenario does not explicitly identify technology. However, it is generally accepted that advancements in production technology will need to be attained to get below $1 to $2 per peak watt of array. A number of flat plate silicon technology options are currently under development that may hold the potential for $0.50 per peak watt or less. However, their ability to get into the $0.10 to $0.30 per watt range (a price thought required for central station utility use) is subject to serious question. The ability of concentrator arrays to get below $1 per watt (electric) is also in question. While thin film cells are still in early stages of development, some analysts feel that only they are likely to reach the $0.10 to $0.30 per watt level.

It is important to realize that achievement of array price goals at whatever level is not sufficient in itself to ensure the availability of cost-effective photovoltaic systems, which must compete in terms of life-cycle cost with other energy alternatives. Various ways exist to estimate life cycle and energy cost-effectiveness, but to be useful they must reflect:

a. First costs of <u>all</u> system components (of which the array is one),

b. Performance, life and reliability of all system components,

c. Installation and operating and maintenance costs,

d. Amount, availability and cost of nonphotovoltaic backup required, and

e. The time-dependent value of capital.

Utilization of such approaches to calculate busbar energy costs for photovoltaic systems indicates that to provide busbar energy at costs under 100 mills/kWh utilizing arrays costing in the neighborhood of $0.50 per peak watt requires balance of system costs of less than $1 per watt. Currently, photovoltaic systems cost $16-22+ per peak watt consisting of arrays costing $6-12 per peak watt and balance of system costs ranging from $5-10 per peak watt and upwards (BOS costs again include structure, power conditioning and control, storage, if needed, and installation.) These cost figures are those that have been experienced in the mounting of recently emplaced systems. Hence, reductions in BOS cost of the same order as those required for array cost are necessary to yield busbar energy costs approaching competitive levels, under generally accepted scenarios for costs of conventional electrical energy alternatives. Economies of scale in power conditioning, utilization of d.c. directly, and exclusion of storage could sidestep technology problems and drive down BOS costs for some applications.

The level of private market activity in 1977 is estimated to have been roughly 750 kilowatts (peak). That market is confined to remote applications--communications system elements, navigation systems, corrosion protection and the like. Such applications, remote from existing electrical grids and difficult logistically to supply with fuels, are life-cycle cost-effective even for photovoltaic systems at current price levels. This "remote" market also includes a significant although unknown fraction of purchases by buyers wishing to test or display photovoltaics in an admittedly non-cost-effective application.

Federal purchases (see Figure 1) have constituted a major market (25 percent of the total) for photovoltaic module manufacturers in the past. It is likely that the Government will continue to provide a major market for some years, with purchases shifting to systems, via a variety of mechanisms.

A few general comments may be made with regard to market size and penetration potential in the three nonremote, broad application classes defined earlier:

a. Given the current United States electric energy system and a business-as-usual scenario for future operation thereof, central power stations may represent the largest <u>potential</u> market over the long term. However, the penetration of photovoltaics into this market faces perhaps higher barriers--technical, economic and institutional--than in any of the other application areas.

b. Approximately two-thirds of all domestic end-use of electrical energy is in the sectors (commercial, institutional) embodied in what is herein called dispersed intermediate. The vast majority of these applications are currently serviced by the existing central powerplant system. Hence, the market associated with supplying this end-use with onsite (dispersed) photovoltaic systems involves a shift in the nature of electrical energy supply from centralized to decentralized. Other issues include ownership and operation control, nature and economics of the utility interface, and heterogeneity of decisionmaking (on the part of potential users). It is possible that the extent and complexity of the grid system may facilitate interconnection of dispersed photovoltaic sources and a gradual decentralization of electricity sources.

c. Most of the remaining one-third of end-use of electrical energy is in the residential sector--that is, the "small dispersed" category. The same comments apply here as were put forward for the dispersed intermediate case, with utility interface issues taking on even more importance because of the "ultimately" distributed nature of the residential application.

The technological issues associated with photovoltaics are inextricably entwined with economic issues--that is, while increased cell efficiency, reduced cell performance degradation and increased system efficiency are obviously beneficial, they must not be achieved at the expense of cost effectiveness. Hence, all increases in performance or lifetime must be carefully evaluated to ensure that they yield a net reduction in system level life cycle cost or energy cost.

III. Program Strategy and Goals

The current DOE photovoltaic program strategy portrayed consists of:

"o Strong high-risk R&D effort;
o Technology development toward cost goals (design to cost);
o Support key process steps;
o No Federal manufacturing facilities; and
o Market pull stimulation".

The most recent available broad statement of photovoltaic program goals is found in Solar Energy--A Status Report (U.S. DOE, June 1978):

> The objectives of the DOE program are to stimulate the development of the technology required to produce low-cost, reliable photovoltaic systems, and to stimulate the necessary industrial manufacturing capability.

The most widely exhibited "Program Goals" are the familiar array price goals (sometimes appearing as cost goals) of:

a. \$2.00 per peak watt* in 1982 (with 20 MWe production)
b. \$0.50 per peak watt* in 1986 (with 500 MWe production)

c. $0.10 - $0.30 per peak watt* in 1990 (with 10-20 GW production in 2000)

It is of interest to compare these to the stated objectives of the Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978 (H.R. 12874, May 25, 1978 version):

> (1) to double the production of solar photovoltiac energy systems each year during the decade starting with fiscal year 1979, measured by the peak generating capacity of the systems produced, so as to reach a total annual United States production of solar voltaic energy systems of at least two million peak kilowatts, and a total cumulative production of such systems of four million peak kilowatts by fiscal year 1988;
>
> (2) to reduce the average cost of installed solar photovoltaic energy systems to $1 per peak watt by fiscal year 1988; and
>
> (3) to stimulate the purchase by private buyers of at least 90 per centum of all solar photovoltaic energy systems produced in the United States during fiscal year 1988.

DOE budgets for photovoltaics RD&D have grown rapidly from $55.4 million in FY 1977 to $76.2 million in FY 1978 and $105.8 million in FY 1979 (including a $30 million supplemental increase).

The major expenditure emphasis (67 percent or $33.7 million) of FY 1977--technology development efforts aimed primarily at single crystal silicon arrays and cells--is continued through FY 1979 and FY 1980 plans, although as a decreasing percentage of total expenditures. FY 1978 Federal purchases increased threefold to 23 percent of the budget ($19.2 million). As a result of the FY 1979 initiative increment, gradual program reemphasis, and a new (and likely accurate) perception of opportunities for improved collectors, funding for advanced R&D concepts has increased from $6.2 million (11.2 percent) in FY 1977 to $35 million (33 percent) in FY 1979, joining technology development--(primarily silicon) cells, arrays, and concentrators ($40.8 million and 35.6 percent)--and Federal purchases ($16.6 million 17.7 percent) as the major components of the DOE RD&D program.

Recent steps by the DOE program to articulate cost goals for BOS, including photovoltaic-adapted storage, and to complete system testing

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*1975 dollars; peak watts at 28°C.

facilities (in 1978) indicate progress in the transition to a systems engineering viewpoint. However, the absence of generic development and innovative engineering program elements for BOS are viewed as program shortcomings by many analysts. Similarly, test and evaluation standards for system performance have not been developed and performance criteria are not complete.

Management tools to make use of information developed from tests of extensive buys and from more limited "systems support" testing have received low levels of support. This and the lack of "looping" to feed system test data to components developers pose dangers to the speedy success of any RD&D program.

Continuing purchases by the Federal Government are a basic strategic element of the DOE photovoltaics program. The "market pull" strategy postulates that substantial Federal purchases will "move the industry down the learning curve;" and that mounting these systems in user-operated applications will at the same time stimulate subsequent private demand.

The above definition of the "market pull" strategy is oversimplified; much debate over how it will work--and if it will work--has taken place. Among the issues under debate:

a. Which technology option(s) should be "pulled",

b. Will a learning curve phenomenon really take place,

c. Will manufacturers make appropriate and necessary investment decisions to install advanced production processes,

d. Will needed capital emerge,

e. What are the risks and consequences of "premature" technology failing or degrading at disastrously high rates in highly visible projects,

f. Is there sufficient supporting systems engineering work going on to minimize these risks, and

g. Will "pulling" one technology option impede other, later-blooming technology options.

In an attempt to answer some of these questions, the Solar Energy Research Institute (SERI) undertook a costs/benefits "Venture Analysis" of the market pull concept. Results appear to suggest that the "market pull", as originally proposed, would not be particularly effective, but the venture analysis itself remains to be evaluated to ensure that it answers the key questions.

A key presumption of the "market pull" strategy is the existence of a substantial "intermediate" market for arrays in the $1-2 watt range. The intermediate market is anticipated both in the United States and in foreign countries, particularly LDC's without well-developed electricity grids (and, hence, with relatively scarce supplies and expensive supply options). The intermediate market is anticipated to be triggered by the Federal stimulus of a large photovoltaic buy program, in turn stimulating private investment, strengthening and expanding the domestic industry and further reducing photovoltaic prices.

Yet, public studies to date are inconclusive as to the dimensions of foreign markets and domestic applications appear largely limited to off-grid sites until energy prices drop below 100 mills/kWh. Reliance on foreign and domestic intermediate markets to absorb an ever-increasing volume of photovoltaic production appears questionable in the absence of a more definitive evaluation of intermediate users, especially LDC's (see Appendix B for more details on the existing Federal photovoltaics program).

IV. Advanced Cell and Array Concepts

A brief identification of advanced device and cell concepts is included in section I.

Essentially all system concepts must be classed as advanced--with the exception of stand-alone systems with d.c. output and either no storage, or lead acid battery storage--because they presently exist only as single prototypes, in breadboard, or on paper.

The object of advanced cell and array R&D, as with single crystal silicon RD&D, is to reduce array cost per peak watt. The advanced R&D is attacking all aspects of the problem, attempting to find approaches to increase cell/array efficiency more rapidly than cost (e.g., concentrator systems, GaAs, and reradiating systems) and seeking approaches to reduce cost more rapidly than efficiency (e.g., thin films). Other "unconventional" techniques, such as photochemically produced fuels (e.g., hydrogen for fuel cells) or heat and electricity are also under study.

Striking theoretical cost and efficiency possibilities have been postulated, and initial laboratory studies have produced optimistic predictions for some of the advanced concepts. But it must be kept in mind that operational verification of such predictions is generally lacking.

Environmental issues, which are not sufficiently defined, may exist with some technologies, particularly advanced concepts, "hybrid" systems producing hot fluids as well as electricity, cell manufacture involving toxic or hazardous materials, and photochemical and thermochemical cells which produce dangerous chemical products all pose environmental and workplace questions. Nevertheless, if careful attention is paid to potential health hazards as photovoltaics are developed and commercialized, they should offer substantial environmental benefits in conjunction with most conventional energy sources.

Recent major funding increases for advanced cell and array R&D reflect a growing sentiment that long-term cost/efficiency goals may be reached more readily by advanced techniques. Rapid developments in the laboratory in such technology areas as thin film, photochemical, and thermochemical cells have fueled optimism. But laboratory success in advanced concepts must be followed by technology development (of production techniques) before this promise can be realized. Similar efforts may be required in some BOS areas, perhaps most notably in structures, power conditioning and installation techniques.

V. Technology Evaluation

A. Ability of the Technology to Supply Energy Without Further Federal RD&D

The ability of photovoltaics energy systems to provide useful electrical energy has been established; at least one cell technology--single crystal silicon--is available today and would continue to be so for certain applications even if all Federal RD&D efforts were terminated tomorrow.

There is little disagreement among analysts that without Federal RD&D the cost of photovoltaic-produced electrical energy would remain at or near its current levels--at least an order of magnitude too high for widespread cost-effectiveness. The status of the technology is being advanced through rapid, Federally-supported innovation, particularly in the area of cell and array technology. Of the balance of photovoltaic system components, storage also stands out as being the subject of significant development attention.

Development of low cost power conditioning awaits RD&D initiatives. Reduction of costs of structures, systems controls, and installation may flow from systems engineering and evaluation RD&D efforts.

The role of Federal RD&D then is to effect the reductions in photovoltaic energy cost necessary for competition with conventional and other emerging energy sources. Similarly, competitive energy costs must be accompanied by competitive reliability and acceptability (in all senses of the word) at the systems level. Federal photovoltaic RD&D programs can also address these factors and must bring the mills/kWh cost of photovoltaic electricity down from its current 1,500 to substantially less than 100 if photovoltaic energy is to make an appreciable contribution.

B. How Federal RD&D Might Accelerate Energy Supply and In What Timeframe

1. Advanced Research and Development: Many semiconductor devices exhibiting the photovoltaic effect have been discovered. Some are quite well understood; others, less so. The investigation--advanced research and development--of such devices to determine whether they might be capable of reproducible high performance is an accepted aspect of Federal RD&D.

2. Technology Development: Once a device or cell has proven its ability to perform attractively, it must be determined whether or not it is possible to produce such cells in volume at suitably low cost. Further, low cost methods must be found to support, protect, and collect cell output via modularization, while minimizing system cost and reducing transportation, installation, and maintenance expenses.

   Low energy costs require not only low cost cells, modules and arrays, but also low cost, long-lived, reliable, efficient, non-array components--inverters control systems, support structures, etc. The development of such components (both array and nonarray), and of methods to produce them, is generally termed technology development and is generally viewed as an appropriate element of Federal RD&D.

3. Application and System Analysis: Efficient technology development requires knowledge of the conditions that the components under development will experience in actual applications. The generation of such subsystem and component requirements (cost performance, life, etc.)--via characterization of potential applications and conceptual definition and analysis of systems to use in those applications--form part of Federal RD&D efforts.

4. Systems Engineering: To verify cost and performance predictions, and to identify technical problems impossible to foresee on paper, it is necessary to devise and carry out actual hardware tests on components, subsystems, and breadboard systems. The planning, carrying out and analyzing of such tests, as well as the process by which results are fed back to provide evolutionary improvements in succeeding generations of hardware, may be termed system engineering. This, too, is generally accepted as a valuable pursuit of Federal RD&D.

5. Design, Fabrication, and Operation of Production Process Experiments: Such experiments might range in size from benchtop scale to essentially full scale production plants; considerable controversy exists as to what scale of experiment is appropriate for Government participation. The fact that such hardware projects are by their nature expensive relative to other RD&D activities must be weighed against the need to verify at an appropriate scale the capabilities of important advances in production technologies. Several knotty issues are involved:

    a. What scale of experiment is necessary and sufficient to verify a given process?

    b. Will successful verification lead ultimately to industry adoption?

    c. Might the RD&D resources committed to the experiment be better utilized elsewhere?

    d. Does (or will) the verified process integrate with other elements of the overall industry?

    e. What sort of cost-sharing arrangements are appropriate (degree of cost sharing volunteered by private industry can be a useful indicator of the perceived attractiveness of the process)?

6. Design, Fabrication, Installation and Operation of Actual Systems in Actual Applications: Here, too, opinions differ as to the appropriate scope of Government involvement. There are at least two major objectives which most observers agree are appropriate for Federal RD&D projects of this type:

    a. Generation of economic, performance, and acceptability data and information

b. Exposure and involvement of potential suppliers, financiers, operators, regulators, etc.

Most of the disagreement arises when the size, scope and/or number of such projects is increased beyond that seen to be sufficient to meet those two objectives, i.e., when such projects are used to implement a "market pull" strategy of the type described in earlier sections.

The current Federal RD&D program features three major areas of emphasis. These are:

1. R&D of advanced cell and array concepts.

2. Technology development of cell and array production methods (primarily in silicon technologies).

3. "Market pull" with applications tests and evaluations.

Relatively low emphasis appears to exist in two key areas:

1. R&D and technology development in Balance of System (BOS) components.

2. Systems engineering and feedback.

A major new emphasis is contemplated in the DOE preliminary planning for FY 1980. This is entry by DOE into production process scale-up experiments (for polycrystalline silicon material production, cell fabrication, and array manufacturing).

Taken together, initial DOE planning for FY 1980 and the National Energy Act provide massive support for the "market pull" despite the rapid innovation underway in the photovoltaic R&D area, the uncertainty of intermediate markets, and the near-term need for system engineering, BOS cost reduction, and photovoltaic standards. A major concentration on the near-term technology may be counterproductive, freezing technical developments by draining private R&D resources into production investment, thus forcing a shotgun approach to system engineering, and draining resources which will be needed to develop promising cell technologies and BOS components emerging later from R&D.

The simultaneous emphasis in the DOE program on advanced concepts R&D induces uncertainty in industry players: a very large production investment may be rendered worthless by a significant technology breakthrough. Thus, preservation of balance between "market pull"--or more appropriately, "systems engineering and evaluation"--and R&D in advanced collectors and BOS components is a major issue with far-reaching import.

In light of the rapid innovation in photovoltaic technology, the current emphasis on long-range breakthrough strategies appears proper, the "market pull" very questionable, and increased, systematic systems engineering and related work necessary. The initiation of a "market pull" strategy at a later date may have the desired effect, but the existence of demonstrated production technology(ies) capable of reaching $0.50 per watt, more systems experience, and lower BOS costs are needed to make the strategy potentially viable.

C. Non-RD&D Incentive Mechanisms Which May Further Accelerate Market Introduction

Clearly, the difference between the price that the user must pay for photovoltaic energy and the price of alternate energy represents an area that could be addressed by incentive mechanisms (the Federal RD&D program aims, of course, to erase that difference via developing and introducing low cost technology). As RD&D diminishes the difference, at some point financial incentives to either the suppliers or the purchasers could be instituted to close the remaining gap. Several issues must be addressed before the initiation of such a strategy:

1. At what point should such incentives be initiated?

2. What mechanisms might be used to ensure that further technological progress in cost reduction is not impeded?

3. Are demand-side or supply-side incentives more appropriate?

It is clear that incentives should not be viewed as an alternative to RD&D; rather, incentives must be used in conjunction if they are to be utilized at all. It is the RD&D Panel's view that financial incentives beyond those already incorporated into the Federal RD&D budget are not appropriate at this time but should be studied for potential future application.

D. Institutional, Manpower and Federal Program Management

The current program management and implementation structure is described elsewhere (see the RD&D Panel's "Existing Photovoltaic RD&D Program," Appendix B).

Perhaps the major area needing improvement is program integration. The direction of component and subsystem development must, in an efficient program, be provided from the "top down," e.g., via definition of application and system requirements. Such requirements must be derived, assessed and transmitted from applications and systems analyses and tests to the appropriate technology development efforts. Information on technical and cost data needs must also travel the other way, e.g., system and application testers in particular, must be made aware of component availabilities and must conduct tests in such a manner as to provide needed verification data. Maintaining and directing this type of information flow is the essence of program integration, and needs more attention.

A less critical Federal program management issue is in the area of environmental research. Coordination between DOE/Environment and EPA is in need of improvement.

E. International, State and Local Issues

As has been indicated elsewhere, the question of international markets and their possible contribution to industry growth and/or cost reduction is a major issue that requires resolution.

Regional, state and local differences in both physical (insolation, climate) and economic (costs of alternative energy sources, taxation, regulation, etc.) factors have, in general, not been analyzed in depth. Clearly, such factors impact the potential applicability and penetration of photovoltaics, and therefore should be investigated to yield guidance for development and testing activities.

F. Energy Impact

No meaningful energy impact is expected by 1985. Estimates for the year 2000 vary significantly in their quad impact projections (0.1 to 5 quads). Any major quad impact must, of course, embody major commercialization of photovoltaics, of which a necessary (though not sufficient) precursor is the meeting of cost goals and the availability of acceptable, reliable systems--the objectives of the RD&D program.

G. RD&D Opportunities

The panel's recommendations for the photovoltaics program are based on its assessment of the developmental nature of the photovoltaic technology, its perception of the need to more deeply incorporate a total system approach in the DOE photovoltaics RD&D program, and its consequent concern about the advisability of conducting a massive market pull approach. Accordingly, it is suggested that for the near term (3 to 4 years) the following opportunities appear to warrant priority attention:

1. A delay in the Federal "market pull".

2. Increased emphasis on meeting Balance of System (BOS) goals.

3. A concentrated R&D effort in promising array concepts <u>and</u> in BOS areas.

4. Continued applications testing of photovoltaic systems for the purpose of developing hands-on experience in emerging photovoltaics markets, establishing photovoltaics O&M cost and durability data, and developing industry standards.

5. Accelerated development of manufacturing methods for photovoltaics and nonarray system components.

6. Improved coordination between EPA and DOE in an increased environmental program for photovoltaics.

Programs exist in DOE which bear complementary roles to the photovoltaics RD&D program and which may be critical to the ultimate competitiveness of photovoltaics systems. Included in this category are the storage program and the power conditioning portion of the transmission program. Management integration with these programs and others is, thus, a necessary step. Appropriate program goals must be jointly developed and resources earmarked for support of the photovoltaics program. Additionally, coordination between the commercialization program in the Office of Conservation and Solar Applications will be essential in testing photovoltaics purchased with Federal funds.

APPENDIX A

Current Photovoltaic Module Prices

Of the three major photovoltaic collector technologies, flat plat, concentrator and thin film, only the first two may be said to be commercially available today. Presented here is data indicative of (1) current market prices for production flat plate modules and (2) the range of current prices for installed concentrating systems to be purchased in the near future by the DOE photovoltaic program.

(1) Table B-1 indicates the prices contracted for by JPL in the recent DOE Program Block III Procurement of flat plate silicon cell photovoltaic modules. Such modules are believed to be the least expensive form available today. It should be noted that the price per kilowatt varies substantially with quantity; the price for small quantities would be considerably higher on a per kilowatt basis. The prices are for modules only and do not include other system costs such as support structure, power conditioning, etc.

