PLANNING

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Planning and Technology Transfer Project
for the U.S. Department of Energy
Solar Thermal Energy Systems Division

A Review of the Solar Thermal Energy Systems Program: Accomplishments to Date and Future Plans

Backup Sunset Review Document

Pursuant to Title X- Sunset Provisions of the Department of Energy Organization Act of August 1977 (PL95-91)

DRAFT

August 1981

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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CONTENTS

I. PROGRAM NAME AND DESCRIPTION (Question 1)

The Solar Thermal Energy Systems (STES) Program is managed by the STES Division of the Department of Energy's Office of Solar Applications for Industry. The Program is divided into two branches. The Research and Technology Branch conducts advanced research and development, and manages technology development, on STES materials, components and systems. The Systems Test and Assessment Branch tests and assesses the performance of prototype solar thermal systems, and conducts the Program's overall planning and evaluation functions (see Figure I-1). The budget for these activities increased steadily from $104 million in 1978 to $142 million in 1981. In FY 1982, the Program de-emphasized technology and engineering development activities in response to the reduced appropriation of $44 million (see Table I-1). Operating expenses of the program comprised, on average, seventy percent (70%) of total budget authority from 1978 to 1981. In 1982, with the deletion of construction funds, operating expenses comprised ninety-seven percent (97%) of total budget authority (see Table I-2). In 1981, over 96% of the Program's management was decentralized to field organizations and national labs (see Table I-3).

The STES Program conducts advanced research and development on solar energy conversion concepts that include four types of concentrating collectors (i.e., central receiver, parabolic dish, parabolic trough and hemispherical bowl), and large-scale salt-gradient solar ponds. The four concentrating concepts all use reflective surfaces to focus or concentrate the sun's rays on a small area where the radiant energy is converted to either latent or sensible heat. A salt-gradient solar pond is a shallow (several meters deep) body of salt water capable of converting solar energy to sensible heat which can be stored for extended periods (weeks to months). After the solar energy is converted to