Table B-1. DOE Program Block III Procurement

Company	kW Purchased[1]	price per kW ($77/60°C)[2]	price per kW ($75/28°C)[3]	5-year warranty premium[4]
Arco Solar, Inc.	20	$16.0K	$11.3K	$0.25K
Solarex	30	17.8K	13.6K	3.50K
Sensor Tech	40	16.0K	11.5K	0.50K
Solar Power	50	14.5K	10.5K	2.30K
Motorola	50	13.4K	9.5K	1.60K
Total	190	$15.2K[5]	$11.0K[5]	--

Notes regarding Table B-1:

[1] Kilowatts contracted for (performance at 60°C).

[2] Price FOB manufacturers' dock, current year dollars, performance at 60°C (thousands of $/kW).

[3] Price FOB manufacturers' dock, coverted to standard reference conditions--1975 dollars, performance at 28°C (thousands of \$/kW).

[4] Prices listed include "free" 1-year warranty. The 5-year warranty premium values are manufacturers' quotes in terms of thousands of dollars per kilowatt.

[5] Weighted averages.

(2) A wide variety of concepts is currently under consideration in photovoltaic concentrator systems. The responses to a recent DOE Program Research and Development Announcement (PRDA) indicate current installed concentrator system costs to be in the range of \$10 to \$25/watt-peak-power. The wide range of prices reflects the variety of applications system concepts and locations proposed in the responses, as well as the fact that all the systems will be the first of their kind to be built.

The only available concentrator array purchase data reported is a figure of \$6 per peak watt (1975 dollars; 25°C) for 250 kW of concentrator array purchased as part of the DOE Mississippi County Community College MCCC project.

Source: "California State Photovoltaic Program--A Program Plan," April 1978.

APPENDIX B

Program Review: Photovoltaics

I. Description

A. Purpose and Goals

The overall objective of the DOE photovoltaic program is to develop low cost, reliable systems and to encourage the creation of a viable industrial and commerical capability to produce and distribute the systems for (1) residential and commercial applications, and (2) electric utility applications. The main subobjectives of the DOE program are:

1. Starting in 1977, to reduce silicon array prices by a factor of 10 by 1982 to $2/peak watt and by a factor of 40 by 1986 to $0.50/peak watt (in 1975 dollars).

2. To develop a concentrator photovoltaics array costing $2/peak watt by 1980.

3. To develop advanced array concepts that show potential for technical and economic feasibility.

4. To conduct systems and applications studies on all components of photovoltaic energy systems.

5. To conduct experimental system tests and demonstrations of photovoltaic power systems for a variety of residential, commercial, industrial, and Federal applications. A major aspect of the test applications program is the proposed "market pull" approach, under which annual Federal buys over an 8-year period would be used to stimulate private sector capital investment and support the establishment and growth of the private market infrastructure.

6. To continue mission analysis and economic overview studies, and to work with industry to develop voluntary standards by 1981-1982.

7. To coordinate with DOE programs developing related technologies (e.g., batteries and flywheels for storage) to assure development of photovoltaics applications.

It is notable that although photovoltaic array and energy cost goals are enunciated by the DOE program, cost goals for the Balance of System (BOS) are not given prominence and may, indeed, only be inferred. To achieve the mills/kWh targets established for 1982, 1986, and 1990 will require balance of system (BOS) cost reductions of approximatley the same ratios as are required of array costs!

B. Assumptions

Major assumptions underlying the DOE photovoltaic program include the following:

1. A major Federal role in developing photovoltaic technologies and applications.

2. No Federal role in manufacturing or commercial marketing of photovoltaics.

3. Encouragement of market competition, small businesses, and basic research.

4. Consideration to stimulating the photovoltaic industry and markets by Federal "market pull" strategy.

C. Consistency With Other Federal Programs

Photovoltaic-related RD&D projects exist in several other agencies, although the largest effort is centered in DOE. Table 1 summarizes non-DOE projects (some with cofunding), which focus on specific applications of interest to each agency. (The major exception is EPA, which also is evaluating potential environmental issues related to photovoltaics.)

Other DOE programs bear a relationship to the photovoltaic program because photovoltaic systems include components being developed under separate efforts. These include the storage program and power conditioning part of the transmission program. Storage is a necessary element of photovoltaic applications to reduce the requirement for backup electricity supply, and power conditioning is required to convert direct to alternating current. Coordination between the storage and photovoltaic programs has increased significantly in the last year. Less coordination exists between the photovoltaic and DOE power conditioning programs.

Federal Photovoltaic Studies and Projects

Agency	Studies/Projects	DOE Resources	Other Resources[1]
Agriculture w/DOE	Insect Survey Traps	10 K	4.2 K
USAID w/NASA/Lewis (DOE)	Village System in Africa		55 K + 55 K
NOAA w/DOE	RAMOS Project--atmosperic stations	12 K	173 K (includes structure cost)
U.S. Forest Service w/DOE	Forest lookout structures	15 K	186 K (includes) structure cost)
DOD w/DOE	Incl: Air Force radar site, Mt. Laguna, California	1.7 million	0.8 million
NJEPA w/NASA/Lewis (DOE)		3.2 million (est.)	384 K
Indian Health Service (HEW/DOE)	Gun Sight, Arizona--Popago Village, Indian Reservation	total: 50 K	(mainly ODE)
Arizona DOT w/NASA/Lewis	Highway warning signs	5 K	21 K (includes structure cost)
State of California w/DOE	Visitors Center, Lonepine, California	12 K	N.A.
Mississippi County Community College	MCCC Demonstration	6.3 million	25. million (for school structure)
EPA	Several environmental assessments of solar technology	0	150 K
EPA	Assessment of air quality impacts applied to AQCRS	0	300 K
University of Nebraska w/Lincoln Lab	Nebraska irrigation system	1.545 million	0
National Park Service w/Lincoln Lab	Natural Bridges, Utah (100 kW)	3.17 million	200 K
FHA	Highway applications--RFP issued	N.A.	N.A.

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[1] Various fiscal years.

Environmental programs conducted by EPA and DOE do not appear to be coordinated at this time. Overlaps exist and may be anticipated to continue in the absence of concerted efforts to coordinate.

D. Major Participants in RD&D

Principal participants, in addition to DOE/Energy Technology, that have key roles in the photovoltaics program are as follows:

1. SERI is program manager of advanced array concepts RD&D.
2. JPL is program manager of manufacturing process technology development for arrays, all of which to date have been in silicon.
3. Sandia and Albuquerque Operations (ALO) manage photovoltaic tests and applications efforts, including mission analyses, systems tests (at Sandia, MIT, NASA/Lewis, and SERI), design efforts, performance testing, and Federal buys.
4. DOE/Conservation and Solar Applications administers Federal purchases through FPUP, photovoltaic/ thermal demonstrations, commercialization planning, market development planning, and systems development.

Private participants include:

1. Spacecraft Photovoltaics: OCLI, Sensor Technology.
2. Semiconductor/Electronic: GE, Honeywell, IBM. Motorola, Rockwell International, RCA, Texas Instruments, Westinghouse.
3. Hardware Research: Bell Labs, Hughes Research, Spire Corporation, UTL, Varian Xerox E.O.S.
4. Energy Companies: Arco (Arco Solar), Exxon (SPC), Mobile (Mobile-Tyco), CFP (Photon Power), Shell (SES), Chevon.
5. Independents: Solarex, Solenergy, Solic, Aerotherm/Aernex.
6. Materials Suppliers: Allied Chemical, Dow Coraing, Dupont, Monsanto, Owens Corning, Union Carbide.

E. DOE Budget and Personnel Allocations

Table 2 below summarizes the DOE budget for photovoltaic RD&D activities. In general, budget levels have increased by 50 percent over the period FY 1977 to 1979, while headquarters personnel levels have remained constant. Funding of silicon array development and Federal purchases of silicon-based systems have absorbed two-thirds or more of the budget each year, although over 70 percent of FY 1979 initiative funds are targeted for advanced cell concepts R&D). Approximately 190 man-years are involved at the four principal DOE laboratories.

F. Impact on Competition in Energy Industry

The photovoltaics program is designed to develop photovoltaic technology options for application by the energy industry. Attention is being paid to new participants and to create opportunities for competitive involvement by industry. The demonstrations undertaken by the systems test and applications element will help identify and remove commercialization barriers, including system reliability, performance, and durability. Voluntary industry standards are planned. R&D efforts will fill technology gaps and add "horses" to the race.

G. Evaluation Criteria

The principal criteria being applied are energy cost per kWh peak and array cost per kWh peak. However, less widely articulated criteria have been established for subsystem components other that arrays (e.g., storage and power conditioning) and for other aspects of photovoltaic systems, e.g., installation costs, operation and maintenance costs, array durability, life cycle costs, etc. In light of the major importance of BOS costs to the ultimate competitiveness of photovoltaics, increased attention to meeting cost criteria in BOS is a prerequisite to development of viable photovoltaic systems.

Table 2

Program Area	FY 1977		FY 1978	FY 1979	FY 1979[c] Initiatives
	BA[a]	BO[b]			
Technology Development (silicon array and concentrators)	33.7	31.9	36.0	32.8	8.0
Advanced R&D	6.2	6.2	8.7	13.5	22.0
Systems Support (analysis and engineering)	7.0	4.7	9.0	9.3	
Testing and Applications	6.5	6.1	19.2	16.6	
Mission Analysis and Engineering	2.0	2.1	3.3	3.9	
TOTAL PROGRAM[f]	55.4	51.0[d]	76.2[e]	76.1	30.0

[a] BA = Budget Authority

[b] BO = Budget Obligations

[c] Proposed H.R. 12874

[d] Rounded

[e] Includes $19 million supplemental (Tsongas Amendment)

[f] Plus $50,000 in FY 1977, $400,000 in FY 1978, and $550,000 in FY 1979 for photovoltaic-related energy storage.

Further, no industrywide consensus standards for material quality, testing procedures, or system performance have yet been established for photovoltaic materials, cells, or assemblies. These are necessary for full commercial application of photovoltaics.

II. Current Status

A. Accomplishments To Date

Significant accomplishments have been achieved in the last several years in photovoltaics. As listed by DOE, these include:

1. Silicon array costs have been reduced tenfold in 4 years.
2. Array manufacturing cost reductions of an order of magnitude have been identified.
3. Rapid progress towards meeting the 1980 \$2/watt goal for concentrators.
4. Rapid progress in advanced cell concept development.
5. Industry is spending risk capital.
6. The advent of viable terrestrial nongrid-connected applications.

B. Anticipated Accomplishments Timetable

See Section I/A (Purpose and Goals).

C. Barriers to Goals Achievement

Several significant barriers exist which may delay or prevent achievement of the goals of the photovoltaics programs.

1. Cost Reduction for BOS: Cost goals for storage, power conditioning, controls, structures, installation, and O&M for photovoltaic systems have not yet been accorded major focus in the DOE program. Goals for the former group may be inferred from the mills/kWh goals, and although subsystem goals exist for BOS, DOE has put very limited emphasis on BOS in funding and planning. Program coordination between relevant parts of DOE is increasing (particularly between photovoltaics and storage), but efforts are not yet fully complementary.

2. Technological Uncertainties: Several major uncertainties have been identified for photovoltaic systems. Array efficiencies and system efficiencies must be increased. Significant cost reductions are required for each system component. System reliability must be increased and standards set. Inexpensive encapsulation techniques must be developed for arrays. Technological advances in most subsystems are required to meet ultimate system cost goals, notably for arrays, storage, and small scale power conditioners.

3. Institutional Barriers: Limited work has been done to date on institutional barriers. Further definition of these is required and programs must be devised to reduce them. Particularly difficult problems may exist in the areas of financing (because of high first costs) and grid interconnection.

III. New Factors

The initial photovoltaics program began before DOE existed as an effort to develop devices that would convert sunlight directly into electricity. Presently, the photovoltaics program is aimed at the broader goal of developing complete energy systems. Accordingly, the program should (and has begun to) change its perspective to add an emphasis on nonarray system components.

TAB F

Technology Evaluation: Biomass Energy

I. Current Engineering/Scientific Status

A. Definition

Biomass is the term used to encompass all forms of plant matter and its derivatives including residuals from crops and forests, animal wastes, sewage, and the organic components of municipal solid waste.

B. Solar Technology Involved

Biomass is a form of energy that can be used directly as a solid fuel or converted to a variety of liquid, gaseous, or other solid fuels. Biomass also has environmental advantages over fossil derived fuels that they could replace and is a renewable resource.

Biomass energy systems involve a broad array of technologies. These include:

- Production, collection, and beneficiation of biomass
- Direct burning
- Biochemical or thermochemical conversion into gaseous, liquid, and modified solid fuels
- End-use systems that are compatible with the various forms of biomass energy

C. Energy Demand Sector Served

Biomass-derived fuels are potential substitutes for all fuels, and hence biomass could serve all energy end-use sectors. Of the solar technologies, it represents the most practical means of obtaining liquid fuels. It also can provide an alternate to petrochemical feedstocks. The number of different possible resources and the number of conversion processes combine to form a large number of possible approaches to producing, converting, and using biomass. Figure 1 illustrates the multifaceted character of biomass energy. Many biomass sources are regionally or locally specific, as to their use.

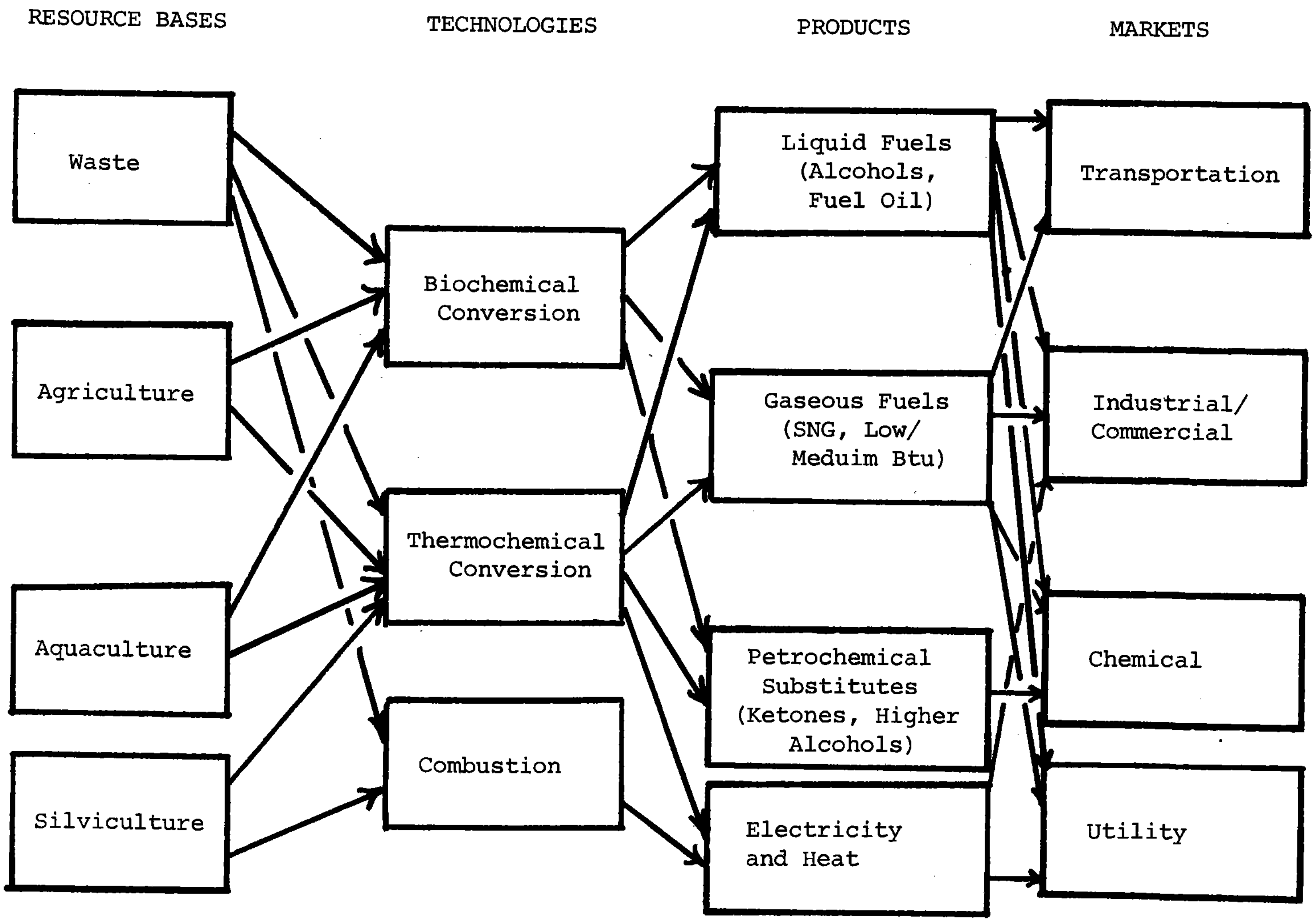


Figure 1. Routes of Biomass from Source to Use

D. Phase of Development

Energy derived from biomass has been used throughout history. Until the late nineteenth century, it was the major source of energy in the United States, and, even now supplies over 1 quad per year.

Direct burning of biomass, especially wood, is a commercial technology. Many other conversion technologies, such as anaerobic digestion and alcohol fermentation, have an extensive history of development, but previous work was not directed primarily to energy. Thus, even existing technologies may require further development to maximize energy yield, process efficiency, or adapt them to new applications.

There is a wide variation in the state of development of the technologies included in production, conversion, and use of biomass energy. Table 1 shows the general status of the more advanced technologies. In most cases, there is continuing R&D activity on improving the efficiency of those technologies that have gained commercial status. The technologies were grouped as follows:

(0) Latent

Little activity is known, but is a possible area for exploration.

(1) Research

Investigations, both fundamental and goal directed, into the physical and biological processes occurring in the production and conversion of biomass.

(2) Development

Engineering design, testing, and improvement of processes judged most likely to succeed from the results of research. Pilot scale tests to evaluate operational performance and correct problems.

(3) Demonstration

Near commercial scale systems installed to demonstrate satisfactory performance and process economics in order to gain commercial acceptance.

Table 1

Status of Biomass Technological Development

	Biomass Source Technology Process	Urban Sewage	Municipal Solid Waste (trash, garbage)	Animal Wastes	Agr. Residues	Forest Residues	Processing Residues (sugar, lumber, cotton gin, etc)	Agr. Commodities	Standing Trees	Energy Farming, Agriculture	Energy Farming, Silviculture	Energy Farming, Aquatic	Hydrocarbon Producing Plants
Production	Cultivation	NA	NA	NA	NA	NA	NA	5	4	1,2	2-3	1,2	1
	Collection/ Beneficiation	5	2-5	4,5	2-4	2	4,5	5	4,5	2-5	2	1-5	0
	Densification	NA	2-5	NA	2	4	4	NA	NA	NA	NA	NA	NA
Biochemical Conversion	Anaerobic Digestion	4,5	2,3	2-4	1	1	0	0	NA	1	1	1	NA
	Sugar/Starch Fermentation	NA	NA	NA	NA	NA	4	4,5	NA	2,3	NA	NA	0
	Cellulose Conversion Fermentation	NA	1-3	1	1,2	1	1-5	NA	1	1	1	1	0
	Fermentation to Chem. Feedstocks	NA	1	0	1	1	1	2-5	1	1	1	1	0
Direct Combustion	Direct Combustion, Residential	NA	NA	NA	1,4	4,5	5	NA	5	4	4	NA	NA
	Direct Combustion, Commercial (including co-firing)	NA	2-4	NA	1	4	4	NA	4	4	4	NA	NA
	Direct Combustion, Industrial (including co-firing)	NA	2-5	NA	4-5	4-5	5	NA	5	4	4	NA	NA
	Direct Combustion, Elect. Generation	NA	2-5	NA	4	4	5	NA	4	2-4	2-4	NA	NA
Thermochemical Conversion	Pyrolysis	NA	2,3	1,2	3,4	3,4	3,4	NA	2-4	0	2-4	NA	NA
	Thermochemical Liquefaction	NA	1	1	2	2	2	NA	2-4	2	2	NA	NA
	Low Btu Gas Conversion	NA	2	0	2,3	2,3	2-4	NA	2-4	0	2.4	NA	NA
	Medium Btu Gas Conversion	NA	2,3	1,2	1,2	1,2	1,2	NA	2	0	2,3	NA	NA

NA - Process not applicable to this source
0 - Latent: Little known work but processes believed to be possible
1 - Under research
2 - Under development
3 - Being demonstrated
4 - Commercially available
5 - Commercially accepted
Values given indicate relative status rather than precise, absolute status

(4) Commercially Available

Products are currently offered for sale, or vendors are available to design and deliver system.

(5) Commercially Accepted

Same as commercially available with the addition of a distribution/supply infrastructure and sufficient market penetration to indicate user confidence and favorable economics.

1. Production and Harvest

The silviculture sources of biomass have been actively developed by public and private owners of forests. Emphasis has been on increasing yield and also improving the stock as a source of timber and pulpwood. Forest and woodland areas, however, produce at far below their maximum potential. The concept of energy silviculture is in the developmental stages. Tree harvesting is well developed but may need alteration for energy usage. The collection of forest residues is in an intermediate state of development; mill residues are being used, but not to their fullest extent.

The general potential for production of grains crops is well known. Additional research on production of field crops, such as sugar cane and sweet sorghum, for energy has recently been initiated. Brazil has a large-scale program for production of sugar cane as a feedstock for alcohol production. Agricultural energy farms are in the early developmental stages, and exotic plants for energy and chemical sources are being studies in the laboratory.

Studies on the feasibility of using aquatic plants as a source of biomass have been initiated. Kelp is commercially harvested on the West Coast, but this is to provide a source of algin. A test module for open-ocean kelp farming primarily for energy is going into place. Aquatic plant production related to waste management systems has gained some acceptance, but the development of harvesting techniques for energy usage is relatively unexplored.

Municipal solid waste (MSW) and municipal sewage collection systems are well developed. The separation of biomass from MSW is still not a fully-developed technology. Animal manure residues are readily available and require no major changes in collection technology.

The degree of technological development for various aspects of production and harvest are summarized in table 2.

Table 2: Status of Biomass (Production and Harvest)*

	Research	Development	Demo	Commercially Available	Commercially Accepted
Woody Plants					
Silviculture Farm	X	X	X		
Standing Timber	X	X	X	X	X
Forest Residue	X	X	X	X	
Processing Residues				X	X
Herbaceous Plants					
Agricultural Crops	X	X	X	X	
Agricultural Residues	X	X	X	X	
Agricultural Farms	X	X			
Hydrocarbon Producing Plants	X				
Aquatic Plants	X				
Wastes					
Sewage	X	X	X	X	X
Trash/Garbage	X	X	X	X	
Manure	X	X	X	X	X

*A full range of activity is shown up to the status of some of the most advanced aspects of the various technologies. Generally, all technologies have a continuing program of improvement even after commercial acceptance is attained

2. Conversion Processes

The biochemical processes of anaerobic digestion and fermentation are well established technologies. However, these technologies were generally not developed for fuel production, and their use for this purpose requires improved conversion and thermal efficiencies. Improved anaerobic digesters for methane production are being developed, and their economic and technical viability for a broad range of uses needs to be demonstrated. Small, farm-sized anaerobic digesters for production of gas have been developed and have gained notable acceptance abroad, and their use in digestion of sewage (with energy recovery in some cases) is considered standard practice. Some attention is now being turned to improving thermal efficiency of ethanol production via fermentation. The conversion of lignocellulose into a form that can be converted into alcohols is still in the research and development state. The liquefaction (nonfermentation) of biomass is being investigated at the process development level; however, technical and economic problems have been encountered. Pyrolysis of biomass to produce low Btu gas, oil, and charcoal is being developed and demonstrated.

The direct combustion process is commercially viable in some industrial sectors, particularly wood and wood residues in the forest products industry. The small wood stove for residential use is an established commercial product, but may have some environmental and economic limitations, particularly when used in urban areas. Refuse derived fuel from MSW is being commercialized in large pulverized-coal fired utility boilers, and direct combustion of unprocessed MSW in waterwall incinerators for steam production, is also commercial. However, techniques for burning densified forms of refuse-derived fuel in the much more numerous stoker boilers remain under development. The gasification processes are at the stage where demonstrations are being planned. The front-end systems for making use of biomass feedstocks in gasifiers are being developed. The degree of development for various conversion technologies is summarized in table 3.

3. End Use

Technologies for production and conversion will need to be tailored to the end use. Biomass that is consumed on or near its point of origin will not require the densification or other processing that is needed for shipping to large centralized facilities. The degree of automation required will also vary by use.

Table 3: Status of Biomass Conversion Technologies*

Conversion Technology	Research	Development	Demo	Commercially Available	Commercially Accepted
Direct Combustion		X	X	X	X
Anaerobic Digestion	X	X	X	X	X
Fermentation	X	X	X	X	X
Gasification	X	X	X	X	
Pyrolysis	X	X	X	X	
Liquefaction	X	X			

---

*A full range of activity is shown up to the status of some of the most advanced aspects of the various technologies. Generally, all technologies have a continuing program of improvement even after commercial acceptance is attained.

End use equipment or facilities will also need to be modified. Biogas from anaerobic fermentation can be used as a natural gas replacement but conversion devices must be modified for efficient performance. Gasohol offers only a limited opportunity to utilize ethanol since it can only substitute for 5 to 10 percent of gasoline usage in today's automobiles. Engines that can use 100 percent ethanol have been built. Further technology development could provide a much greater opportunity for replacement of gasoline.

E. Technological Issues

Since some biomass production and use for energy is already a reality (primarily direct combustion), the technological issues deal primarily with economic and technical problems that might limit use. The principal issues are:

1. How can major advancements be made in efficiency of production and conversion of biomass? While current development efforts are bringing about improvements in biomass production, basic research is needed to uncover new opportunities, such as improving the efficiency of green plants as solar energy converters, and identifying new processes for biomass conversion.

2. If biomass materials become extensively used as an energy source, can a supply be assured? Competition for production of food and feedstocks on the same land does not exist now, but might be expected to increase as world population increases or weather patterns change. On the other hand, yields per acre could be substantially increased with improved crops, multiple cropping within a year, and other land and water use improvements.

3. Will biomass production be seriously limited by the productivity of the marginal land used or the available supply of water? Expansion of biomass production will lead to use of marginal land, for which the yield potential is uncertain (decrease in energy efficiency). Water availability will also be a serious constraint.

4. How much can biomass yield be increased through species selection and breeding? Conventional field crop yields have been substantially improved, but the focus of this work has been upon maximizing those portions of plants useful for their food content rather than energy uses.

5. Can collection and storage processes and equipment be developed that have acceptably low cost? The diffuse nature of biomass

resources, their relatively low energy per unit volume, and seasonal variability are specific factors that require attention.

6. Can biochemical processes be developed that can economically convert a wide range of biomass feedstocks to useable fuel substitutes? Lignin, hemicellulose, and cellulose represent major components of biomass that currently do not economically suit biochemical processes.

7. Can net energy efficiency of conversion processes be improved while meeting competitive cost requirements?

8. Are there suitable uses for all the products resulting from thermochemical conversion or pyrolysis of biomass? For example, can liquid and char components be used without separation?

9. What will be the long-term energy demand for biomass products and what are the site-specific potentials for producing biomass material? Prospective users of biomass energy systems need more complete and accurate information for appraising the availability of biomass for the site and system biomass energy conversion that they are contemplating.

F. Environmental Issues

Expanded reliance on biomass for energy raises a number of important environmental concerns. On a global scale, many areas within Africa and Asis are already threatened with deforestation and dessertification by improper management of biomass. Ecological concerns associated with the increased reliance on biomass energy in the United States include (1) air- and water-quality effects from increased agricultural and silvicultural operation; (2) possible depletion of soil organic and inorganic content due to residue removal; (3) gaseous, liquid, and solid pollutants or residuals associated with combustion and conversion technology; (4) increased application of pesticides and fertilizers; (5) possibility of plant epidemics due to the expanded use of monoculture; and (6) potential for inadvertent modification of ocean ecology due to large-scale use of ocean farming.

On the positive side, the use of biomass as a renewable fuel helps to limit the increase in atmospheric carbon dioxide (CO_2) levels associated with the combustion of fossil fuels. The risks of substantial climatic change due to CO_2 buildup are not well established but may be severe. In some cases the use of biomass for energy actually eliminates a present environmental problem, e.g., if crop residues are used in environmentally controlled energy processes rather than being burned in the fields. Aquaculture, as indicated, also removes water pollutants; and the digestion of the resulting biomass permits recovery of scarce chemicals in the digester residue.

If the biomass energy program is implemented on a sustained yield basis with a careful balance between production and land conservation, environmental problems should not be a major issue.

G. Factors of Scale

The relatively low density of biomass (except for MSW) will limit the size of conversion plants because of transport cost to the conversion site and the reduced rates of throughput of the feedstock. The practicial size for electrical generation facilities fueled from biomass sources appears to be within the range of 20 MWe to 50 MWe. Since the kinds of biomass vary regionally and sources may be dispersed throughout a large area, the optimal scale of conversion facilities will vary. For example, large anaerobic digesters would be used with large feedlots, smaller digesters would be used at individual dairy farms, and ethanol fermentation plants could serve a specific geographic area and be sized accordingly.

II. Economics

Some biomass energy systems are currently competitive with conventional energy systems on a site-specific basis but most of them are not.

Economic breakthroughs may be easier to obtain with silviculture energy materials than agricultural crops because production of woody material is expected to be predominantly on lower valued land which has fewer possible high value uses. Appreciable progress in aquatic biomass production is required in order to meet the same cost goals of material produced from agriculture and silviculture. The prospects for marine crops will be better known after new information is available from the first open-ocean farm, due to start up this fall.

Reduction in the production and process costs of fermentation is necessary to make the products economically attractive as fuels. This will require development of lower cost conversion systems which use lower cost feedstocks. Fermentation derived alcohols and other products such as acetone are most likely to economically compete in the chemical feedstock market far sooner then in the fuel market. Development of fermentation processes could end in the decoupling of the chemical industry from oil and natural gas.

Beneficiation of MSW--processes to remove noncombustibles, recover high-value materials, and prepare biomass for energy use--requires additional development for some unit process steps to make them more economical.

Direct burning of wood and wood wastes is economically proven for several applications (space heating and steam generation), but direct firing of other biomass and an extension of its application to more uses are needed. Key refuse options--particularly cofiring densified refuse-derived fuels with fossil fuels--are economically promising, but are not fully developed for all possible applications.

While low Btu gas production from biomass is competitive, in some applications, with that from coal, appreciable development is required to lower product costs to make it competitive with petroleum-derived fuels. Many biomass conversion processes have considerable potential for additional returns from byproducts. However, market saturation of the byproducts may occur, reducing their value.

The existing infrastructure for biomass conversion is quite varied. A large number of companies offer equipment or systems for the direct combustion of biomass (straight or cofired). Some companies have begun market development work in small portable gasifiers. A small number of companies now offer their services for design and construction of anaerobic digesters. The fermentation industry is mature, but relatively little work is known to be under way by industry to develop processes and equipment oriented toward fuel production.

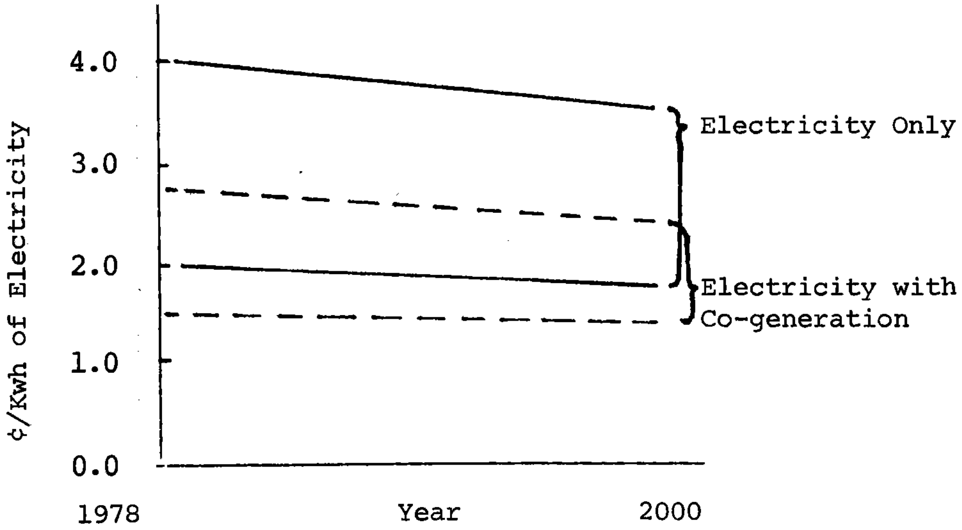
Cost estimates for some biomass-derived fuels and end products as a function of time as shown in figures 2 to 5.

III. Federal Strategy

In the aggregate, the objectives of ongoing work are to develop and demonstrate technologies for (a) production, harvest, and beneficiation of biomass, (b) direct burning, and (c) conversion to clean fuels and petrochemical substitutes.

The Federal biomass RD&D program is conducted within several parts of DOE, USDA, EPA, and other agencies. Broad Federal objectives do not appear to have been formally developed, and thus objectives are

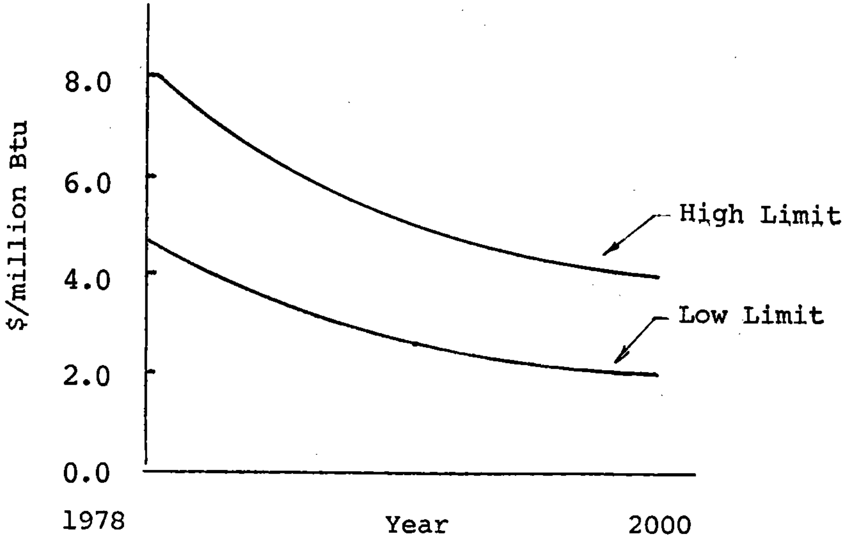
Figure 2
Direct Burning of Biomass for Electricity and Heat



Notes:

- o Wood burning and electrical technologies are sufficiently well-established to expect only modest reductions in costs through RD&D
- o Doesn't include possible Biomass production breakthroughs

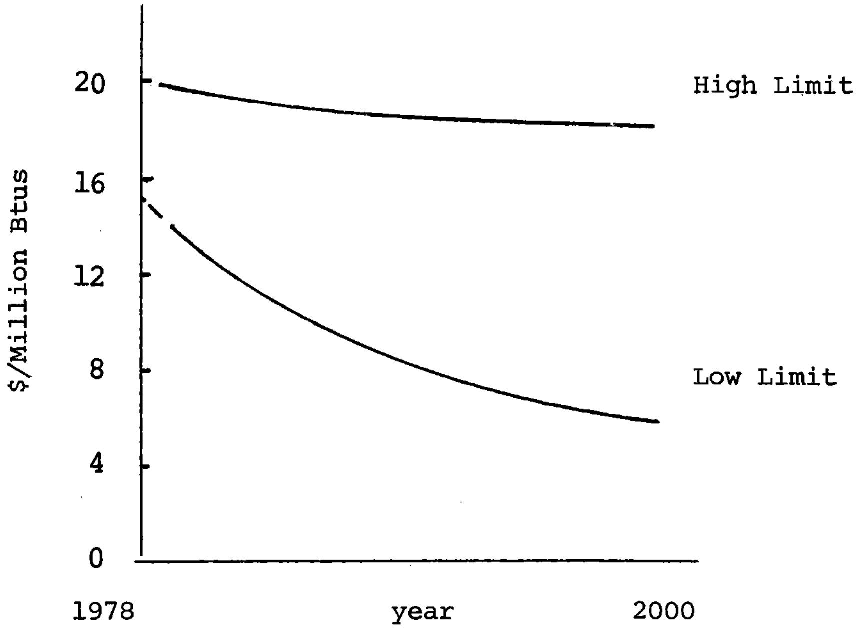
Figure 3
Gas Production - Anaerobic Digestion
Using Agricultural Residues



Notes:

- Major gains are expected through refinements of current digester designs
- Spread reflects differences in size of units and lack of experience

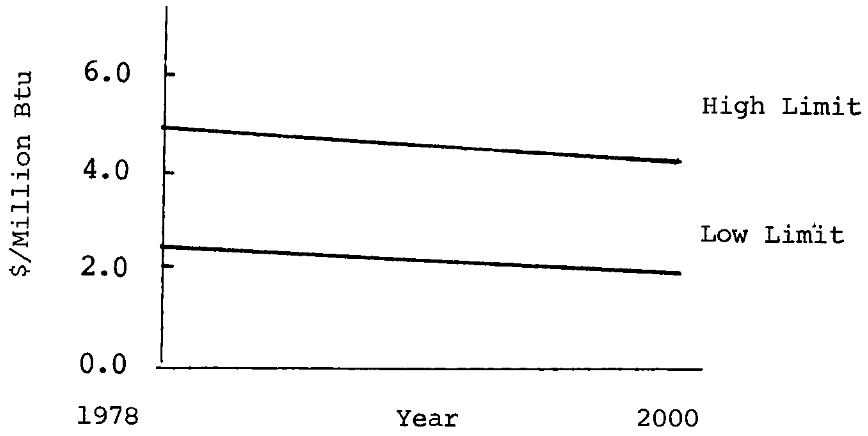
Figure 4
Ethanol by Fermentation



Notes:

- Divergence with time are due to uncertainties of competitive usage markets
- Lower limits apply to cellulosic materials
  Upper limits more aptly apply to sugar crops

Figure 5
Low and Medium Btu Gases



Notes:

- Wide range due in part to uncertainty of feedstock costs. Lower curve would most aptly apply to recovery of energy from wastes

- Conversion technologies capitalize on established technologies limited to those of individual agencies. Within DOE, direct combustion RD&D is conducted by the Power Systems Division, biomass research in production and conversion is conducted by the Solar Technology Division, and research in processing and conversion of urban wastes is conducted by the Office of Conservation and Solar. The SERI program now being developed, includes analysis and assessment, basic research programs, and biomass market development activities. The USDA program deals primarily with biomas production but also includes efforts on direct combustion and conversion to other fuels and applications to forest, industry, and agricultural uses. The EPA program derives from its basic mission pertaining to resource recovery from municipal solid waste, sewage disposal processes, and protection of the environment from emissions from energy-related processes. Both USDA and NSF are conducting basic research on photosynthetic processes that is not specifically directed to biomass energy. A more detailed description of the various Federal programs is given in appendix A. A summary of the Federal program budgets is presented in table 4.

There is considerable lack of coordination among these programs, within and between agencies. Furthermore, although the DOE program covers a wide variety of overall needs, it's effort toward the commercialization of biomass has lagged.

IV. Advanced Concepts

In general, Federal biomass programs have emphasized activities that have the most immediate energy payoff. Biomass has a potential to provide a much greater contribution to the future, particularly post 2000, energy needs if R&D efforts are placed on advanced concepts in production and conversion. Areas where basic research should be emphasized include:

1. Production

Short rotation cropping of poplar, sycamore, alder, and other rapidly growing species may provide yields of wood much higher than the productivity of conventional forestry methods, as well as facilitate easier and cheaper cultivation and harvest. Nitrogen fixing species will reduce dependence on commercial fertilizers.

Basic comparisons of energy pathways in plants have shown that plants using C_4 photosynthesis have greater efficiency than those using C_3 mechanisms. Considerable basic work is now under way that attempts to transfer C_4 processes to plants that now use

Table 4
FY 1978 Federal Biomass Program Funding

	DOE	USDA	EPA
Production and Harvest			
Silviculture	3.5	.5	
Agriculture	.8	.7	
Aquatic	1.2	.1	
Harvest	.7	.1	
Municipal Waste			1.0
Agricultural Waste		.1	
Biochemical Conversion			
Anaerobic	1.8	.5	.4
Fermentation	2.5	.1	.3
Thermochemical Conversion			
Direct Combustion	2.0	.4	1.6
Gasification	4.3		
Pyrolysis	.2		.9
Liquefaction	2.0		
Chemical Feedstock	1.0	1.6	
Environmental Assessment & Controls			.7
Biomass Conversion Facility	3.0		
Biophotolysis and Photoelectrolysis	.4		
Other	1.0		
	24.4	4.0	4.9

C_3 processes. If successful, this technique could be used to improve yields and efficiency of biomass crops.

Cell culture and tissue culture techniques have recently come into use to accelerate development of cultivars having more desirable characteristics. These techniques should be of enormous value in accelerating development of crops to be grown especially for energy yield.

There is evidence that hydrocarbon-producing plants such as Euphorbia and Guayule may have potential for direct pathways to liquid fuels that bear further exploration. At present, only a small fraction of the world's plant species have been evaluated for their value in energy production.

Other microflora have been found that carry out photosynthesis and other metabolic processes to yield hydrogen. This overall phenomenon, called biophotolysis, may have potential for production of hydrogen directly from biological processes, which can be used as fuel or as an intermediate in producing other fuels or chemicals.

2. Conversion

Anaerobic digestion is widely practiced around the world in a primitive form, but a number of advanced concepts are under investigation, including production of higher hydrocarbons, physically supported organisms, two or more stage digestion, low-moisture digestion, and anaerobic conversion of hydrogen and carbon dioxide to methane.

Fermentation technology offers a wide variety of advanced concepts for exploration. Many fermentation processes for non-energy uses that have been studied in laboratories provide a reservoir of potential processes for biomass conversion. Several pretreatment processes show promise for improving the efficiency of fermentation or other conversion processes.

Butyric acid production by fermentation has been advanced as an alternative system for biomass conversion. This was a commercially accepted system prior to inexpensive petroleum. Separation techniques required for these products have low energy requirements and these products serve as intermediates to other possible synthetic fuels, such as propyl ketones. Processes yielding butanol, acetone, and butanediol are other examples of alternative fermentation processes.

Since reagent recovery efficiency and cost of separation have serious effects on the economy of operation and net energy recovery of most biochemical processes, new separation technologies have good potential for improving the processes. For example, controlled permeability membranes have been suggested for product recovery from acid hydrolysis of cellulose to glucose and for alcohol purification after fermentation.

Thermochemical conversion and direct liquefaction also have a number of avenues of development that are still unexplored. In view of their potential for producing useful liquid fuels, there has been a disproportionately small amount of basic work done on these processes. New methods of oxygen gasification, fluidized-bed gasification, and pyrolysis oil conversion now being investigated could significantly improve existing technology. In addition, hybrid systems using direct solar heat for process heat could be used to substantially increase overall efficiency. Other smaller-scale hybrid systems are also of interest, e.g., solar-heating/wind/wood stove.