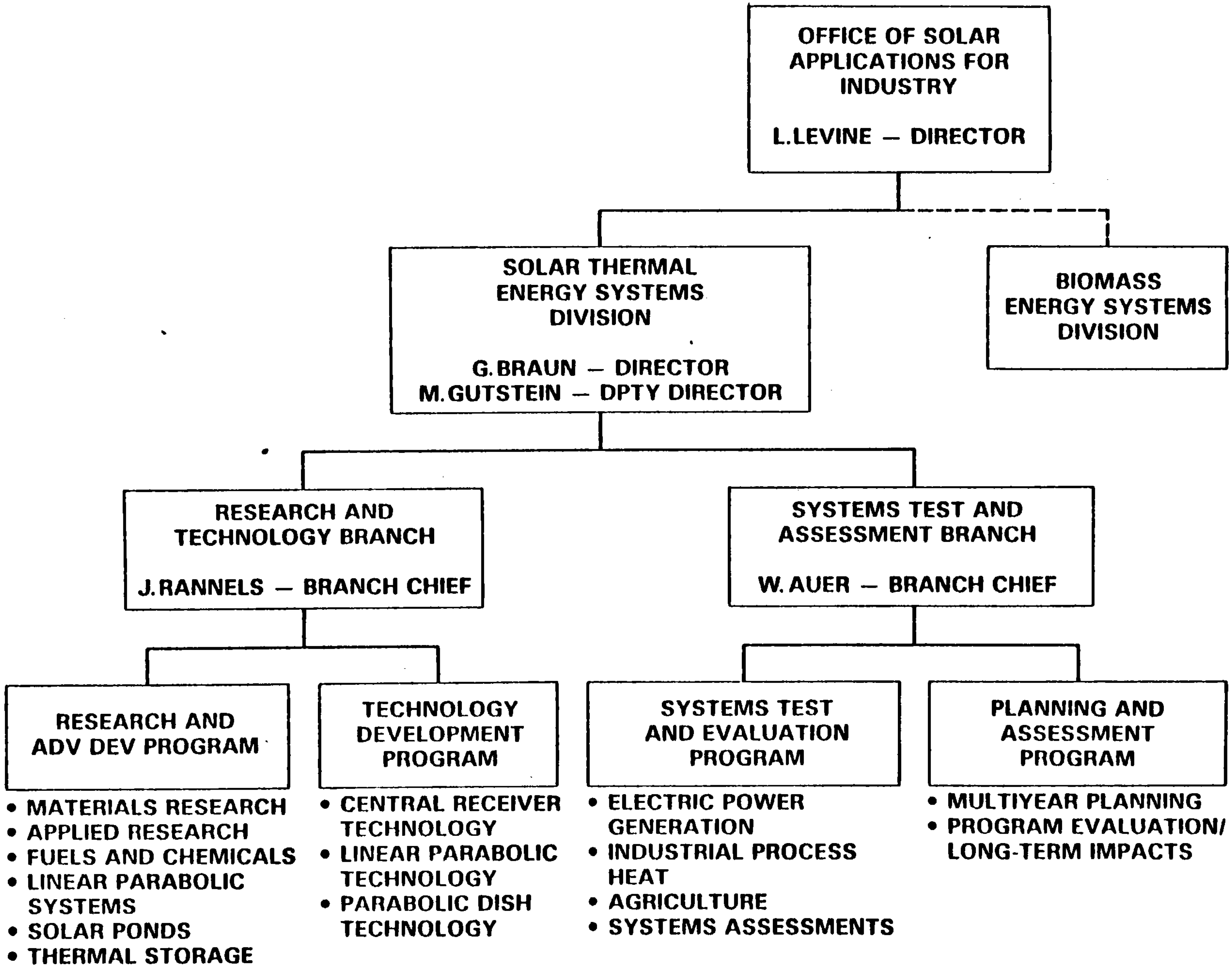

Figure I-1. Solar Thermal Energy Systems Organization

Table I-1. PROGRAM TYPES
SOLAR THERMAL ENERGY SYSTEMS

Sunset Review Question #1 ($M)

	FY 1978	FY 1979	FY 1980	FY 1981	FY 1982
Basic Research					
Applied Research	$ 10.550	$ 5.350	$ 6.105	$ 9.600	$11.600
Exploratory Development	14.950	8.094	24.475	8.250	10.850
Technology Development	21.107	45.468	52.800	59.550	13.050
Engineering Development	57.493	58.288	58.495	61.750*	6.000
Demonstration - Process					
Demonstration - Market Development					
TOTAL R&D $	$104.100	$117.200	$129.600	$139.150	$41.500
Regulatory - Performance Standards					
Regulatory-Outreach Services					
TOTAL REGULATORY $					
Price Support, Loan, & Loan Guarantee					
State Grants for Conservation and Solar Projects					
State Grants for State Energy Management					
TOTAL INCENTIVE $					
Information Services/Education					
TOTAL INFORMATION $					
Program Evaluation					
Planning Studies and Analyses	-	-	1.325	2.600	2.500
Other (specify)					
TOTAL $	$104.100	$117.200	$143.200	$141.750**	$44.000

*Includes $8,000,000 deferred from FY 1980 for 10-MWe Central Receiver Pilot Plant Project.

**Does not include $18,250,000 deferral and $3,480,000 rescission.

Table I-2. PROGRAM COMPONENT PARTS AND RESOURCES EXPENDED
SOLAR THERMAL ENERGY SYSTEMS

Sunset Review Question #1 ($M)

	FY 1978	FY 1979	FY 1980	FY 1981	FY 1982
Research and Advanced Development	$ 9.607	$13.444	$ 21.305	$ 13.600	$21.100
Technology Development	27.547	43.168	52.800	59.550	13.050
Systems Test and Evaluation	23.646	10.688	15.400	29.900	6.000
Planning and Assessment	-	18.900	13.600	2.600	2.500
TOTAL OPERATING EXPENSES	$60.800	$86.200	$103.650	$105.650	$42.650
Capital Equipment	2.300	3.000	3.000	4.250	1.350
Construction	41.000	28.000	37.095	31.850*	-
TOTAL BUDGET AUTHORITY	$104.100	$117.200	$143.200	$141.750**	$44.000

*Includes $8,000,000 deferred from FY 1980 for 10-MWe Central Receiver Pilot Plant Project.

**Does not include $18,250,000 deferral and $3,480,000 rescission.

Table I-3. Form F
FY 81 RESOURCES BY ORGANIZATION
SUNSET REVIEW QUESTION #1 ($M)

	RESEARCH AND ADVANCED DEVELOPMENT	TECHNOLOGY DEVELOPMENT	SYSTEMS TEST AND EVALUATION	PLANNING AND ASSESSMENT	TOTAL
HQ	2.5		2.5	.5	5.5
DOE/ALO		2.79	10.55		13.34
SNLL		23.7	3.2		26.9
SNLA		25.1			25.1
DOE/SAN	5.1		38.4		43.5
DOE/CHO	4.0	2.5	3.0	.55	10.05
JPL	2.0	9.5	3.75	1.10	16.35
Other	___	.21	.35	.45	1.01
TOTAL	13.6	63.8	61.75*	2.6	141.75**

*Includes $8,000,000 deferred from FY 1980 for 10-MWe Central Receiver Pilot Plant Project.

**Does not include $18,250,000 deferral and $3,480,000 rescission.

HQ - Headquarters
DOE/ALO - Albuquerque Operations Office
SNLL - Sandia National Laboratory: Livermore
SNLA - Sandia National Laboratory: Albuquerque
DOE/SAN - San Francisco Operations Office
DOE/CHO - Chicago Operations Office
JPL - Jet Propulsion Laboratory
OTHER - Regional Solar Energy Centers and other

heat, either by a concentrating collector or a solar pond, the energy can be used directly as process heat, or converted to mechanical or electrical power.

II. PROGRAM OBJECTIVES (Questions 2, 3 and 4)

<u>Historical and Current Objectives</u> (Question 2)

Congress, in the Solar Energy Research, Development and Demonstration Act of 1974 (PL 93-473, Sec. 2(b)(1-2)) established a policy to:

- "pursue a vigorous and viable program of research and resource assessment of solar energy as a major source of energy for our national needs; and
- provide for the development and demonstration of practicable means to employ solar energy on a commercial scale."

Furthermore, this act established six functional objectives which prescribed the work to be done by the STES Program (PL 93-473, Sec. 7(a)(1-6):

"(1) production of electricity from a number of power plants, on the order of one to ten megawatts each;

(2) production of synthetic fuels in commercial quantities;

(3) large-scale utilization of solar energy in the form of direct heat;

(4) utilization of thermal and all other by-products of the solar facilities;

(5) design and development of hybrid systems involving the concommitant utilization of solar and other energy sources; and,

(6) the continuous operation of such plants and facilities for a period of time."

A seventh functional objective--the demonstration of a 5-MW solar thermal electric system for small community applications--was added by the Energy Research Act of 1977 (PL 95-39, Sec. 102(d)).

Also in 1974, Congress passed the Federal Non-nuclear Energy Research and Development Act (PL 93-577), the Solar Heating and Cooling Demonstration Act (P.L. 93-409), and the Energy Reorganization Act (P.L. 93-438). P.L. 93-577 established a national program of basic and applied research and development, and mandated commercial demonstrations of advanced technologies in accordance with P.L. 93-473. P.L. 93-409 provided for the early development and commercial demonstration of solar heating systems. P.L. 93-438 mandated increased reliability and efficiency in the use of solar energy sources.

In establishing these objectives, the Congress knew that solar thermal technology could perform all of the specified functions. The challenge was to develop "practicable means to employ solar energy on a commercial scale." Meeting this challenge means being competitive in the bulk energy markets, by pushing the limits of the underlying technology base for solar thermal systems. This raises concerns for the life, durability, and performance of these systems, and suggests the need for research and development. Concerns for the underlying technology base are compounded by the increase in size associated with commercial systems, and the changes in detailed design that will be associated with producing major subsystems in mass-production quantities. Since these latter concerns indicated a need for demonstration projects, DOE established a 10- to 15-year research, development and demonstration (RD&D) program on solar thermal technology. The goal of the program is to accelerate the introduction and widespread use of solar energy to provide fuels, petrochemical substitutes, thermal and mechanical power, and electricial energy.

At the outset, the STES Program developed phased functional objectives and cost/performance objectives. The phased functional objectives set a timetable of technology-specific activities for accomplishing the Congressional objectives mandated in P.L. 93-473 (see Table II-1). Similarly, three cost/performance objectives established system costs and target dates for demonstrating that STES technology was ready for industry to commit to mass production (Domestic Policy Review, 1978-1979):

- for utility electric power applications - $1300/kWe by 1985-87
- for total energy and cogeneration applications - $1000/kW (electric and thermal) by 1983-84
- for industrial process heat applications - $9-11/MMBtu by the early 1980's

The cost/performance objectives were established to help management evaluate proposed designs and decide which ones were worth pursuing. To improve their usefulness for this purpose, the measure of cost-performance was converted from "capital cost per rated output" to "total annual cost per annual output" in 1980 (see Pre-1981 column in Table II-2). These cost targets reflect the value of competing conventional energy systems in the southwest and are deemed to be achievable at concentrator production volumes on the order of 1,000,000 square meters per year per factory. The dates reflect the completion of factories capable of producing concentrators at 1,000,000 m^2/year. Embedded in these cost/performance objectives are a complete set of specific cost and performance measures associated with subsystems and components (some of the more important are listed in Table II-1). Consistent with both the Solar RD&D Act and post-1981 budget levels the program will be concentrating future research and development (R&D) effort on the high pay-off objectives originally set for 1995 (see 1981 column in Table II-2).