V. Technology Evaluation

A. RD&D Opportunities

Some biomass energy technologies have already gained acceptance. Examples of usage are residential heating with wood stoves and the direct burning of forestry and lumber residues at the site where they occur. However, commercial technologies for off-site usages are not adequately developed. The conversion techniques of anaerobic digestion, and fermentation of sugars and grains into alcohol are well understood, but current processes are energy intensive and too costly for nationwide acceptance. Various pyrolytic conversion techniques have been developed and advanced to prototype stages yielding low Btu gas, solid, and/or liquid fuels, but little commercial acceptance has been gained. Two systems being commercialized which may yield significant quad impact for combustion of MSW are waterwall incineration and cofiring of refuse-derived fuel in large electric utility boilers. Methane gas recovery from sewage and landfills is in limited use; usage is expected to increase as the technologies for the process improve.

Use of biomass-derived fuels will require demonstration for various kinds and sizes of usage. The scale of usage ranges from centralized industries or electric generation plants to small farms or individual residences. Usually, each kind and size of usage will represent a different production, marketing, conversion, and utilization technology. To date, the status of technology is principally that of developing components and systems for sizes of usage. Most have not been sufficiently demonstrated as being economical to gain acceptance without substantial financial incentives.

The near-term market for direct biomass combustion is expected to consist of residential heating and firing of boilers for small (less than 50 MW) electric generation and industrial process heat. Use is expected to be regional, chiefly in the Northeast, Southeast, upper Midwest, and Pacific Northwest, because of availability of wood supply, costs, and limitations on other energy supplies.

Technological improvement programs should emphasize the near-term opportunities and include operational testing of actual facilities (and production-through-use technologies) rather than model analysis. A wide variety and scale of applications should be investigated.

Near-term potential exists in several areas. Those that should receive priority include development and demonstration of the following:

- Direct burning of biomass for industrial and agricultural process heat
- Better systems and equipment for collection and beneficiation of forest and agricultural residues
- Densified refuse-derived fuels systems (fuel preparation and combustion) for MSW
- Improved designs and operational procedures for other direct combustion techniques for wood, wood wastes, MSW, and crop residues--including issuance of emission guidelines
- Energy efficient and cost effective fermentation approaches to producing alcohols for chemical feedstocks and possibly gasohol, particularly techniques to use less expensive feedstocks
- Guidelines, technical information exchange, and technical assistance, on a state and regional basis for proven technologies
- Commercial/industrial cogeneration applications using low Btu gas generators

- Point-of-production conversion and use of biomass for gaseous fuels

The approaches for accelerating biomass activity also should concentrate on potentially important long-term opportunities, which include:

- Research and development to identify candidate biomass species (crops and trees) for various regions of the country, collection of breeding stock for candidate species and breeding to maximize energy production, and development of husbandry practice and harvesting equipment for candidate species.

- Development of a variety of biochemical and thermochemical conversion processes yielding alternative fuels and chemical feedstocks, and development of ancillary separation and purification methods.

The long-term market resulting from accelerated research is difficult to predict because of the multiplicity of routes to development. Generally, the market is expected to concentrate on displacement of petroleum fuels and natural gas because of its greater potential for these products compared with other solar technologies that yield mainly electricity. Biomass products that could cause such displacement include alcohols, synthetic aliphatics, and high/medium Btu gas.

In addition, biomass processes would yield a variety of feedstocks for the chemical industry, which can displace a portion of the energy now supplied by petroleum.

B. Non-RD&D Incentive Mechanisms That May Further Accelerate Market Introduction

There are incentive mechanisms that will facilitate market introduction without further RD&D for some aspects of biomass production. The basic need for incentives in biomass production is to bridge the gap between the more costly biomass technologies and the less costly petroleum-derived fuel technologies (which already receive substantial subsidies). Appreciable capital costs may be required when biomass energy is regarded as a complete system, including end use of the energy. New units or retooling may be needed. Even farm-sized digesters represent a relatively large investment relative to the profit margins of the enterprise, and there is currently little well documented experience on how well digester outputs can be applied to farm uses. Non-RD&D innovative incentives would be useful in encouraging utility, industrial, and agricultural users to test biomass-energy production in their enterprises.

Ethanol production is considered a proven technology to be eligible for incentives. Even this concept, however, will require further RD&D to bring economies of production down to a level that will be realistic for widespread adoption.

The rising costs of various forms of energy will provide some incentive. Indeed, it has been responsible for the adoption of wood stoves for residential heating in fuel-oil dependent or high-electrical energy rate areas where wood fuel is readily available.

C. Institutional, Manpower, and Federal Program Management

Biomass production potential should be assessed on a local basis, taking into account crop and forest land ownership and other infrastructure effects.

The planning and implementation of RD&D programs for biomass requires a wide range of expertise. The bulk of the current program is managed by the Fuels from Biomass Program in DOE. This is a relatively small unit that has to rely considerably on contractual effort for program support/management. Substantial technological expertise and programmatic opportunities, supported by legislative authority, exist in other agencies, notably USDA and EPA. Full involvement of these agencies in planning and implementing biomass RD&D is needed to accelerate the realization of the large potential for biomass energy supplies.

As noted earlier, the biomass program within DOE is divided among several units. The management responsibility must be clarified and defined within DOE. There also appears to be insufficient effort within the Department to address the problem of commercialization in the biomass area. If biomass is to make a maximum contribution to the nation's energy supply, a more detailed commercialization strategy must be developed.

The Fuels from Biomass Program is understaffed. This is presumed to have resulted in strong reliance on the contract process for management assistance. The contract/procurement process may result in substantial influence by a few private contractors in major policies and decisions. The procurement process itself has created substantial delays in implementing the program, and has made it difficult for small companies to compete.

Current interagency coordination is too limited to be effective, and the abilities of agencies other than DOE are not adequately integrated into the overall planning and program implementation.

D. International, State, and Local Issues

1. International

The United States has entered into an information exchange agreement through the International Energy Agency, which has a working group on biomass. This type of agreement is necessary but in the past has not proven to be especially productive. Also there appears to be a lack of active communication, e.g., between the United States and Canada. There is an exchange to include more cooperation between government agencies. Other examples of foreign research and development in the biomass area include Brazil's efforts to reduce the fermentation time for alcohol production, Sweden's work on fast growth silviculture plantations, and Japan's fundamental research on marine biomass.

2. State and Local

The fact that biomass tends to be a regional resource has fostered the interests of the individual states. Nebraska has conducted fleet tests and plans a 100,000 ton per year plant for producing ethanol from surplus grain. The California State Energy Commission has served as broker between suppliers and users of biomass harvesting and conversion equipment, and has conducted resource assessments and technology demonstrations.

Other states have similar programs. There is, however, a lack of coordination between the Federal Programs and the state efforts, which should be corrected to avoid duplication of effort.

E. Energy Impact

Biomass supplies at least 1.3 quads of energy per year in the United States, but this is not counted in conventional consumption data. This is mostly from waste streams of the forest products industries that are being used to provide process steam and internal electrical supplies, and from anaerobic digestion of municipal waste. The contribution from biomass by 1985 may be increased by an additional 0.3 to 1.0 quad per year. This will mainly result from increased utilization of municipal solids waste, forestry residues, and agricultural residues. The conversion methods will probably still be predominantly direct combustion, with modestly increasing contribution from digestion and the possibility of some from pyrolysis.

With expansion and redirection of the current Federal R&D biomass programs, we can anticipate a contribution of 4 to 7 quads by the year 2000. These increases would probably result from increased utilization of municipal wastes, agricultural residues, forest residues, and some contribution from energy crops. The expected major conversion technology will be direct combustion to yield steam and direct heat but biochemical and thermochemical conversions may have an important impact, too. If fully developed, biomass could provide a high percentage of the nation's energy needs. However, achieving this contribution would require substantial adjustments in land use. Further, quad usage would also be constrained by incremental cost escalations that would be associated with the more difficult technological applications and with the added costs of bringing less economic production opprotunities into use.

APPENDIX A

Program Review of Biomass

I. Introduction

The Federal biomass program is presently represented by several departments and agencies and may involve others as the biomass effort expands. The DOE effort includes the Fuels from Biomass Program, which has had the lead role for DOE, the Division of Power Systems, and the newly established Solar Energy Research Institute. The Department of Agriculture has an energy oriented biomass program that is actively supported by cooperative state agricultural experiment stations and extension services. The Environmental Protection Agency has programs which utilize municipal, agricultural, and forestry residues as sources of energy. The total Federal budget for biomass in FY 1978 is $33.3 million, and the breakdown is shown in table 1. The estimated budget for FY 1979 is $54.8 million.

II. Department of Energy

A. Fuels from Biomass (FFB)

The purpose/goals of the FFB program are to develop technologies for the production and harvest of renewable biomass resources for energy utilization and for converting the plant biomass to clean fuels, petrochemical substitutes, and other energy-intensive products that can substitute for products made from conventional fossil fuels. The DOE goal is for biomass to provide 10 quads of energy per year by 2020.

The assumptions for attaining early energy availability are predicated on the use of existing biomass sources from agricultural and silvicultural waste and the use of conversion technologies such as direct combustion and anaerobic digestion of manure. Assumptions for the remainder or more futuristic elements of the 10-quad goal depend on production from energy farms and more advanced conversion technologies that will improve or increase the application of biomass fuels. The fuels from biomass program does not include conversion of municipal solid waste. The FFB has only two professionals to administer the program.

The program consists of the following major elements:

TABLE 1

FY 1978 FEDERAL BIOMASS PROGRAM FUNDING

	F x10^6		
	DOE	USDA	EPA
Production & harvest			
Silviculture	3.5	.5	
Agriculture	.8	.6	
Aquatic	1.2	.1	
Harvest	0.7	.1	
Municipal waste			1.0
Agriculture waste		.1	
Biochemical Conversion			
Anaerobic	1.8	.5	.37
Fermentation	2.5	.1	.3
Thermochemical Conversion			
Direct combustion	2.0	.4	1.6
Gasification	4.3		
Pyrolysis	.2		.89
Liquification	2.0		
Chemical Feedstock	1.0	1.6	
Environmental Assessment & Controls			.77
Biomass Conversion Facility	3.0		
Biophotolysis and Photoelectrolysis	.4		
Other	1.0		
	24.4	4.0	4.9

1. Near-Term Systems

These systems are identified as those that are, or will be, ready in or about 1980 for transfer from the Fuels From Biomass Branch to other DOE organizations and/or to appropriate market sectors for commercialization. The biomass sources are forest, crop, and animal residues. Direct combustion and anaerobic digestion of manure are the conversion processes available and currently in the demonstration phase.

2. Long-Term Systems

(a) Production and Harvest: This program element concerns developing the technology for managing the resource base and providing the feedstocks for conversion to fuels. Activities are keyed to specific crops grown expressly for their energy content.

(b) Conversion to Clean Fuels: Activities in this element are divided into technologies classified as either biochemical or thermochemical. Biochemical conversion processes use cultures of micro-organisms to produce fuels from organic feedstock, whereas thermochemical conversion employs catalysts, chemical reactants, or elevated temperatures or pressures to produce fuels. The goal is to increase conversion efficiencies and reduce costs.

(c) Integrated Systems (Production/Conversion): The purpose of this element is to establish and operate the systems combining appropriate production and conversion technologies, and to determine overall system economics. Two systems have been chosen for design, construction, and operation: (1) the gasification of woody biomass, and (2) the fermentation of herbaceous biomass produced on energy farms. Integrated systems will rely on energy farms for a substantial part of their supply of raw materials.

Current Status

The Fuels From Biomass Program has developed estimates of land availability for biomass production, design criteria for biological and thermochemical conversion of biomass to energy, and constructed pilot plants for some biomass energy conversion technologies. Examples of the FFB's accomplishments are:

- Baseline data on biomass production potential was developed.

- Experience was gained on: (a) an anaerobic digester methane production pilot plant converting 25 dry tons per day of animal residues (300,000 SCF of gas/day); (b) an experimental digester facility (300 lb/day capacity) for cattle manure from a dirt feedlot; and (c) a 3,500 lb/day digester for dairy manure from a concrete lot.

- Laboratory-scale studies were made on the conversion of cellulose to sugars and on the production of acetone and butanol.

- A liquefaction facility was developed and is converting 3 tons of wood chips into 6 bbls. of oil per day.

- Laboratory-scale tests provided new knowledge on using manure to produce medium Btu gas and on the catalytic gasification of wood residues.

- Analyses were made of the technology for the combustion of wood residues and costs of collection and delivery to conversion sites.

Anticipated accomplishments, as prepared by FFB program, are given in table 2.

The serious shortage of manpower in the program office may prove to be major barrier in attaining it's goals. The lack of adequate review of existing and planned projects is an inherent danger in the present management system. The lack of adequate RD&D funding is a major constraint to the attainment of the energy recovery potential for biomass. Current technologies need to be substantially improved to make them economically competitive with nonrenewable sources of energy. The procedures to accomplish this end are expensive since they require full-scale testing under a variety of operational situations. The deemphasis of basic research could also be detrimental to the success of future biomass development.

New Factors

In the past, the DOE biomass program has placed too singular emphasis on large centralized systems. A broader range of alternatives needs to be developed.

TABLE 2

STATE OF DEVELOPMENT--BIOMASS PRODUCTION AND CONVERSION TECHNOLOGIES AS ENVISIONED BY FFB PROGRAM OFFICE*

Process	Current	1980	1985	1990	1995	2000
Terrestrial biomass production agricultural crops	System studies field tests	Pilot farm recommended	Start-up of demo farm	Demo farm operation	Decision on commercial farm and plant	Completion, commercial scale farm and plant
Silviculture crops	Field tests	Conversion plant and plantation complete	Complete demo farm and plant	Complete demo scale farm and plant	Commercialization complete	
Aquatic biomass production	Lab and field tests	Decision on pilot plant	Complete marine farm and pilot plant	Start-up demo farm and plant	Complete demo operations	Commercialization
Anaerobic digestion to produce SNG	Pilot	Pilot tests complete	Complete commercial plant			
Fermentation to produce petrochemical substitutes or liquid fuels (enzyme-acid hydrolysis)	Lab and field tests	Testing complete demo unit demonstration	Demo unit complete	Possible commercial plant		
Liquefaction to produce fuel oils	Field and process development tests	Decision on pilot plant	Decision on demo plant	Possible commercialization		
Gasification to produce SNG	Equipment and lab tests	Pilot test start-up demo recommendation	Demo plant start-up	Possible commercial plant		
Direct combustion to produce process steam and electricity	Small-scale units in operation	Complete commercial plant				

*From FFB Program Plan (July 1977)

B. Solar Energy Research Institute (SERI) Program

Program Description

SERI's basic missions are to (1) conduct analysis and assessment, (2) conduct research and development in important long-term, high-payoff areas, (3) support university research and promote cooperative university programs, and (4) develop a strong technology commercialization program to bring about the earlier utilization of biomass.

The biomass program at SERI is currently funded at about $400,000 (FY 1978) and the staff has four members. Both the funding and personnel levels are expected to increase as the Institute has just recently been inaugurated.

Current Status

SERI is in the initial stages of establishing a program; its main accomplishment so far is its existence. They have carried out some preliminary assessments. If it is to accomplish its goals, it must have the full support of the DOE as well as USDA and EPA. It is necessary that all these agencies understand the goals and programs of SERI if R&D efforts are to be enhanced and duplication of efforts is to be avoided.

C. Division of Power Systems (DPS)

Program Description

The Power Systems program seeks means by which agricultural and forest residues can be substituted for liquid petroleum products and natural gas. This particular task was initiated in FY 1977.

The program assumes that there are currently 12 quads/year of agricultural, fuel wood, and industrial waste residues. It also assumes that technologies could be developed which would economically recover 4 quads/year.

DPS considers its role to be in the area of applied combustion technology. This does not conflict with the Fuels From Biomass Program, which considers its systems boundaries to end when the fuel is delivered. It does, however, overlap with EPA's efforts in direct combustion of wood waste combined with coal and USDA's program on wood-burning technology.

The DPS plans a major role in its program to be carried out by USDA through its Extension and Forest Service agencies. Brookhaven National Laboratory is providing a research and technology plan for the residue and waste fuels program. The Maine Audubon Society is developing a small woodlot utilization model for home firewood use. Auburn University is generating a data base and model for design of home fuel wood heaters. The National Bureau of Standards is reviewing the status of fire and building codes. Other work is being done on the utilization of pyrolysis char/oil mixtures in a Brayton cycle engine. Also, a survey is being conducted to survey and classify the market potential for onsite combustion of industrial wastes (5 to 10 tons a day) and to publish a fuels combustion handbook.

The technology programs are related to (1) direct combustion of residue/waste fuels, (2) combustion and energy conversion of storable liquid/solid two-phase fuels derived via pyrolysis, and (3) energy conversion systems fueled from completely gasified residue waste sources.

It is anticipated that assessments will be conducted during the life of the program to ensure technical relevancy and to assist in the technology transfer to ensure early market penetrations.

The program budget is summarized below:

FY 1977	FY 1978	FY 1979
$350,000	$1,200,000	$2,250,000

Current Status

Preliminary assessments of some of the technical barriers to commercialization have been performed. To date, results have indicated a lack of performance standards or modern safety criteria to provide guidance for manufacturers, consumers and installers of home fuel-wood heaters. The potential of storing two-phase fuels from pyrolysis has been identified, but the pyrolysis techniques have not gained sufficient adoption to warrant commercialization of the storage systems.

New Factors

The results of the activities funded in FY 1977 have led the Division of Power Systems to believe that the energy potential of the program and the energy cost benefits to be obtained warrant an accelerated and broadened program. This program would require cooperation with USDA, EPA, and TVA.

III. Environmental Protection Agency

The potential ability of biomass conversion processes to reduce environmental problems associated with disposal of solid waste, and to utilize currently wasted energy and material resources attracted EPA to the biomass area. One major EPA program goal is to develop and demonstrate energy and materials recovery systems from municipal solid waste, sewage, agricultural residues, and forestry residues. The ~~program covers combust~~ion, thermochemical, and bioconversion processes. Combustion of refuse-derived fuels (RDF) and anaerobic digestion of sewage sludge are being commercialized. A thermochemical conversion system that produces char and some heavy oils is entering the demonstration stage. Extensive residuals characterization, environmental assessment, and control technology studies are being conducted as part of EPA's primary major program goal--minimizing environmental problems associated with waste reuse. EPA studies on biomass waste use include:

- Combustion of waste wood chips with coal in industrial-sized boiler ($100K). Evaluation report to be published October 1978.
- Portable pyrolysis of forestry and agricultural wastes ($1,300K). Construction completion in August 1979.
- Emission characterizations of wastes as fuel systems ($1,500K over 3-years). Continuing evaluation; progress reports quarterly.
- Co-firing RDF with coal to generate electricity (system technology and environmental assessment) in Ames, Iowa (FY 1978, $900K).
- Acid hydrolysis 1-ton pilot plant (FY 1978, $300K).
- Development of air pollution control technology for wastes as fuel systems (FY 1978, $100K).
- Development of water pollution control technology for wastes as fuel systems (FY 1978, $430K).
- Pyrolysis studies for conversion of cellulosic materials to oil and gas (FY 1978, $500K).
- Preparation and cofiring of densified RDF with coal (FY 1978, $515K).
- Environmental implication of non-coal synfuels (FY 1978, $250K).

- Anerobic digestion technical studies (FY 1978, $420K).
- Municipal waste materials recovery and energy feedstock preparation (FY 1978, $1,000K).

IV. U.S. Department of Agriculture and Cooperating Agricultural Experiment Stations

Program Description

The USDA agencies that have RD&D activities that relate to biomass energy production are: (1) Science and Education Administration (SEA), which is responsible for agricultural production, marketing and processing research and demonstration; (2) Forest Service (FS), which is responsible for forest and forest products industry research; (3) Economics, Statistics, and Cooperatives Service, which makes economic feasibility analyses, and conducts annual surveys of agricultural practices--the results of which are the basic data bank that has been used for predicting biomass production potential; (4) Soil Conservation Service (SCS), which provides technical assistance to farmers and analyzes the potential of soil and water resources. Biomass programs include State Agricultural Experiment Stations which receive part of their funds through the USDA. All USDA energy RD&D efforts are coordinated through an Office of Energy in the Office of the Secretary of Agriculture.

Current projects are conducted at State Agricultural Experiment Stations and at laboratories of the Forest Service and the Science and Education Administration. The projects specifically deal with: (1) development of practical onfarm anaerobic digestion systems for utilizing animal wastes; (2) increased production of potential biomass species, such as sugarcane and sorghum; (3) annual national surveys of land usage, crop production, and marketing of agricultural commodities; (4) survey of domestic crops for production of hydrocarbon feedstocks, and processes for introducting them as chemical feedstocks; (5) crop residue harvesting and utilization; (6) aquacultural production of biomass; (7) forestry biomass production, harvest and benefaction; (8) technology of wood combustion; and (9) the development of energy education and demonstration programs.

Current Status

The agricultural and forestry research program has produced a number of achievements relating to biomass energy. Recent examples are:

- Improved fuel value of certain tree species.
- In cooperation with industry, developed and tested several approaches to whole tree harvest.
- Provided guidance to forest products industry on technologies for recovering energy from wood residues.
- Identified and studied a large number of fermentation micro-organisms.
- Determined the effects of onsite operating conditions on anaerobic digestion and methane production from various animal manures.
- Developed a prototype swine waste management system that includes the anaerobic production of methane.
- Tested fertility value of digestion sludge.
- Identified high yield cultural methods for many silvicultural and agricultural crops.
- Tested short-cycle silviculture for biomass yield.
- Tested some procedures for burning various crop residues as fuel.
- Identified a wide variety of biomass-based products as chemical feedstocks.

V. Other Programs

A. Department of Interior

The Geological Survey Laboratory at Reston, Virginia has a small advanced concepts project underway investigating the properties of an electrobiochemical fuel cell. The exploratory research experiment is looking at a process to convert biological energy into electrical energy and petroleumlike hydrocarbons. The entire project has a projected FY 1979 funding of $100,000. An electrical current has been measured and hydrocarbons detected, but it is too early in the experiment to forecast the feasibility of the concept.

B. Department of Commerce

The National Oceanic and Atmospheric Administration has a program to study the basic biology of seaweed culture. Its immediate interest is in the application of these plants as a source of chemical extracts which are used in the food industry. The results of these studies, however, may be valuable to aquatic production of biomass as an energy feedstock. The funding level of 1978 amounts to $392,000 in Federal funds, with a cost sharing amount of $235,400 being provided by the academic institutions where the research is being carried out. This is a basic research program, and thus is building the data base for fundamental biological production processes, and not designed to result in near-term applications.

C. National Science Foundation

The National Science Foundation finances basic research that includes research on photosynthesis. Current projects in this area amount to about $300,000.

TAB G

Technology Assessment: Ocean Energy Systems

I. Technical Status

A. Background/History

Many techniques have been advocated for utilizing the energy which is available in the oceans in the form of waves, tides, currents, salinity gradients and thermal gradients. The magnitude of each of these resources that is available to the United States (and to the world) varies widely depending upon the resource and the conversion technology used to convert the ocean resource into useful forms of energy. The thermal gradient resource is recognized to be the largest followed by salinity gradient, tides, waves and currents in that order.

The United Kingdom has developed technology to extract energy from waves which, analagously to wind represent a flow of power past a line drawn perpendicularly to the direction of motion. The waves gather their power from the wind over a relatively long fetch and deliver it in relatively concentrated form. It has been projected that a conversion efficiency of 25 percent can be achieved for electric power on the beach.

The notion of ocean currents as a power source has attracted speculative attention because of the very large power involved. The physical principles are those of fluid dynamics and have strong parallels in windpower. Most of the speculations to date have taken the form of proposed machine designs for generating electricity, but none of the designs has been subjected to thorough engineering analysis of practicability and cost.

United States efforts have been almost exclusively oriented towards extracting energy from the thermal gradient, the 20^{o} to 24^{o} C differential between the cold deep water and the warm surface layer of the tropical oceans. The concept of converting the energy stored in the thermal gradient into useful energy was first proposed by the Frency physicist d'Arsonval in 1881 and the technical feasibility was partially demonstrated by Claude in 1930. Current United States design attention and R&D support is centered on a closed cycle Ocean Thermal Energy Conversion (OTEC) system. All of the other ocean systems and other concepts for OTEC are in a relatively early phase of development and will be described in section IV (Advanced Concepts).

B. Description

In closed cycle OTEC, the warm and cold ocean waters are used to evaporate and condense respectively, the working fluid in a Rankine cycle heat engine that drives a turbine to produce electricity. The critical components that comprise such a system include the power system (heat exchangers, working fluid, turbine and pumps), cold water pipe, platform and mooring or positioning equipment. A submarine electric cable wil be required if baseload electricity is to be transmitted to land.

Working Fluid

Ammonia has been selected as the baseline working fluid because of its superior thermal properties. Freon and propane have also been evaluated and would provide some corrosion advantages; however, the cost of freon and the explosion potential of propane are additional important considerations since maintaining leak-tight heat exchanger units will not be possible.

Heat Exchangers

The heat exchangers are the most critical components of the power system from the perspective of cost and performance. Depending on the design, 30 to 50 percent of the plant cost is associated with the heat exchangers. Thus, it is important to maintain high performance in the heat exchangers. Methods to enhance heat transfer and to clean biofouling slime are possible approaches to achieving and maintaining acceptable performance. The baseline design for the heat exchangers is shell and tube construction using titanium although aluminum is being seriously considered as a possible candidate. Use of aluminum could yield considerable cost reductions; however, further work is required on the susceptibility of aluminum alloys to corrosion. Other metals are being examined in conjunction with appropriate working fluids in plate type (shell-less) construction to arrive at lower system costs.

Cold Water Pipe (CWP)

For a 200 MWe plant operating with a thermal gradient of 22°C, a pipe approximately 20 meters in diameter and up to 1,000 meters long will be required to bring the cold water to the heat engine condenser. Structures of steel, reinforced concrete, aluminum, fiber-reinforced plastic and rubberized materials are being studied.

Platform and Mooring

The designs proposed for structures to accommodate an OTEC facility include surface and partially or totally submerged structures constructed from concrete or steel. To maintain location in the open ocean, the OTEC platform will require dynamic positioning or mooring to the ocean floor.

Submarine Transmission Line

For island applications, state-of-the-art underwater a.c. cables appear adequate to transmit power to shore for plants in the 100 MWe range. For mainland United States applications, OTEC plants between 250 and 400 MWe are planned that would be stationed approximately 100 to 150 miles from the shore. Transmission of electricity from such plants would necessitate the development of reliable deep-water cable systems (most likely carrying d.c. power). If submarine cables capable of carrying very high power levels (>1 GWe) can be developed, there can be an economic advantage associated with clustering a number of OTEC plants together to feed into a single cable. A submarine cable would not be required for OTEC plants designed to produce at sea materials that require energy intensive processes.

C. Phase of Development

OTEC technology is in the component design and evaluation stage. Conceptual designs for commercial plants have been produced by major United States contractors. However, no total system design has been carried out in which all the major subsystems have been integrated.

D. Resource Availability/Applications

Estimates of the extractable OTEC resource in the Gulf of Mexico have varied widely (10 to 1,000 GWe) with additional resources directly accessible to tropical islands such as Hawaii, Guam and Puerto Rico. Most estimates of the resources available in the Gulf of Mexico are over 200 GWe. Worldwide the resource is extremely large, limited primarily by the economics of conversion, accessibility to markets, and the global climatological implications. Seasonal variations, frequency of major storms and ocean currents may limit the attractiveness of particular sites.

E. Availability Dates

The earliest credible estimates for operation of small commercial scale OTEC plans (40 to 100 MWe)` suitable for island utility applications are in the early 1990's. Most estimates look towards deployment of large plants (250 to 400 MWe) suitable for United States mainland applications to begin in the mid to late nineties. OTEC experiments for island applications in the 10 MWe range are being considered for the mid-eighties. If these experiments are carried out successfully in the time frame stated, a commercial demonstration of a small plant (40 to 100 MWe) could be operational by 1990. These plants would compete with baseload electrical sources (via submarine transmission cables). The size of OTEC plants suitable for the onsite production of energy intensive fuels, chemical and materials (e.g., H_2, ammonia, and aluminum) for transport to markets on shore has not been determined, however, widespread deployment of such plants is unlikely before 2000.

F. Technical Issues and Uncertainties

The heat exchangers constitute the major source of uncertainty in terms of producibiity of large hardware, heat transfer performance, and materials. Some progress has been made in this area over the past 2 years although all risk factors associated with the heat exchangers have not been resolved. Tests at Argonne National Lab (ANL) on 1 MWt components have confirmed earlier single tube data. Biofouling rate measurements show that the rate is much lower in the open ocean (OTEC sites) than in coastal regions and that the rate is fairly site-independent reaching in 30 days a fouling resistance which corresponds to 20 percent of the total thermal resistance. Cleaning experiments have shown that titanuim and aluminum can be cleaned by periodic brushing. Nevertheless, heat transfer remains an important factor which materially influences cost.

The producibility of large hardware seems tractable by new design (spherical shells) or modular construction. There remains the problem of quality control in the production of enhanced heat transfer surfaces on a large scale and the cost associated with such control. For the heat exchangers, well planned experiments on biofouling, material tests, and repeated cleaning should be continued because only data collected over a long period of time can alleviate the valid concerns mentioned. To reduce the uncertainity in cost and performance, the other major components of an OTEC facility will have to be addressed. These engineering risks are difficult to evaluate without experiments at the appropriate scale and include:

- Deployment of a cold water pipe significantly larger than any structure previously handled in the off-shore oil drilling industry;

- Design of the cold water pipe to deal with problems of stress relief, dynamic loading, and interconnections along the length of the pipe and the interface between the pipe and the platform to withstand wave action on the platform;

- Techniques to minimize the biofouling and corrosion of the cold water pipe, platform and warm water intake;

- For large commercial plants ($\geq$250 MWe), construction of platforms much larger than current state-of-the-art off-shore oil drilling platforms. Operating experience with such large structures is limited, construction sites and assembly areas will have to be developed;

- Design of a mooring system which will be a significant extention of current deep water mooring experience. Designs will have to deal with very large forces at some sites where ocean currents exist and stress corrosion problems will constrain the material selection. Conventional spar buoy experience predicts a limited lifetime;

- Design of a submarine transmission cable which would significantly extend the current state-of-the-art (an 80-mile, 250 MW d.c. cable at 550 meters depth between Norway and Denmark). Experience with flexible connections at high power levels is limited.

The key environmental issues are:

- Ocean water mixing which includes the perturbation of temperature and salinity gradients, dissolved gas levels, nutrients, and turbidity;

- Metallic discharges from the corrosion and erosion of the heat exchanger surfaces;

- The effect of biocides, if used to reduce the biofouling problem, on the biosphere surrounding the OTEC facility;

- Leaks of the working fluid at either small steady state levels or resulting from major accidents;

- The climatological impacts of large scale OTEC deployment on a local and global scale due to the perturbation of the surface temperature and the disturbance to the local thermocline; and

- The climatological effects of the possible release of CO_2 from the deep ocean water.

G. Factors of Scale

The size of a single moored OTEC faciity is limited to approximately 500 MWe by the local impact on the thermal resource. There is a definite economy of scale. Large plants have a lower cost $/kW) than smaller plants. The cold water pipe losses are influenced by the pipe diameter. Finally the heat exchanger costs decrease as the module size increases. While these trends are analytically valid, their significance is reduced somewhat by the practicality of handling and manufacture of large equipment. Gantry cranes, lift equipment, drydock space and other facility attributes tend to constrain the design of an OTEC plant to levels below 500 MWe.

H. Assessments

Detailed technical assessments of the closed cycle OTEC concept have been performed by TRW and Lockheed as part of the baseline conceptual design studies. Recently assessments by the National Academy of Sciences (NAS), the Solar Working Group (SRI/SWG), and the Office of Technology Assessment (OTA) have provided a more general review of the potential of OTEC. The OTA report and an associated working paper provide an excellent review of the issues and define options for continued OTEC support for Congress. Although widely touted by critics of OTEC as a negative report it should better be termed cautious and emphasizes the post-2000 nature of the technology.

The issues are universally recognized and differences in perspective are predominately reflected in differing estimates of the level of effort and the ultimate cost of the solutions.

II. Economics

A. Cost Estimates

Previous cost estimates of OTEC systems have varied from an unrealistic low of $500/kW to a high of over $3,500/kW. This large cost uncertainty is primarily due to uncertainties concerning component performance (e.g., heat exchangers) and the methods by which the major engineering problems (e.g., platform, cold water pipe, underwater cable) will be resolved. Additional factors which strongly effect costs are the size of the temperature gradient, which is site dependent; the cost of component replacement; the utilization intended, electricity on-shore or chemical products at sea; the size of the facility, and the distance of the facility from shore. For example, the cost of the underwater transmission cable, estimated at $1 million/mile, is an important component of the entire facility costs for transmission distances of 100 miles or more. Cost estimates based upon the most recent design studies generally range between $1,500 and $2,500 per kilowatt of electricity delivered on shore. At the current stage of OTEC development, it is also difficult to estimate the cost per kilowatt-hour of electricity. Reasonable estimates fall between 30 and 70 mills per kWh.

Most studies predict a small market penetration before the year 2000 and a much larger penetration by the year 2020. In terms of the island markets, the penetration could be a large percentage of the total demand.

III. Current Program Strategy and Goals

A. International

Only Europe and Japan have ongoing OTEC programs. These programs are supported by the private sector through industrial consortia. The Japanese program is at the $2 million level and is experimentally oriented. The European effort consists of international market assessment and heat exchanger development. Both are oriented towards export to underdeveloped nations and chemical production on the open oceans.

B. Federal Program

The goal of the DOE OTEC program is to assist the development of an economically viable commercial-scale closed cycle OTEC to deliver baseload electricity to the continental United States. The original development schedule for the DOE effort, predicated on the need for large powerplants (greater than 100 MWe) for the Southeastern United States market has been recently modified by the recognition that island markets present a more favorable near-term opportunity that can be accessed by smaller OTEC facilities (40 to 100 MWe). The Federal OTEC program is described in detail in the RD&D Program Review for Ocean Energy Systems. (Appendix A).

IV. Advanced Concepts

Advanced concepts for OTEC include open cycle systems, foam and spray systems, and thermoelectric conversion.

A. Open Cycle Technology

The earliest demonstration of the OTEC concept was an open-cycle approach, accomplished by Claude on the coast of Cuba in 1930. The concept uses sea water as the working fluid, thus eliminating the need for both of the heat exchangers employed in the closed-cycle approach. However, this also requires that the pressure over the boiling water be reduced to the vapor pressure of water at the input temperature, in this case approximately 1/2 psi (about 1/30 of an atmosphere). The elimination of the heat exchangers is somewhat offset by the added costs of (1) an evacuated chamber, (2) extremely large turbomachinery (because of the high specific volume of the working gas), and (3) air removal from the working fluid. However, recent studies indicate that this tradeoff may be possible and that the open-cycle approach may be competitive in terms of dollars per kilowatt capacity. Initial feasibility studies have been completed, and an engineering design program is now underway to more accurately size the equipment.

B. Foam or Mist Cycle

A subset of the open-cycle concept is an approach which eliminates the need for the large turbine required in the open cycle. In this approach, liquid water is entrapped and lifted in a vapor stream or within a foam structure. It is hoped that this foam can be created through the use of detergent or the natural foaming action of sea water. The liquid in the vapor stream, or in the foam, is lifted to a height sufficient to drive a hydraulic turbine. This approach is in an early feasibility study stage and cannot yet be considered a viable alternative to the other OTEC approaches.

C. Thermoelectric Conversion

An alternative to a fluid heat engine for Ocean Thermal Energy Conversion is the use of the Seebeck solid state effect. Recent advances in material and thin film device development indicate that conversion efficiencies may be achieved that are competitive with the low-temperature Rankine cycle. The primary advantages of a solid-state conversion approach are high reliability, long life time, and reduced corrosion and contamination. Thermoelectric conversion is in the conceptual design phase.

D. Waves, Currents and Salinity Gradients

The United Kingdom remains the leader in wave-power development. It is currently carrying out feasibility studies intended to lead initially to engineering tests at about 1/10 scale, with the intention of achieving a prototype power station module in about 3 years. It is envisaged that power modules will be moored 15 to 20 km offshore in territorial waters, with minimal ecological impact. Four designs are currently under development, with other more advanced designs in the concept stage.

The annual average wave power flux off the coast of northwest England has been estimated at 70 to 80 kW/m. If fully utilized it is projected that waves could supply half of the electric power demand of the United Kingdom. Cost projections prepared by the Wave Energy Steering Committee in the United Kingdom indicate that the cost of wave-produced utility electricity at the beach will exceed $1,500 per installed kilowatt. Designs for ocean current hydroelectric systems are essentially marine versions of wind turbines because of the fluid dynamical similarity of the ocean current and wind resources. Ocean current hydroelectric is on the far fringe of speculation. It has no active champion and lacks definition and goals.

The availability of the ocean current resource is geographically constrained to very strong ocean currents flowing close to shore (power flux is proportional to the cube of the current speed), of which the Florida current is the most promising resource for the United States. Foreign applications are oceanographically constrained to mid-latitude continental east coasts, such as Japan, New Zealand and Argentina. An estimate of the economics of ocean-current hydroelectric power cannot be made, because of the early stage of the technology.

Significant salinity gradient resources exist in salt domes and if recyclable solar ponds can be established the resource becomes limitless. However, the eventual application and utilization will depend on the ultimate economics.

A conceptual design study for a renewable salinity gradient system indicated system costs would be about $0.40 kWh. In order to be more competitive it will be necessary to increase flux rates through membranes by two orders of magnitude, develop a salinity gradient solar pond and improve the lifetime of membranes beyond 5 years. Also a better understanding is required of pump and ducting costs before a final economic projection can be made. However, system costs with technology improvements should be greater than $0.15 kWh.

A system study is planned for late 1978 and 1979 to resolve these issues. Legal and environmental issues are also being addressed in these periods.

Non-OTEC ocean systems R&D activities in foreign countries are limited to wave energy. A cooperative agreement of wave energy has just been concluded between the United States, the United Kingdom, Ireland, Canada, and Japan, with coordination through the International Energy Agency. The current United States strategy is to use this agreement as a vehicle for conducting an international engineering development project to build and test and experimental prototype of a particular type of wave power machine selected as the leading candidate. The United States contribution will include both financial support and provision of certain items of equipment. International efforts to extract energy from ocean currents and salinity gradients are funded at very low levels or not at all.

V. Technology Evaluation

A. Future of Technology Without Federal RD&D

The withdrawal of Federal RD&D support would mean that essentially no industrial R&D activity would be pursued and that no demonstration of OTEC could be expected for at least 10 years and possibly significantly longer. The capital necessary to develop OTEC to the pilot plant stage (several hundred million dollars) is too large to be assumed by private investment in the face of the technical, market, environmental, and regulatory uncertainties that exist.

The attention now being given in the United States to other ocean energy systems is insufficient to lead to an analysis at this time of these technologies as candidates for further development. It is important to raise the level of basic understanding of these technologies and resources so that the potential importance of each to the energy supply can be evaluated.

B. Impact of Federal RD&D

OTEC can potentially contribute a very large amount of power to the United States electrical supply in the post-2000 year time period. The resource is regional and can be considered as a potential substitute for fossil and nuclear if the economics are proven and the design uncertainties resolved. In order to have a commercial technology ready by 2000 it will be necessary to systematically resolve the technical issues during the next decade.

A more fundamental issue is whether to develop OTEC in this century. The impact of OTEC on the funds available to develop other solar technologies and the impact of the successful commercialization of other energy sources on the need for OTEC must be considered. Funding at the current or at a reduced R&D level will put a residual drain on the solar budget and will likely neither lead to a successful demonstration nor disprove the viability of the concept. It is the opinion of the RD&D Panel that the potential of OTEC cannot be denied on the basis of the analyses that exist to date and that a timely investment in at least one 10 MWe modular experiment is the appropriate approach to maximizing the opportunity and minimizing the economic impact of OTEC within the context of the entire solar program. In addition, the RD&D Panel recommends that a 5-year effort to assess the technical and United States resource potential of waves, tides, ocean currents, and salinity gradients be funded at a modest level and that the United States participate more fully in international projects attempting to assess the various technologies in this area.

The current OTEC program strategy is to move through conceptual and engineering designs and component test phases to system experiments at approximately a 10 MWe scale. System tests are necessary to resolve the technical issues, determine the operating and maintenance requirements, and evaluate the economic feasibility of constructing an operating facility. The primary strategy variations consider the schedule, size, and number of such system experiments. A low-risk strategy proceeds serially with component and system scaleup, and an intermediate strategy introduces some parallelism between component testing and large-scale experiments. It is likely that at least two experiments at the 10-40 MWe scale will be required to demonstrate economic feasibility.

The program priority of demonstrating OTEC technology leading to the commercial island market remains unchanged. Significant budgetary impacts are associated only with the 10 MWe scale experiments. Each modular experiment will require approximately $100 million in capital outlay, spread over a 3-year period.

If successful the 10 MWe scale experiments will lead to commercial OTEC facilities that deliver 40 to 100 MWe baseload electricity to tropical islands such as Hawaii, Puerto Rico, and Guam. Delay until the mid-1980's in committing to the first 10 MWe modular experiment may lead to the dissipation of some of the industrial technical expertise that has been assembled in the OTEC program.

C. Non-RD&D Incentive Mechanisms

If the 10 MWe modular experiments demonstate the economic feasibility of the OTEC concept, incentives in the form of guaranteed and/or low-interest loans for construction of early commercial plants will aid early market penetration. However, this consideration is up to a decade removed.

D. Institutional, Manpower and Federal Program Management

The Ocean Systems Branch in DOE/DST has four full-time senior technical staff. Additional program management support is being contracted outside of DOE and large-scale projects will be managed by a prime contractor. This structure will be adequate if the role of the Government is restricted to final acceptance of a large system. On the other hand, if the Government continues to be involved in the design process itself, an in-house capability must be provided. This would require additional technical and managerial manpower.

Timely interagency consideration of the regulatory aspects of OTEC which include the environmental regulations and sea surface and ocean floor rights is essential for the commercial introduction of OTEC. One of the largest barriers to private sector involvement in any energy technology is the perceived uncertainty in regulatory policy.

E. International, State, and Local Issues

The primary international and local issues are the local and global environmental impacts of large-scale OTEC deployment discussed in Section I(F) (Technical Issues and Uncertainties). The impact on competing uses for coastal waters such as fisheries will need careful analysis. Evolving International Sea Law may have an impact on OTEC commercialization. In the early phases of OTEC deployment the 200-mile territorial limit will exceed the distance at which a baseload electric OTEC plant can be economically tethered. However, it may be argued that the environmental impact of even near-shore plants extend into international waters and the resolution of these issues will require careful study, documentation and negotiation.