Table II-1

COST/PERFORMANCE OBJECTIVES AND PHASED FUNCTIONAL OBJECTIVES
OF THE SOLAR THERMAL ENERGY SYSTEMS PROGRAM

PRODUCTION OF ELECTRICITY FROM A NUMBER OF POWER PLANTS ON THE ORDER OF 1-10MWe EACH

- Cost/Performance Objectives
  80-100 mills/kWh by 1990s
  Central Receivers
  -System capital cost, $1000-$2300/kWe
  -Heliostat cost $86/m^2 for glass
  -Receiver cost, $50/kWe

- Phased Functional Objectives

Historical	Current
Central Receiver Systems	
-Design, build and test prototype heliostat, receiver and storage subsystems suitable for use in pilot plants by 1980.	-Complete the construction and operate the grid-connected 10-MWe central receiver pilot plant to prove system technical feasibility by 1986.
-Design, construct and operate cost-shared grid-connected central receiver pilot plant of 10-MWe capacity to prove system technical feasibility by 1986.	
-Design, construct and operate cost-shared repowering plants to prove system economic feasibility by 1988.	
Hemispherical Bowl Systems	
-Design, build and test a protytype 65-foot diameter hemispherical bowl system to prove technical feasibility by 1981.	-Complete assessment of economic potential of full-scale bowls based on experimental results of 65-foot diameter bowl by 1982.
Salt-Gradient Solar Pond Systems	
-Design, build and operate cost-shared 5-MWe prototype solar pond to prove technical feasibility by 1988.	-Design, build and operate cost-shared 5-MWe prototype solar pond to prove technical feasibility by 1991.

Table II-1 (continued)

COST/PERFORMANCE OBJECTIVES AND PHASED FUNCTIONAL OBJECTIVES
OF THE SOLAR THERMAL ENERGY SYSTEMS PROGRAM

PRODUCTION OF SYNTHETIC FUELS IN COMMERCIAL QUANTITIES

- Cost/Performance Objectives (still to be determined--will depend upon specific product chosen for development)

- Phased Functional Objectives

Historical	Current
-Design, build and test prototype heat receiver/reactors for use in process development units by 1982. -Prove commercial feasibility of fuel or chemical processes by conducting tests at CRTF before 1986. -Design, build and operate prototype process development units to prove technical feasibility by 1995.	(same as Historical)

UTILIZATION OF THERMAL AND ALL OTHER BY-PRODUCTS OF SOLAR FACILITIES

- Cost/Performance Objectives (A separate objective is not needed since meeting the objectives for electric systems is the dominant concern in establishing competitive total energy or cogeneration systems.)

- Phased Functional Objectives

Historical	Current
Parabolic Dish Systems -Design, construction and operation of 400-kWe dish cogeneration system to prove technical feasibility by 1982.	-Complete construction and operation of 400-kWe dish cogeneration system to prove technical feasibility by 1982.
Central Receiver Systems -Design, construction and operation of cost-shared industrial retrofit (hybrid) process heat and cogeneration systems to prove economic feasibility by 1987.	-Design, building and testing of hot air and saturated steam process receivers by 1984.

Table II-1 (continued)

COST/PERFORMANCE OBJECTIVES AND PHASED FUNCTIONAL OBJECTIVES
OF THE SOLAR THERMAL ENERGY SYSTEMS PROGRAM

DEVELOP HYBRID AND SMALL COMMUNITY POWER SYSTEMS

- Cost/Performance Objectives
  80-100 mills/kWe by 1990's
  -Parabolic Dish
  - System efficiency 20-30%
  - System life 30 years
  - Concentrator cost $80-120/m^2$
  - Receiver cost $24-45/kWe
  - Power conversion cost $120-$230/kWe

- Phased Functional Objectives

Historical	Current
Parabolic Dish-Electric System	
-Design, fabricate and test prototype dish concentrators, coupled heat engine/receivers, and controls for use in dish electric modules by 1985.	-Complete testing of prototype dish-electric modules and transfer technology to industry by 1983.
-Design, fabricate and test prototype hybrid dish-electric power modules to prove technical feasibility of subsystems by 1987.	
-Design, construct and operate cost-shared 1-MWe multi-module parabolic dish hybrid electric power plants to prove system technical and economic feasibility by 1992.	