F. Energy Impact

OTEC will contribute at most a few 400 to 100 MWe baseload electric plants to the tropical island market in the 1990 to 2000 year time frame. Without a Federal RD&D program of at least the present magnitude ($30 million per year plus 10 MWe modular experiments) it is unlikely that any commercial plants will be operating by the year 2000. None of the other ocean systems can be expected to contribute to energy supplies by the year 2000.

APPENDIX A

Program Review: Ocean Energy Systems

I. Program Description

A. The OTEC program has the goal of achieving a technical and economic demonstration of a 10 MWe scale facility in the mid-1980's. Goals for other ocean systems are to demonstrate the operation and performance of (1) a pressure-retarded osmosis engineering experiment, (2) a shrouded water turbine operating in the Florida current, and (3) small-scale wave power conversion devices, in cooperation with the United Kingdom, Ireland, Canada, and Japan.

B. The current program is based on the following assumptions:

- OTEC represents the largest ocean resource accessible to the United States and offers the opportunity for the lowest system costs.
- The closed-cycle concept for OTEC represents the best balance of technical risk and cost; alternatives such as open cycle, foam and mist systems, and thermoelectric systems are long-term considerations.
- The economies of large-scale equipment are balanced by the engineering and local resource problems associated with large plant sizes to yield and optimum size for Gulf Coast utility applications of between 250 and 400 MWe.
- Large markets (10 GWe) for baseload electricity can be penetrated at island sites beginning in 1985 with 40 to 100 MWe scale plants. United States Gulf Coast sites will provide a later and larger market (150 GWe) for 250 to 400 MWe scale facilities. A market for energy intensive products from "grazing" plants is about 30 GWe by 2010.
- The extractable OTEC resource at Gulf Coast sites considering environmental limitations, currents, weather, seasonal variations, and thermal efficiency is very large (greater than 500 GWe).
- Direct intensive Federal RD&D support is only necessary to the 10 MWe scale. Island markets combined with Federal

incentives should be sufficient to put the OTEC industry through the appropriate scaleup phase once technical and economic feasibility is demonstrated at the 10 MWe scale. Scaleup to the 250 to 400 MWe size can also be accomplished by the industry through market pull.

C. The OTEC program is structured around four elements:

- o Program support and planning;
- o Advanced research and technology;
- o Engineering development; and
- o Engineering test and evaluation.

The program management activity is scheduled to grow to 50 man-years of effort by 1982, from 35 man-years in 1978. The program support activity consists of studies of conceptual designs, mission and market analyses, and studies of environmental impacts, resource characterization, and legal/institutional issues.

Advanced research and technology includes work on heat exchanger thermal performance, effects of biofouling, biofouling cleaning, corrosion, and advanced concepts such as open cycle, foam, and mist systems.

Engineering development includes design and bench-scale testing of heat exchanger concepts, and design/analysis of cold water pipes, electric transmission cables, platforms, and mooring schemes.

Engineering test and evaluation activities are focused on the deployment of OTEC-1 and the associated 1 MWe scale ocean test of integrated components. Additional tests of cold water pipes and electric transmission cables are included in this activity.

The schedule for the detailed engineering design and construction of a 10 MWe modular experiment has not yet been determined. The commitment of funds to the 10 MWe experiments at $100 million per experiment represents a substantial increase in the level of funding for the OTEC program (described in table 1).

Conceptual designs for large (> 100 MWe) OTEC plants have been completed but detailed component design and testing are not planned in the current program. Another round of conceptual design studies is planned for FY 1980.

Small programs to assess the resource and the technical and economic feasibility of extracting energy from salinity gradients, ocean currents and ocean waves are in the research phase. The budget for these activities is projected through FY 1980, in table 1. The larger numbers for FY 1980 and beyond are predicated on the quick movement to a system experiment phase.

The primary responsibility for Ocean Systems program planning, management, and execution is centered in the San Francisco Operations Office. The DOE Ocean Systems Branch plans strategy, implements the plans through a field office, which develops detailed programs and continually assesses program results to provide feedback to the planning activities.

The OTEC program has established a good working relationship with the Department of the Navy, which provides assistance in the planning and coordination of facilities for OTEC subsystem and component testing. The Department of Commerce, through its National Oceanic and Atmospheric Administration (NOAA) and Maritime Administration (MARAD) is participating in ocean engineering and siting analysis of OTEC systems.

The overall responsibility for the closed-cycle power system development program element is delegated to the Argonne National Laboratory (ANL), in conjunction with Pacific Northwest Laboratory (PNL) in the areas of biofouling and corrosion. The open-cycle power system development program is the responsibility of Oak Ridge National Laboratory with support from the Solar Energy Research Institute (SERI). Advanced research and development activities are currently being managed by the Ocean Systems Branch with participation from ANL, NOAA, and MARAD. The management of OTEC-1 has been delegated to DOE's San Francisco Operations Office. MARAD is proposed as the overall coordinator of major projects, the OTEC-1, and the modular experiments. The Electric Energy Systems Division of DOE is supporting the Ocean Systems Branch in the design and development of the undersea transmission cable.

Major contractors in the OTEC program to date are TWR, Inc., and Lockheed Missile and Space Company, Inc. Although not involved in the RD&D phase of ocean energy systems, a number of Federal and state agencies will need to address commercial issues such as siting, land use, sea floor allocation, fisheries, navigation, emissions/effluents, and public and worker health and safety. The Federal agencies include the Bureau of Land Management, U.S. Geological Survey, Corps of Engineers, Bureau of Sport Fisheries and Wild Life, Environmental Protection Agency, U.S. Coast Guard, and the Occupational Safety and Health Administration.

II. Current Status

A. Accomplishments

The program has produced conceptual and engineering designs of systems and major components--heat exchangers, platforms, cold water pipes, mooring, and electric cable. Testing of small heat exchangers has indicated that an acceptable heat transfer coefficient can be obtained and that the biofouling problem may be amenable to a mechanical scrubbing solution. Large-scale tests of the cold water pipe have been initiated in the Santa Barbara channel.

Preliminary resource and market analyses have confirmed that OTEC could make a small GWe contribution to the electrical supply of the Southeastern United States by 2000 and a more significant contribution in the post-2000 time period.

B. Anticipated Accomplishments

Major program milestones are:

- OTEC-1 is to be operational by March 1980.
- Biofouling and corrosion R&D at five sites will be augmented by a seacoast facility beginning in 1979 and OTEC-1 beginning in early 1980.
- Shell-and-tube heat exchanger tests were completed in early 1978. Plate heat exchanger tests are to be completed by the end of 1978.
- Cold water pipe development, aimed at platform integration, cost reduction, and deployment approaches, is scheduled for completion by the end of 1979.
- Submarine power cable development is scheduled for completion during 1980.
- Heat exchanger performance tests on OTEC-1 (five types, three materials) are to be applicable to the modular experiments. Long-term corrosion and biofouling data will be acquired.

C. Barriers and Issues

The schedule for the initiation of design and construction of the 10 MWe modular OTEC experiment is the key programmatic issue. The technical problems associated with advancing the ocean engineering state-of-the-art appear to be solvable, but the technical feasibility of OTEC within the constraint of economic design and operation remains to be demonstrated.

The environmental impact of large-scale OTEC deployment remains to be addressed. The potential limitations due to regional (e.g., Gulf of Mexico) and global perturbations of the physical and biological ocean/atmosphere system is a serious concern.

III. New Factors

Since the beginning of the OTEC program in 1972, an island market for baseload electricity at the plant size of 40 to 100 MWe has been recognized and has directed the RD&D strategy toward the 10 MWe modular experiment.

The site-specific attractiveness of alternative ocean energy systems has led to increased program emphasis on waves, ocean currents and salinity gradients.

TABLE 1: Ocean Systems RD&D Funding[1]

	1972	1973	1974	1975	1976	1977	1978	1979	1980
Program Support and Planning	.085	.23	.58	1.73	4.87	4.41	4.8	4.3	8.4
Engineering Test and Evaluation						1.50	20.3	18.9	12.2
Engineering Development					.25	1.92	9.6	8.1	8.3
Advanced Research and Technology			.15	1.22	3.47	5.68			
OTEC TOTAL	.085	.23	.73	2.95	8.59	13.5	35.3	32.5	34.6
Other Ocean Systems							0.6	1.2	5.0

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[1] 1972 to 1977 represents budget obligations and 1978 to 1982 represents budget authority.

TAB H

Technology Evaluation: Small-Scale Hydropower (SSH) Development

I. Current Engineering/Scientific Status

There is a mature technology in being. However, there has been almost no domestic market for many years, and domestic products have only recently begun to take advantage of technological advances. There continues to be an active market abroad, and European commercial products represent the state of the art. Technological uncertainties are not an issue.

The product of SSH is onsite power. The expectation expressed for the DOE program is that new SSH power would be 75 percent to 90 percent delivered to electric utility grids and 10 percent to 25 percent to dispersed local off-grid customers or consumer-owners. However, some suggest that onsite mechanical, thermal, and chemical uses may have been under appreciated and that analysis regarding this approach should be expanded. The objectives of the initial DOE program were based on optimistically estimated rates of market penetration, assuming SSH to be technically sound, economically efficient, and environmentally benign. They encompass expectation of SSH on both existing dams and all sites suitable for SSH development. The energy supply objectives are:

Year	Installed capacity, GW	Annual output, TWh/yr*	Quads
1985	1.5	7	0.1
2000	20	100	1.0

The most recent estimate by DOE shows new SSH of 0.6 GW installed capacity by 1985 and 9 GW by 2000, under an aggressive Federal development program scenario, or about 0.5 quad.

Information about the hydrologic and major environmental parameters of existing hydropower dams and SSH systems comes from the data bank of the Federal Power Commission. Information about these parameters for potential sites for SSH development has come from the Corps of Engineers. Data concering performance, cost, and similar parameters

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*Expected capacity factor of about 0.55.

of typical SSH systems has come from the manufacturing industry and from consulting engineers. Some information pertinent to cost-effectiveness has come from recent purchases and development of SSH properties.

At the present time, there are many uncertainties concerning both the economic characteristics of SSH sites and their hydrologic and environmental characteristics. To date, none of these uncertainties have been mitigated by a well-developed alternative assessment.

II. Economics Affecting Current Technology

According to the DOE, cost of new SSH installations will range from $500 to $2,500 per installed kW, with most costing between $900 and $1,500 per kW. The cost will depend mainly on characteristics of the site, the lowest costs being for sites recently abandoned where only a minimum of rehabilitation will be necesary. Rehabilitation or development of many of the lowest-cost sites is already under way where there is an established use for power and SSH is cost effective. However, at the more typical cost of $1,000 per kW, the resulting cost of SSH-generated electricity, about 3.5 c/kWh at the generator, is mostly noncompetitive for utility-network distribution and is cost-effective mostly in dispersed, onsite settings where the competition is with the retail cost of energy or fuel. For this reason, the practicability of SSH at a given site cannot be determined from the hydrological, physical, and environ mental parameters without evaluation of the onsite economics of the energy for a specific end use or for sale to a utility willing to buy it. Economics must be considered one of the prime constraints on development of SSH.

The economics are affected to a significant degree by the cost of turbines, generators, inlets and outlets, penstocks, and associated equipment. For the most specialized items, turbines and generators, foreign wares are (with some exceptions) priced much lower than their domestic equivalents. It is possible, therefore, that only for a few selected items would engineering development have a reasonable chance to alter the situation in favor of United States components.

Cost goals for SSH have not been set by DOE, and would not be much affected by RD&D. The present market, a modest one, is mostly overseas and is being supplied by foreign manufacturers. The United States industry is represented by a relatively small number of manufacturers, one of which, a large diversified concern, has mounted a vigorous sales campaign.

III. Current Strategy and Rationale

The short-term objective of the DOE program in SSH is to speed redevelopment of existing dams found suitable for hydroelectric generaton. A second, longer-term objective, is to encourage utilities and others to develop hydroelectricity at new small-scale sites. The current program strategy is to provide appropriate assistance to private and public sectors where SSH might be applied. Six strategic elements have been identified, as follows:

- Assess existing dams and sites for commercialization potential.
- Reduce cost of feasibility studies by direct assistance and by providing simplified engineering and economic assessment techniques.
- Reduce cost of construction and engineering through engineering development.
- Provide environmental data and analysis techniques.
- Reduce or eliminate legal and institutional barriers to development.
- Demonstrate the commercial viability of conventional development and the technical and economic merit of new equipment and cost-reduction techniques.

There is now a program element, in one stage or another of execution, corresponding to each of these strategy elements.

The rationale derives originally from the National Energy Plan orientation to take early, effective action to utilize energy sources that will help relieve the oil import problem. The Hydroelectric Development Report prepared by the DOE Office of Policy, Planning, and Analysis cites the expectation that SSH will provide a significant increase in generating capacity and that development of SSH at existing dams offers an attractive tradeoff between power production and environmental problems. A further rationale is the perception that a major barrier to SSH implementation during the early part of the program is uncertainty about engineering and economic assessment and lack of demonstrated cost reductions from new technology. The strategy of facilitating feasibility and environmental studies also gives recognition to a rationale of cooperation with non-Federal entities to achieve results in the local and private sectors and tends to relieve the front-end burden on small entrepreneurs (see appendix A for more details on the Federal program effort).

IV. Advanced Concepts

Several novel designs for low-head hydroelectric devices have been submitted to DOE for consideration, and a working model of one of them is being prepared for testing.

V. Assessment of Strategy

In view of the downward revision that has taken place in the goals for the SSH program, the first question to be assessed is whether a program aiming at these goals remains justifiable, or whether the national energy goals would be better served by applying the resources now budgeted for this program to some other alternative. The Panel concludes that the outlook for cost effectiveness of the RD&D aspects of the current program is commensurate with its present relatively modest budget and that the program should be continued in its present general form at least until a firmer estimate of the national SSH resource can be made on the basis of data now being assembled.

The next question is whether SSH should remain a separate program or whether it should be merged into a program dealing with hydropower on all size scales, large and small together. The Panel concludes that the potential developers of SSH in the private sector are distinctively different from those concerned with large hydropower developments and that a separate program strategically addressed to solving the distinctive problems of SSH is therefore appropriate.

The Panel is convinced, however, that the assumptions on which previous estimates of potential SSH power contributions ranging from 34 to as high as 200 GW cannot be fulfilled under present conditions. These estimates assumed that maximum hydraulic head would be available continuously, that all other uses of reservoir storage would be subject to preemption for hydropower, and that all available sites would be utilized regardless of environmental constraints. If one considers as potential SSH only that which could be developed cost-effectively under an aggressive scenario, the old estimates must be reconsidered and be supplanted as soon as possible by firmer estimates based on more reliable data and more appropriate criteria.

The Panel feels that the data needed for evaluating the effectiveness of the present program, in addition to the SSH site survey are now being conducted by the institute for Water Resources and its cooperators, is analysis of a statistically valid sample of SSH sites from the viewpoint of energy end-use economics. Faced with the lack of realism in the projections so far put forward, it can only suggest that the sights should probably be lowered. It offers 0.5 GW as a short-term goal for additional installed capacity, and around 5 to 10 GW as a likely ceiling. For strategy, the lesson is not merely that a more detailed and comprehensive examination of the data base, which will be accomplished by the present program element, but more importantly that the highly individualistic nature of the SSH sites and their energy uses should receive greater attention. The current program has been trending in this direction.

We turn now to assessing internal aspects of SSH program strategy as embodied in the six elements previously identified.

- Assess commercialization potential of existing dams and sites. There is a distinction between compiling data that allow a good estimate of the national SSH resource to be made and assessing the commercialization potential of individual sites as a step toward their rehabilitation or development. The former clearly belongs as an element of program strategy. The Panel is of the opinion, that with the exception of the statistical sampling of SSH sites from the viewpoint of energy end-use economics, the latter belongs in the private sector, with limited Federal assistance.

- Reduce cost of feasibility studies. The Panel considers that there needs to be wide distribution of authoritative information on SSH, such as that to be contained in the handbook now in preparation, and that this strategic element is sound. A further step in this direction might be to establish an SSH information center that could supplement the handbook by making available up-to-the-minute information on suppliers of related products and services.

- Engineering Development. In the present setting where engineering development of SSH is being actively pursued abroad and to some extent in the United States by private initiative, the degree to which direct expenditure of Federal funds may accelerate such development and their efficaciousness in overcoming the cost barrier must be considered. The willingness of individual manufacturers and manufacturers' associations to undertake engineering development and standardization on their own may be a valid measure of the realistic potential and may strategically be a better program guide than their willingness to recommend Federal expenditures for this effort. The panel supports the present program provided that items for development are carefully chosen with an eye to successful market penetration and the Federal side of cost sharing is held to a minimum.

- Provide environmental data and analysis techniques. The Panel readily appreciates the need for a simplified approach to analysis of environmental impacts of SSH and especially for effective exchange of information as precedents are established or change for interpretation of environmental regulations pertinent to SSH. This strategy element is therefore considered sound.

- Removal of institutional barriers. The objective of this strategic element is to simplify the procedures required for obtaining the many permits, licenses, and clearances required before a SSH development can proceed. The Panel considers this an essential strategic element.

- Demonstrate commercial viability of new technologies and cost reductions in rehabilitation and retrofit applications. The Panel considers that identification of attractive opportunities for investment in SSH, not their demonstration with Federal assistance, is the key to expanded development. It does not consider that lack of confidence in the quality of feasibility studies, such as might be removed by follow-on demonstration, is a considerable factor. Its assessment is therefore that demonstration should not be relied upon as a major element of SSH strategy, and that other means may achieve the same ends better.

APPENDIX A

Program Review of Small-Scale Hydroelectric

Program Description

The purpose of the small-scale hydropower program is to enlarge the Nation's electric generating capacity in a cost-effective and environmentally benign manner, delivering electricity primarily to utility lines and secondarily to dispersed off-grid users. The initial goal stated in the Department of Energy's multiyear plan was to contribute 1.5 GW of new capacity by 1985 and 20 GW by 2000, ultimately reaching 50 GW, with a capacity factor of 0.55. A more recent estimate made by DOE and based on a market penetration model that considers constraints not taken into account in the multiyear plan, estimates a contribution of only 0.5 GW by 1985 rising to 8 GW by 2000. The estimates for 2000 correspond to fuel displacements of about 1 quad and 0.4 quad respectively.

No inconsistency with other Federal programs has been identified at the RD&D level. The program is managed by the Resource Applications office of the Department of Energy with R&D activities being carried out partly in-house, partly by other Federal agencies under cooperative agreements, and partly by contractors in the private sector. The Army Corps of Engineers is a principal participant in the development of this energy source through its resource assessment responsibilities. The first key demonstration activitiy is to be cost shared with the City of Idaho Falls.

The states play a significant role in hydropower, small as well as large scale, through regulations involving environmental, safety, and utility rate issues.

Although there is considerable interest by small private developers in materiel for small-scale hydropower development, there is as yet little response in the marketplace in the form of new domestic products. The market is dominated for the most part by European imports which are more economically viable than present United States products. Although market developments may come to have some impact on competition among the few suppliers involved, implications for competition in the energy industry as a whole are minimal.

Criteria for evaluation of the small-scale hydropower program relate directly to the major barriers to its more widespread application and to the success of the program in overcoming them. The foremost barrier is the briarpatch of permits, regulations, licenses, and approvals into which the would-be entrepreneur is thrown. The cirterion is the reduction in delay and front-end costs and the lowering of the psychological barrier that these disincentives now represent. A second major problem is the cost and availability of equipment and materiel especially suited for small-scale hydropower installations. The corresponding criteria are to be found in the marketplace in reduction of cost, more widespread distribution of goods and supporting services, and improved performance for the dollar since imports represent the major supply source.

Current Status

Six program activities have been begun. They are:

- The Corps of Engineers is developing the technology for improved assessment of small-scale hydroelectric development at existing and new sites and is continuing with assessment of specific sites in river basins having a large potential. It has also begun preparation of an updated handbook of small-scale hydropower practice.
- Engineering studies are being made with the aim of improving the performance and reducing the cost of key components.
- Regional environmental evaluation frameworks are being prepared for guidance in developing baseline data for licenses and permits, environmental impact statements, and safety assessments.
- Legal, institutional, and economic analysis are being made of possible incentives and constraints affecting small-scale hydroelectric.
- A data bank is being designed that will serve the needs for technology transfer and information dissemination, and support is being given to state-level standard reference files on dams.
- Initiation of two or three demonstrations is being planned, and about 50 cost-shared feasibility analyses of representative sites are being made by potential developers.

The current round of about 50 feasibility site studies will be followed in the next fiscal year, if legislation is passed, by a second round financed by loans that will be repaid out of earnings, or if the studies show infeasibility, DOE has the option to forgive the loan. Otherwise, DOE plans on continuing a small feasibility grant program to perform this analysis. The timetable for construction of small-scale hydropower installations might be accelerated and the program budget be affected if legislation now pending before the Congress should be enacted that provides additional financial assistance.

The role of a demonstration program for small-scale hydropower represents an unresolved issue. The DOE management, to varying degrees, regards demonstration essential for engendering confidence in the feasibility studies, implying that lack of confidence in them is a key barrier. The Panel, after discussions with numerous sources, believes that the results of feasibility studies, both those resulting from the Federal program and those prepared by engineering consultants operating independently, enjoy a high degree of trust and that the principal barrier is the gap between the cost of producing energy from small-scale hydropower resources and its current market value.

New Factors

Even within the very brief lifetime of small-scale hydropower program, some new factors have become significant. Early in July 1978, New Hampshire passed a law exempting hydropower plants of less than 5 MW capacity from regulated-utility status provided they sell all their electricity to a utility, requiring utilities to buy all power offered by these powerplants in their service areas, and designating the New Hampshire Public Utilities Commission as the ratesetting agency for this transaction. Similar legislation recently went into effect in New York and has been proposed in Michigan.

Another significant new factor is the increasing insistence on the part of states, especially those in the western United States, that they be involved in Federal programs of energy resource development from the outset, giving explicit recognition to their roles.

In addition, significant applications of small-scale hydropower other than for the generation of electricity have been identified. These include a variety of direct mechanical uses such as sawmills, heat pumps for industrial process heat and grain and lumber drying, etc., and chemical conversion processes.

TAB I

Technology Evaluation: Solar Powered Heat Engines

I. Current Engineering/Scientific Status

Heat engines provide the means to convert heat into mechanical motion for turning pumps, turbine generators, and other rotating or reciprocating machines. They are compatible with concentrating or other solar collectors producing temperatures above 150°F. Solar powered heat engines are now being installed as components of solar RD&D systems for electrical generation, total energy systems, pumping water, and air conditioning. Small solar engines are thought to be imperative for widespread use of small, dispersed electric generating and pumping stations. Only a handful of vendors produce engines adapted for solar systems, and these are primarily prototype or test engines rather than production models.

The federally supported Central receiver power tower and total energy system demonstrations will use steam Rankine engines, while the smaller, lower temperature irrigation pump and air conditioning projects use organic Rankine engines. Advanced engine designs--closed-cycle Brayton and Stirling--require significant additional development and testing, and are available only as prototype or test models. Each of the engine concepts offers advantages for solar application, as shown in Table 1. At the same time, each engine has disadvantages depending on its status of development, availability, and technical issues as shown in Table 2. Of the factors listed in the tables, efficiency improvement is the most important if heat engines are to receive widespread use. Efficiency is related to total system cost in that an inefficient engine requires a larger physical plant and larger collector areas to do the same amount of work that could be obtained from a more efficient engine. Engine cost, generally a minority fraction of total systems cost, is expected to decrease with time. Increasing engine efficiency presents a more basic problem and will require going to higher temperature collectors or the more risky advanced engines.

Simply stated, an engine's theoretical maximum efficiency increases with higher operating temperatures. Thus, while organic Rankine engines make efficient use of the temperatures available, the overall engine efficiency is limited to five to twenty percent by the theoretical maximum efficiency. With higher temperature (currently more costly) collector's, engine efficiency could be improved; for example, from 5 to 25 percent in organic Rankine engines operating at 150°F and 700°F, respectively, or to 35 percent in a steam Rankine engine operating at 1000°F. Once at higher temperatures, advanced engines such as the Stirling promise the opportunity to raise efficiencies as high as 40 to 50 percent. The move to the advanced engines involves leaving proven

TABLE 1

HEAT ENGINE CHARACTERISTICS

Type	Operating Temperature Range	Promise
Rankine (steam turbine)		
Steam	700-1000°F	Low cost, simplicity, mature technology, compatible with total energy systems
Organic	150-700°F	Low temperature, mature technology (at the lower temperatures)
Brayton (gas turbine)		
Simple	1600-1800°F	Mature technology, compatible with total energy systems
Regenerative Closed Cycle	1600-1800°F	High efficiency, compatible with total energy systems
Stirling and Ericsson	1200-1800°F	Very high efficiency, simplicity quiet operation, compatible with total energy systems

TABLE 2

SOLAR POWERED HEAT ENGINES

Type	Status	Availability of Production Models	Issues
Rankine			
Steam	Developing	A few firms	Low efficiency, non-availability of small engines
Organic	Developing	A few firms	Low efficiency, reliability, non-availability of large engines
Brayton			
Simple	Developing	Not available	Response to load variations, external firing, low efficiency
Regenerative, Closed Cycle	Developing	Not available[a]	Materials, practical design
Stirling and Ericsson	Developing	Not available[a]	Practical designs, materials, seals, reliability

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[a] These engines are not available commercially for use with nonsolar fuels.

TABLE 3

HEAT ENGINE COSTS

(Dollars per Kilowatt)

Type	Current	Forecasted Mass Production
Rankine	$200-600	No Change
Large	More than $600	Less than $100 (steam) $200-300 (organic)
Small		
Brayton		
Large	About $200	No Change
Small	More than $400	Less than $100
Stirling & Ericsson	Unknown	Less than $100

commercial technology and adopting concepts that are just out of the laboratory and lack the years of careful design work and testing required to prove an engine design.

DOE estimates that about three years is required to adapt a proven engine design for satisfactory solar performance, and that about five years would be required to produce an advanced engine. This means that a major engineering effort over basic engine R&D is required to obtain each engine model.

Lastly, solar heat engines, in principle, are generically the same heat engines used with coal, oil, and other fuels, with the difference primarily limited to the nature of the collector/exchanger used to gather heat for the engine and, perhaps, allowable engine dimensions and weight. Internally, solar and oil-fired engines of like size, application, type and quality would be the same. A low-cost, high-efficiency, advanced engine would be important for fossil fuel, conservation, and waste-heat recovery, as well as for solar applications. On the other hand, the capital characteristics of solar systems may permit the use of higher cost engines in these applications.

II. Economics

A. Product Costs

There is a great deal of uncertainty about the costs of solar heat engines. It is clear, however, that current engine costs are much higher than mass-produced systems would be.

Large Rankine steam turbines are relatively available in existing product lines, and their costs can be estimated with fair accuracy (Table 3). Only a few small Rankine engines have been installed, making it difficult to predict their cost. Mass-production techniques could probably bring the cost of these engines down to compare favorably with the cost of the larger heat engines currently used in air conditioners.

Brayton-cycle engines for conventional fuels are already mass-produced. Some forecasts contend that their costs can be brought near those of gasoline and diesel engines. It is impossible to estimate the near-term costs of Stirling and Ericsson cycle engines until practical devices are on the market. Studies done on Stirling engines for automobile power, however, also claim the potential for producing Stirling units in the price range for gasoline and diesel engines.

B. Market Activity

Small and large firms, domestic and foreign, are developing or testing heat engines that would be compatible with solar heat collectors. Only a handful of solar compatible engines have been manufactured and sold. Potential markets include electrical generation, total energy systems, air conditioning, and other forms of mechanical drive for centralized, dispersed, or on-site applications.

III. Federal Strategy and Goal

DOE carries on heat-engine development programs in its solar cooling, solar-thermal, fossil-fuel, industrial-conservation, building conservation, and transportation conservation programs. The heat engine RD&D is following basically two strategies; first, R&D on engine mechanics and materials as well as application of engines to specific devices; and second, adopting and demonstrating known engine designs in specific applications. Table 4 shows the engine concepts being pursued and the approximate FY 79 effort in this area. The budget data should be treated as order-of-magnitude estimates, because heat engines are not generally accounted for outside a larger host program.

IV. Advanced Concepts

RD&D on heat engines needs to proceed along two courses:

1. Adopting proven engine designs to solar applications, to include engineering for cost reduction.

2. R&D on thermodynamics, seals, materials, and the other engine components necessary to establish the technology base to bring advanced engine concepts into use.

The first course is necessary for a solar program such as solar cooling or solar thermal, since individual engine applications generally require extensive engineering to tailor generic engine designs for specific uses. It is conducted in the DOE programs at a level consistent with the pace of overall solar system development.

Since heat engines are components of larger solar systems, specific Federal actions to accelerate engine development may, or may not, accelerate energy supply. Conversely, accelerating development of, say, a small solar thermal electric design would necessitate accelerating the engineering of its tailored heat engine.

TABLE 4

DOE HEAT ENGINE PROGRAMS APPLICABLE TO SOLAR

Program	R&D	Demonstration or Implementation Study	Approximate FY 79 Budget
Solar Cooling	Rankine Engine & Advanced Concepts		4-5 million
Solar Thermal		Rankine (steam) Rankine (organic)	2 million
Fossil Energy	Brayton (open cycle), Brayton (closed), Stirling		2-3 million
Conservation (cogeneration)		Rankine (organic) Brayton	1 million
Conservation (transportation)	Stirling		10 million
Conservation (buildings and cummunity systems)	Stirling, Brayton, and Rankine (steam)		1 million
			20-22 million

The second course deals with advanced engine designs, such as regenerative Brayton, Stirling, and Ericsson engines, whose development would provide major improvements in engine efficiency. These improvements are not unique to solar applications, however, as they could be realized by fossil fuel or waste heat engines. For this reason, it appears that basic engine development programs would be more efficiently managed and conducted as a coordinated program under the guidance of a management group composed of potential engine users. While a coordinated effort might be conducted under the umbrella of a solar program, there is no imperative that says it must be under any specific technology.

Most of DOE's RD&D on advanced engines is on Stirling engines for transportation. This will be only partially useful for solar energy applications for which a variety of engine sizes is needed.

V. Technology Evaluation

A. State of the Technology

Usable, but expensive, heat engines are available today for use in solar powered systems. Their high cost and inefficiency present a severe economic burden for the solar thermal and solar cooling technologies that use them. Early development of more efficient or less expensive heat engines would enhance the likelihood of developing cost-effective dispersed solar thermal, solar pumping, and all forms of solar cooling technology.

B. How Federal R&D Might Help

Federal RD&D can speed the development of solar powered heat engines by developing specific devices, for example, small electric generators or total energy systems that include a heat engine. This would prompt an adaptation of useful engine concepts to solar power from existing and, when they are ready, advanced engine designs. The need is to tailor specific engines to each use. Federal RD&D can accelerate the development of advanced heat engines, some of which might be powered by solar energy, by conducting a coordinated program of RD&D directed specifically at developing the advanced Brayton, Stirling, and Ericsson cycle concepts. This should be done under the mantle of a coordinating body which would ensure that 1) the needs of solar energy are being addressed and 2) the R&D program is structured to facilitate the transfer of ensuing developments to the larger technology applications programs.

C. Non-RD&D Mechanisms

Federal non-RD&D incentives do not appear to be appropriate to accelerate the development of solar powered heat engines.

D. Institutional, Manpower, and Federal Program Management

See above.

E. International, State, and Local Issues

No significant issues.

F. Energy Impact

While the availability of a suitable engine could pace the development of a specific device, solar powered heat engines will have no energy impact independent of the solar energy system in which they reside. Their energy impact will be included in overall impacts for the solar thermal, solar cooling, and solar agricultural and industrial process heat technologies.

TAB J

Technology Evaluation: Windpower

I. Current Engineering/Scientific Status

The technology of windpower comprises methods and means for obtaining power from the wind and delivering it to some user system as useful mechanical or electrical power. The technology involved is an indirect form of solar energy; differential radiation inputs from the sun are converted into wind from which energy is extracted. The technology thus embraces the meteorology of wind, its structure and fluctuations, both short term and long, and its geographical distribution on large and small scales. Because many windy places are remote from large load centers and are sporadically becalmed, the technology interacts with transmission and distribution systems and energy storage. The capricious nature of the wind is rendered more reliable when diverse locations are interconnected in a single network.

The modern technology is set apart from traditional windmills by application of aerodynamics derived from aviation. Its advance, both in the United States and abroad, was sporadic until the establishment in the past few years of Government programs that have given new support and continuity.

A. The Current Thrust of RD&D Activities

1. Mission Analysis

Windpower is potentially applicable to a very wide variety of uses, and an early concern has been to foresee what the major uses would be in terms of power produced and end-use sector served in order to guide development of the program. Preliminary mission analyses conducted for DOE have suggested that small utilities without network interties may be a favorable point of entry. These mission analyses as well as studies by other agencies, including the Bureau of Reclamation, the State of California, and some west coast utilities, suggest that wind farms strongly interconnected with other utility power sources, especially hydroelectric, are also a valid point of entry. A dispersed onsite use of medium- and small-scale wind machines is seen as a potentially valid early mission in those applications in which the energy can displace fuel or network electricity at their retail cost.

2. Applications

Each of the many potential applications of windpower has its own particular set of conditions to be met with respect to such matters as electrical characteristics and stability of output, response to intermittency of supply, seasonal and regional characteristics of demand, and reliability and ease of maintenance. Studies are underway to determine requirements and cost targets for specific applications and to determine what research and development is needed for satisfying these requirements, especially those representing large uses of energy. Applications to onsite electric generation, water pumping, crop and lumber drying, and similar uses do not require research and may be regarded as near-term consequences of further development and demonstration activities.

3. Environmental, Legal, and Socioeconomic

Research into the nature of these aspects of the societal setting for windpower is seen as necessary in order to identify barriers to and incentives for the development of windpower and to develop strategies for dealing with them. These aspects have been studied and further investigations are ongoing.

4. Wind Characteristics

Since the cost effectiveness of a wind machine rises rapidly as the wind speed rises, and since the strength and turbulence of the wind set requirements for mechanical design, research to provide more detailed and reliable information about the distribution of wind in time and space at all scales is seen as necessary, as well as improved means for obtaining and analyzing these data. Specific RD&D issues relate to the effect of geographic diversity on the reliability of windpower and the magnitude of the available resources at given levels of windpower density.

5. Engineering Development

Many possibilities for improving the design and performance of wind machines have been explored. For medium and large systems, however, actual design efforts have been channeled to the single configuration judged most promising and fabrication has been limited to one model. This situation is changing and the next round of design development is planned to achieve more diversity and competition. A wide degree of diversity is currently represented in smaller machines, where emphasis is on achieving greater reliability, durability, and maintainability as well as cost effectiveness.

6. Advanced Systems

There continues to be a flow of innovative proposals for wind machines radically different from the conventional horizontal-axis rotor. One of these, the Darrieus vertical-axis "eggbeater", has advanced through several stages of model testing. Many others involve one means or another of concentrating the airflow so its power can be captured by a smaller rotor. They are in various stages of analysis and research.

7. Multiunit System

The combination of many units into wind farms involves investigation into the aerodynamic and electric interaction among units, the best strategies for development of windy sites, and the interface aspects of energy storage and transmission systems. Preliminary analyses of these issues have been undertaken; more definitive results of systemwide effects will require analyses and onsite tests at specific utilities.

B. Factors of Scale

1. Scale Factors of the Resource

Although the total resource is large, most of it is out of cost-effective reach, since cost effectiveness declines sharply as one goes from a windier to a less windy site. Additional research is indicated to specify more clearly the nature of this relationship and to guide the work of prospecting for high-energy wind sites. Factors of scale enter into the interfacing of individual wind machines and small or large wind farms with utilities and other user systems for the sizing of power transmission and energy storage systems.

2. Scale Factors of Wind Turbines

Mission analyses and design studies have considered what size wind turbine would yield the lowest bus bar cost of electricity per machine. These studies indicate that larger machines (approximately 1 MWe or larger) produce lower cost electricity. At this stage there is still considerable uncertainty regarding the most cost-effective size. Since there are a number of applications and sites which require a variety of sizes, the program should continue a broad coverage of the various size ranges. The number of wind turbines forming the most cost-effective cluster or wind farm is still an open issue. The resolution of this issue will depend strongly upon the specific locale and utility application.

C. Technology of Commercial Products

The only products on the commercial market at the present time are small wind machines in the 1 to 15 kW class. RD&D concerns for them are mainly those of durability and reliability and are seen as the developmental concerns of individual manufacturers. Several manufacturers are developing plans for introducing larger machines commercially.

II. Economics of the Current Technology

A. Present Costs and Near-Term Projections

The cost of electricity from wind machines is calculated as the annual charge rate divided by the average annual energy production, where the annual charge rate includes interest on and recovery of capital, Federal and other taxes, and the costs of operation and maintenance. The first installation of a Mod-OA (200 Kwe) machine, at Clayton, New Mexico, has generated electricity at a cost estimated at $0.20/kWh. The Mod-1 (2 MWe), scheduled for operation at Boone, North Carolina, in early 1979, is expected to operate at about $0.10/kWh. Current commercially available small machines (~15 Kwe), produce electricity at about $0.11 to more than $0.26 kWh.

Projections suggest that second generation systems currently under design and development will achieve $0.05 to $0.08/kWh. It is anticipated by DOE that advanced systems currently in the conceptual stage will be capable of producing electricity at a cost of from $0.015 to $0.03/kWh, depending upon the wind velocity at the site (some wind experts doubt the achievement of this goal). Most of these cost projections assume wind sites of 12 to 14 miles per hour average. There are very high wind sites (16 to 18 miles per hour) where low costs may be achieved, but the total number of such sites is limited. The longer term projection of the costs of advanced systems are uncertain due to both design risks and insufficient data on the full extent of the wind resources.

B. Cost Goals

The Federal Wind Energy Program plan projected a bus bar cost of wind energy at $0.01 to $0.02/kWh as necessary to compete successfully with electricity generated from coal, assuming that wind-generating capacity would not reduce the requirement for conventional generating capacity to meet demand during periods of calm (zero capacity credit). On the other hand, in relationship to substitution for oil-fired capacity, it is the opinion of many experts that a self-sustaining market for windpower can exist if costs in the neighborhood of $0.05/kWh can be achieved.

C. Dependence on Technological Breakthroughs

There are no technological breakthroughs necessary. However, evolutionary technological improvements and engineering developments are needed from current or accelerated RD&D efforts to meet the performance or cost goals of wind machines.

III. Program Strategy and Rationale

The primary strategy emphasis of the Federal Wind Energy Program is to make available reliable, durable, cost-effective wind turbine generators as soon as possible, in a range of sizes to meet end uses that have been identified as potential markets and energy contributors for both large and small wind machines. Secondary elements of the strategy are aimed at making information and techniques available to users for siting and application of wind machines and for identification and removal of legal, social, environmental, and institutional barriers. A tertiary element of strategy addresses advanced wind-energy concepts such as vertical axis machines and vortex generators, which are at various stages of concept development and experimental testing.

The rationale for this strategy is the perception that there already exists a large latent market for wind dynamos that will begin to develop actively as soon as reliability, durability and cost effectiveness have been achieved and machines incorporating these qualities are available from well-established suppliers. Wind machines are not so highly specialized a product that the general manufacturing industry will have difficulty entering the field. However, development of a specialized discipline for analysis of suitable windpower opportunity settings is poorly developed, and the rationale sees the desirability of establishing it. The rationale for placing advanced systems in a tertiary position is that the first need is for successful application of machines nearest market readiness and that their success will subsequently justify more attention to advanced concepts, which will make their main contribution later on. (Appendix A provides more specific detail on the individual elements of the Federal RD&D program.)

IV. Advanced Concepts

The Federal Wind Energy Program includes a program element for technology development that includes research on advanced concepts offering potential increase in energy output per unit cost over conventional systems.

At present in a class by itself as an advanced concept is the Darrieus vertical-axis machine, of which two models are undergoing assessment testing. Although not quite so efficient as the horizontal-axis type in capturing energy from the wind, the Darrieus has a potential for simplicity of manufacture and operation that may translate into lower overall energy costs. An assessment is expected soon to determine whether the Darrieus is ready for development of a full-scale prototype machine.

Other advanced concepts are undergoing preliminary assessment and design evaluation. None appears likely to have an impact on the availability or cost effectiveness of windpower in the near term.

V. Technology Evaluation

A. Ability of Windpower to Supply Energy Without Further Federal RD&D

If the Federal Wind Energy Program were to cease its RD&D activities, the availability of wind machines with sufficient proven reliability, durability, and cost effectiveness to begin developing the potential market on a scale significant to the Nation's energy consumption would be significantly deferred. By how long would be determined largely by the future trend in fuel prices. Furthermore, if at the same time other technologies that serve the same energy end uses continued to receive developmental assistance, the potential ultimate contribution of windpower could be preempted, to a degree not now predictable, by these other technologies. Under this scenario, it is doubtful that wind would contribute significantly to the energy supply before the year 2000.

Continuation of RD&D under the Federal windpower program at its present pace, without significant acceleration, is likely to result in development of prototype wind machines that will be gradually commercialized in a reasonable scale during the next two decades, the pace depending largely on the rate of escalation in the cost of energy from conventional sources. Although the rate of penetration may accelerate during the latter part of this period, the total capacity in 2000 cannot be expected to exceed approximately 1 quad.

B. Effect of Accelerated Federal RD&D

Two alternative strategies suggest themselves for accelerating energy production by windpower through Federal RD&D. These might be pursued jointly or separately. One is to support parallel courses of development toward major goals and toward a wide variety of applications. The other is to broaden greatly the scope of federally sponsored demonstrations.

1. Parallel RD&D

This approach would follow the general strategy of the present Federal Wind Energy Program but would broaden it in several ways. It would embrace the simultaneous development of a considerably wider range of design and engineering options for wind machines. It would address a wider range of specific applications and their associated design features, such as irrigation pumping. It would broaden and accelerate the investigation of wind characteristics, with greater emphasis on identifying and verifying the energy-producing capacity of high-quality wind farm sites. It would lead to early improved assessment of the total wind energy potential obtainable at key levels of wind speed and energy cost. It would include plans for several cycles of product improvement.

The main advantage of this course of action would be in accelerating the availability of early generations of cost-effective wind turbines and speed their installation in quantities sufficient to contribute significantly to national energy needs. Parallel design and development efforts would allow support of a larger number of contractors and, hence, foster a more competitive industry. Another important advantage would be to build and sustain momentum toward increased growth of windpower application toward its achievable potential. The main risk is that a parallel program may fail to achieve the degree of cost reduction that a more orderly (serial) program might achieve with the same budget but over a longer time frame.

2. Expanded Demonstration

This approach would use various incentives to increase the amount and public visibility of windpower use as fast as durable, reliable, cost-effective machines become available for each use. Among the uses to be demonstrated should be large-scale utility network applications, remote non-network utilities, large- and small-scale irrigation pumping, agricultural, rural residential, and industrial applications, appropriate technology settings, and settings having applications to LDC needs. An important feature of the program is purported to be the cost reductions and deepened market penetrations resulting from successive cycles of product improvement.

The main advantage of this option would be in accelerating the application of windpower to appropriate end uses and speeding the day when it would begin to make a substantial contribution to national energy needs. It would also greatly extend the application and acceptance of windpower for widely varied middle- and low-technology uses in agriculture and provide a showcase for transfer of appropriate technology to less-developed countries. The main disadvantage would be the possibility of installing a large number of machines that may become outmoded by later engineering developments. It is, therefore, of great importance to the success of this strategy that the products to be demonstrated should first attain an appropriate level of development and that applications and sites should be carefully screened for their suitability.

Given the above strategic considerations, the Panel believes that the following set of Federal RD&D actions are in order if windpower development is to be enhanced:

- Initiation in FY 1980 of a commercialization plan aimed at beginning relatively large-scale production and marketing of wind turbines in several size ranges as soon as the required characteristics of durability, reliability, and cost effectiveness are achieved, estimated to be about 1984, and potentially earlier for small machines and perhaps midsized machines.

- Increased emphasis upon total systems development and costs, including early improvement and validation of estimates of total developable windpower as functions of bus bar cost and windpower density.

- Support of a wider variety of parallel developments for wind turbine designs in several size ranges, potentially including development of machines adapted for direct mechanical uses at variable rotor speeds.

- Support of an increased, parallel R&D effort on critical components of second generation wind machines. In particular, rotor reliability and design concepts should receive additional emphasis.

- Public- and investor-owned utilities that may be interested in windpower should be identified and joint activities should be initiated including detailed studies of wind farm sites and economics intended to lead to cost-shared demonstration of wind farms.
- Development of a national windpower assessment to facilitate maximum use of the technology as various machines become available.
- Enlarged and strengthened staffing of the Wind Energy Office.

C. Non-RD&D Incentives for Accelerating Windpower Development

Non-RD&D incentives should be tailored to particular energy end-use sectors. For example, major utilities interested in windpower use have expressed concern that incentives provided by one agency may be taken away by another and have stressed the need for a coordinated incentives program that assures long-term stability. Since the range of applications for windpower is very broad, the range of incentives to be considered will need to be equally varied. It is the judgment of the RD&D Panel that the need for incentives to promote the market penetration of intermediate and large-scale wind machines is several years away given the need for engineering refinements to resolve questions related to the operational reliability and durability of these machines.

D. Organizational/Management Assessment

Responsibility for management of certain wind program elements has been delegated to Federal laboratories, and several contractors are involved in studies and in engineering development. The Department of the Interior is conducting a wind farm feasibility study for the Medicine Bow area of Wyoming.

In order to maximize the pace of windpower development, the Federal program has undergone rapid budget growth and has followed a development strategy that has led to significant overlap of program schedules. As a consequence, often there has been insufficient time to fully evaluate and assess the results of experiments and studies. This situation has been accelerated by an undermanned program office within

DOE. Although decentralized program management is being instituted within DOE, modest increases in the staffing level of the Wind Energy Branch at DOE Headquarters is recommended. This would allow improved formulation of an RD&D strategy, improved selection of candidate systems for development and better control of the program. The number of field management centers currently reporting to DOE Headquarters may be excessive and better control of the program may be possible if the number of direct-reporting field centers were reduced to three.

E. International, State, and Local Issues

DOE has a cooperative multilateral agreement with the IEA for exchange of information on wind energy, a bilateral agreement with Denmark, and the United States is in contact with other European national wind programs. Informal contacts suggest that Italian utilities are considering development of a windpower plan for the southern Alps with a gigawatt-scale target. Sweden is also considering a plan for large-scale use of windpower.

Windpower appears to offer especially attractive opportunities for transfer of an appropriate technology to lesser developed countries. Applications in these countries will include most of those expected in the United States but probably with less emphasis on network utility applications and more on dispersed electric and mechanical uses.

Development and demonstration keyed to the opportunities in the LDC's would need to be coupled with careful on-location verification of the appropriateness of perceived end uses for windpower products.

The State of California is planning a wind-energy program with a tentative goal of installing 10 GWe of capacity by 2000, the equivalent of about half a quad of fuel consumption per year. Hawaii has identified large wind-energy resources and is in the early stages of considering a wind-energy plan for the state. Montana is in about the same situation.

There is an increasing insistence on the part of Western States that they be involved in Federal progams of energy resource development from the outset. Explicit recognition of state roles in wind prospecting and wind farm development will be required as part of the RD&D effort to determine the magnitude of the Nation's windpower resources. Similar issues will arise on the local level when the stage of identifying and developing specific wind farm sites is reached.

F. Energy Impact

There is general agreement that the impact of windpower on the Nation's energy supply by 1985 will be symbolic only. Estimates for the year 2000 range widely from near zero to the fossil fuel equivalent of 6 quads per year, with a median of 13 estimates being near 2 quads per year. A developmental plan analysis has strongly suggested, however, that the target of substituting 2 quads per year of fossil energy could be attained only if a plan for early commercial production of wind machines was implemented. All of these estimates recognize that the natural resource is very much larger than even the largest year 2000 estimate of generation, and that the actual impact will therefore be sensitive to economic relationships (especially the cost of energy from alternative sources) and to the effectiveness and timing of RD&D and incentive measures.

APPENDIX A

Review of Windpower Program

I. Program Description

The purpose of the windpower program is to enlarge the Nation's supply of electrical and mechanical power in a cost-effective and environmentally benign manner. It is intended to deliver electricity to utility lines and to dispersed off-grid users, and to furnish mechanical power for a wide variety of dispersed uses. The goal of the present Federal Wind Energy Program includes erection of 128 large and intermediate wind turbines (200 to 2,500 kW capacity) by 1984, some 500 intermediate small machines by 1983, and contribution of the thermal equivalent of 0.01 quads in 1985. The Wind Energy Branch has prepared a preliminary commercialization plan with a goal of 0.04 quads by 1985 and 2 quads by 2000.

In order to achieve the market penetration necessary to reach this goal, the Federal Wind Energy Program has set a goal of $0.01 to $0.02/kWh for the cost of windpower, with a program of successive wind turbine developments planned to simplify designs and lower costs sufficiently by 1984 so that production-line manufacturing of these machines would be able to meet this cost goal. The same cost goal has been set for small wind machines as for large ones.

The Department of Energy has overall management responsibility for the Federal Wind Energy Program, and they make use of the existing expertise available at other Government agencies. The NASA Lewis Research Center is responsible for intermediate and large wind turbine development and technology development. As a part of this effort, NASA Lewis has contracts with General Electric, Boeing, Westinghouse, and Kaman. DOE Rocky Flats is responsible for small wind machine development. Some of the contractors in this effort include North Wind, Enortech, Windworks, Alcoa, and Grumman. Other members of the DOE team include Sandia Laboratories (responsible for vertical-axis wind systems development), Battelle Northwest Laboratories (responsible for wind characteristics), USDA-Agricultural Research Service (responsible for small systems requirements and applications), and SERI (responsible for advanced and innovative concepts development). Outside of the Federal program, there are companies such as Wind Power Products, Inc., and WTG that are developing wind machines on their own funds or other private-sector funds (the Wind Energy Association represents a multitude of private-sector firms). The Department of the Interior has a wind farm feasibility study underway for the Medicine Bow area in Wyoming.

The multiyear program plan projects DOE funding in the following manner ($ million):*

Fiscal Year	1978	1979
Millions of	$41.3	$60.7

The only other Federal funds allocated to wind are the $200,000 funding by the Department of the Interior for a wind farm feasibility study.

The Wind Energy Branch of DOE is staffed by four professionals. Personnel at other agencies are included as part of the DOE funding allocation: for example, NASA Lewis was allocated about $20 million in FY 1978 which includes funds for about 50 man-years of effort.

II. Current Status

Accomplishments to date include development of the first of a family of large wind turbines, the 100 kW Mod 0, to the point of automatic operation in a utility mode and erection of the first of its successors, the 200 kW Mod OA, which began operations at Clayton, New Mexico, in November 1977. This machine accumulated 1,124 hours of operation and produced 104,230 kWh before a planned shutdown on June 1, 1978, for inspection. A second Mod OA has been installed at Culebra, Puerto Rico, and is scheduled to begin operation in July 1978, and a third will be installed at Block Island, Rhode Island, with a scheduled operational date of April 1979. The 2-MW Mod 2 wind turbine will be installed at a utility site in Boone, North Carolina, with operations scheduled for December 1978. Preliminary design work is underway on the 2.5-MW Mod 2.

Regarding small wind machines, a number of commercially available small machines are undergoing testing at Rocky Flats. Multiple contractors have been selected for the development of advanced 1-kW and 8-kW machines.

The NASA Lewis 100-kW Mod 0 wind turbine being used as an engineering test bed has accumulated more than 800 hours of operation. To date, it has been used to validate analytical design codes for horizontal-axis wind machines, to test some advanced design concepts, and it has been operated in both upwind and downwind configurations.

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* See Options Paper for more budgetary detail.

In the technology area, a 150-foot composite blade has been successfully fabricated and is currently undergoing static testing.

Anticipated accomplishments include the operation of the 2.5-MW Mod 2 and an advanced 100- to 200-kW Mod 4 in 1980, and the operation of an advanced, second-generation megawatt-scale wind turbine (Mod 3) in mid-1980. First rotation of the advanced 1-kW, 8-kW, and 40-kW small machines are scheduled for the end of FY 1979. Demonstration programs for small and intermediate to large wind turbines are scheduled to begin in FY 1980-81.

There do not appear to be any insurmountable barriers or unresolved issues that would prevent development of reliable, durable, cost-effective wind turbines. The technology base provides confidence that such machines can be successfully designed and operated. There do remain unresolved technical issues, regarding the size of wind turbine that may be optimum for meeting a determinate energy goal, and the potential role of intermediate machines (50 to 200 kW) for a variety of dispersed electrical and mechanical uses.

III. New Factors

The Panel has noted widespread evidence of interest in windpower as a potential candidate for early commercialization. This interest is reflected in the recent announcement that $20 million would be added to the Federal Wind Energy Program budget for FY 1979. It is reflected also in the decision of one or two major manufacturers to undertake in-depth analyses of windpower markets and in the ordering of a prototype 3-MW wind turbine by Southern California Edison and the entry of that company into a survey program for a wind farm at San Gorgonio Pass. At least three states are also preparing plans for potential windpower programs.

Another new factor is the recognition on the part of Western States, now being looked to as the Nation's energy breadbasket, that they be involved in Federal programs of energy resource development from the outset. To meet this objective will require state participation in wind prospecting and wind farm development as part of any RD&D effort to determine the magnitude of the windpower resource.

TAB K

Technology Evaluation: Satellite Power System

I. Current Engineering/Scientific Status

A. Description

A satellite power system is designed to capture the solar energy with a satellite(s) in geosynchronis orbit and convert it to electrical energy by photovoltaics (solar cells) or other means. This energy, in turn, would be converted to radio-frequency energy and beamed to earth in a focused beam aimed at a ground receiving antenna (rectenna), where it would be reconverted to electricity for distribution in a utility grid. As currently envisioned, an economical system would be sized to deliver 5 gigawatts of electricity. These power levels dictate large satellites of some 50 km^2, if, for example, photovoltaics are used, and with a mass of some 50 x 10^7 kg. Ground receiving stations would require about 80 km^2 of land area. Launch requirements would be well beyond shuttle and present unmanned launch capabilities, and the need for a larger launch vehicle is indicated. Satellite Power System (SPS) assembly would be done in earth orbit with a large crew (perhaps 500 to 1,000).

Unlike other solar technologies examined by the Panel, the SPS at present is only in the concept development and evaluation phase under a joint DOE/NASA program.

B. Background

The SPS concept was first proposed in 1968 and was investigated by various private organizations. NASA, through some small contracted studies and experiments, also conducted investigations from 1971 to 1976. In FY 1976, principal responsibility for SPS studies was assigned by the OMB to DOE (then ERDA). The DOE established a task group on SPS that recommended that "... an efficient program plan be developed which focuses on well-defined objectives, criteria for assessing progress, and relationships among activities and decision points." This recommendation was implemented in a joint DOE/NASA plan, "Satellite Power System (SPS) Concept Development and Evaluation Program Plan, July 1977-August 1980" (DOE/ET-0034, February 1978).

C. Objectives/Goals

The objective of the SPS Concept Development and Evaluation Program is "... to develop by the end of 1980 an initial understanding of the technical feasibility, economic practicability, and the social and environmental acceptability of the concept." Within the plan are four functional activities:

1. Systems Definition (being conducted by NASA);
2. Evaluation of Environmental, Health, and Safety Factors;
3. Study of Related Socioeconomic Issues; and
4. Comparative Assessment of Alternative Energy Systems.

These functional activities will be integrated to meet the program intermediate goals of:

1. A baseline concept(s) selection, October 1978;
2. Preliminary program recommendation, May 1979; and
3. Updated program recommendation, January 1980.

A key milestone for the SPS occurs in June 1980, at which time final program recommendations resulting from the SPS Concept Development and Evaluation Program will be presented to the Administration. Assuming a favorable decision and adequate future program support, it is not expected that SPS could be available before the year 2000.

D. Potential Applications

Because the SPS's are sized, for economic considerations, in the 5 gigawatt-electric range, markets for these power levels would reside with the major utilities that would be capable of receiving and distributing such quantities of electricity economically.

E. Current Status (Program/Technical)

Experiments in 1975 conducted at the Jet Propulsion Laboratory established the feasibility of energy transmission at microwave frequencies. More than 30 kW were transmitted across a distance of over a mile, with reception and conversion efficiency of 82 percent. However, there is today no direct Government funding of experimental technology for SPS. Nonetheless, many technology advances in various DOE programs and NASA space programs are beneficial to SPS technologies (e.g., silicon solar cells). Federal activity is restricted at present to study efforts and laboratory tests under the program outlined in part C of this section, which are progressing on schedule.

F. Funding/Manpower

Federal funding in connection with SPS is solely for the SPS Concept Development and Evaluation Program. Anticipated funding and manpower estimates are shown in Table 1. Funds shown do not include manpower costs.

Table 1. Satellite Power System Concept Development and Evaluation Program Resources Estimates

Budget	Fiscal Year				
	1977	1978	1979	1980	Total
Systems Definition (NASA)	$1,800	1,700	1,300	800	5,600
Space-Related Technology (NASA)	700	—	—	—	700
Environmental Factors (DOE)	220	1,940	2,050	1,740	5,950
Socioeconomic Issues	164	537	537	322	1,560
Comparative Assessment	95	376	754	565	1,790
Subtotals:					
NASA	2,500	1,700	1,300	800	6,300
DOE	479	2,853	3,341	2,627	9,300
TOTAL	2,979	4,553	4,641	3,427	15,600

Federal Manpower	1977	1978	1979	1980	Total
NASA	59	56	40	30	185
DOE	1	3	4	4	12
Total	60	59	44	34	197

G. Key Issues

The scope of the SPS concept can be given some perspective by recognizing that the generating capacity of 40 to 50, 5GW Space Power Satellites would equal total United States electrical power-generating output in 1975. The most critical issues associated with the SPS concept being addressed at present are those relating to the environment, health, and safety. They involve the following:

- Terrestrial operations
- Launch, flight, and recovery operations
- Space operations
- Microwave power generation and transmission
- Land use
- International considerations

There are many subsets to each of these areas. For example, under microwave power generation and transmission there are such questions as possible radio-frequency interference with terrestrial and spaceborne electronic systems, microwave beam interaction with the ionosphere, or the public health impact from microwave radiation. In the latter instance, worldwide standards for maximum levels of long-term microwave radiation exposure are found to vary by three orders of magnitude. Under land use are site availability and local impacts, which include such considerations as the potential for industrial development in the vicinity of the rectennas as well as the overall potential impacts on air, water, and living space. International considerations involve orbit availability, vulnerability, energy export, and microwave frequency allocations.

II. Economics

As the SPS is in the concept development and evaluation phase, no in-depth analysis of the SPS system cost is available. (Initial cost estimates will be developed as part of the SPS Concept Development and Evaluation Program.)

III. Program Strategy/Rationale

Cost goals for the SPS system, viewed in the context of the preliminary nature of the program, are to deliver baseload electric power for $0.065 per kWh or less at the distribution terminal. Similarly, preliminary estimates for deployment of a network of 60 to 100 satellites indicate a capital cost of about $1,700 to $2,700/kWe. A significant cost factor is the estimated $50 to $85 billion research and development cost to accomplish the first full-scale demonstration.

Realistic projected schedules for deployment of an operational SPS system are not available. Projections will be included in the submission of information to the Administration in June 1980, in the form of Final Program Recommendations resulting from the SPS Concept Development and Evaluation Program. The information should allow an informed decision to be made regarding the future direction of the SPS program.

Compared with the enormity of the SPS concept and the many issues and challenges, the level of present-day activity is small. Federal funding for studies is $15.6 million spread over 4 years. And, while significant market potential exists, it is clear that substantial Federal expenditures would be required to advance the SPS concept to the point of commercial viability.

There are a significant number of substantive technical (engineering) issues associated with SPS (e.g., materials availability, industrial manufacturing capacity, launch, orbit assembly, satellite pointing and control, power distribution switching, rectenna operations). And there is a clear need for an intense, long-term R&D program to address these issues, should it be decided to move ahead with SPS. Meanwhile, related technology advances in various DOE and NASA programs should prove beneficial to SPS (see appendix A for more details of program concepts).

IV. Advanced Concepts

Compared with other solar technologies being pursued, SPS stands alone as an advanced concept. In the range from basic research through system development to the popular market, the present status of SPS must be considered in the Basic Research category. New concepts for converting solar energy to electricity (photoemissive cells) at higher efficiency than solar cells are being investigated, as is the use of laser beaming for transmission of energy to earth. Nonetheless, systems definition is a present-day activity, so that projected availability dates and performance and cost estimates remain highly speculative, even for the better-known technologies.

V. Technology Evaluation

A. Ability of the Technology to Supply Energy Without Further Federal RD&D

The federally funded program is the only focused SPS activity in the country. In the absence of this program, there is no question that the SPS technology would not be developed.

B. How Federal RD&D Might Accelerate Development and in What Time Frame

It is too early to judge whether increased Federal RD&D activities could or might accelerate the development of an SPS energy supply. This is primarily because of the great many key issues (environmental, health, safety, socioeconomic, international, etc.) that remain to be addressed in detail and resolved by the present DOE/NASA program. Inasmuch as the program results are due in less than 2 years (June 1980), the RD&D Panel believes that alternate program recommendations should await these results.

C. Institutional, Manpower, and Federal Program Management

As noted earlier, the present Federal program is the joint responsibility of DOE and NASA. DOE recently provided added management visibility to the program with the formation of an SPS Project Office, which reports to the Office of Energy Research. NASA, which is responsible for the Systems Definition Program Element, manages its effort through an SPS Program Manager located in the OAST Energy Systems Division. DOE/NASA program coordination is excellent.

D. Energy Impact

The SPS concept is a potential contributor to post-2000 energy supply, and there will be no energy impact in the 1985-2000 time frame.

APPENDIX A

Program Review: Satellite Power System (SPS)

I. Program Description

The SPS concept was first proposed in 1968 and was investigated by various private organizations. NASA, through some small contracted studies and experiments, also conducted investigations from 1971 to 1976. In FY 1976, principal responsibility for SPS studies was assigned by the OMB to DOE (then ERDA). The DOE then established a task group on SPS which resulted in a joint DOE/NASA plan, "Satellite Power System (SPS) Concept Development and Evaluation Program Plan, July 1977-August 1980."

The objective of the SPS Concept Development and Evaluation Program is "... to develop by the end of 1980 an initial understanding of the technical feasibility, economic practicability, and the social and environmental acceptability of the concept." Within the plan are four functional activities:

(1) Systems definition (being conducted by NASA).

(2) Evaluation of environmental, health, and safety factors.

(3) Study of related socioeconomic issues.

(4) Comparative assessment of alternative energy systems.

These functional activities will be integrated to meet the immediate program goals:

(1) A baseline concept(s) selection, October 1978.

(2) A preliminary program recommendation, May 1979.

(3) An updated program recommendation, January 1980.

A key milestone for the SPS occurs in June 1980, at which time final program recommendations resulting from the SPS Concept Development and Evaluation Program will be presented to the Administration. Assuming a favorable decision and adequate future program support, it is not expected that SPS could be available before the year 2000.

DOE is the lead agency for overall management of the SPS Concept Development and Evaluation Program. Implementation of the current SPS Program Plan, however, is a joint responsibility of DOE and NASA. NASA will conduct the systems definition of the SPS through parallel studies at the Johnson Space Center and the Marshall Space Flight Center. DOE is responsible for environmental, health, safety, economic, international, and institutional issues. As a part of their activity, DOE utilizes Argonne, LASL, Batelle PNW, and EPA, to mention a few. EPA, for example, is responsible to DOE for the microwave health and safety effort. Both North American Rockwell and Boeing are involved in the SPS system definition studies.

Federal funding in connection with SPS is solely for the SPS Concept Development and Evaluation Program.

II. Current Status

Experiments conducted in 1975 at the Jet Propulsion Laboratory established the feasibility of energy transmission at microwave frequencies (over 30 kilowatts were transmitted across a distance of more than a mile with reception and conversion efficiency of 82 percent). However, there is today no direct Government funding of experimental technology for SPS. Nonetheless, many technology advances in DOE and NASA programs are beneficial to SPS technologies (silicon solar cells, gallium arsenide solar cells, etc.).