Table II-1 (concluded)

COST/PERFORMANCE OBJECTIVES AND PHASED FUNCTIONAL OBJECTIVES
OF THE SOLAR THERMAL ENERGY SYSTEMS PROGRAM

LARGE-SCALE UTILIZATION OF SOLAR ENERGY FOR DIRECT HEATING

- Cost/Performance Objectives
  $5-$7/MMBtu by 1990s
  Parabolic Trough
  -4.0 MMBtu/m^2 year
  -Average annual efficiency, 45%
  -System life, 20 years

- Phased Functional Objectives

Historical	Current
Parabolic Trough Systems -Design, construct and test prototype trough collectors, heat receivers, thermal storage and other subsystems for use in process heat and cogeneration field experiments by 1981. -Design, build and operate parabolic trough prototype systems to prove technical feasibility by 1983. -Design, build and operate cost-shared modular industrial retrofit systems to prove economic feasibility by 1985.	-Complete construction and testing of key trough system elements and phase-out program. Transfer technology to industry for commercial implementation by 1983.

TABLE II-2

PROGRAM COST OBJECTIVES

	Pre-1981	1981
For electricity generation	140-160 mills/kWh by 1990 80-100 mills/kWh by 1995	80-100 mills/kWh in 1990s
For industrial heat process	$7-9/MMBtu by 1990 $5-7/MMBtu by 1995	$5-7/MMBtu in 1990s

Similar Programs (Question 3)

Other renewable technologies (e.g., wind, photovoltaics, biomass and Ocean Thermal Energy Conversion (OTEC) address subsets of the same market sectors as STES. However, the production of heat over broad temperature ranges and capacity levels makes solar thermal technologies useful in a variety of applications (e.g., electric generation, industrial process heat and production of transportable fuels and chemical feedstocks). Furthermore, the unique potential for solar thermal energy systems to use efficient thermal storage, the lowest cost energy storage technique, gives it a competitive edge over other solar electric systems--an edge both in the cost of energy and in the potential to save fuel.

In the United States, the DOE has taken a leadership role in STES R&D and is coordinating its program with complementary programs being conducted by the Electric Power Research Institute (EPRI) and the Gas Research Institute.

Internationally, the STES Program has cooperative agreements with the International Energy Agency (IEA), Spain, Italy and Saudi Arabia. Apart from these complementary, mutually beneficial efforts, competition from foreign companies is beginning to build with help from their governments.

The European Economic Community is constructing a 1-MWe central receiver project (Euralias) in a cooperative effort between the Federal Republic of Germany, Italy and France. Japan has built two 1-MWe pilot plants, with operation scheduled for mid-1981. France is involved in three efforts: a two-tower 2-MWe pilot plant; a proof-of-concept 10-meter-diameter hemispherical bowl engineering model, with a 30.8-meter-diameter 85-kWe bowl planned; and a test station consisting of parabolic dish collectors and parabolic troughs. Israel is operating a 70,000-ft^2 solar pond with a 130-150 kWe average capacity and a 210 kWe peak; the pond system is still in its first stage, and a 2000-MWe capacity expected by the year 2000. The Federal Republic of Germany projects that in 1986 it will operate a 20-MWe central receiver with a gas-cooled Brayton-cycle system, which uses a 38% efficient gas turbine with no storage. There is considerable uncertainty about the status of solar thermal technology in the USSR. A central receiver project (anywhere from 1/3 MWe to 5 MWe) was begun in 1977, but is not yet under construction; future plans include a 200-MWe central receiver repowering system, with four 50-MWe modules to be coupled with an existing power grid. Beyond plans for larger-scale facilities, some of these countries have an eye to the U.S. and other export markets.

Alternative Methods (Question 4)

Alternative methods for developing the needed technology would both cost more and involve higher risk than the approach taken by the STES program. In the broadest sense, the goal of the program to "accelerate the introduction and widespread use of solar energy..." could be achieved by either new and increased financial incentives or massive federal purchases of solar thermal systems. For example, to foster the development of the solar thermal industry and the use of parabolic troughs for industrial process heat, tax credits and write-offs could be increased to provide reasonable returns on investments in solar thermal production capacity and systems. Similarly, a combination of loan guarantees and tax credits could encourage electric utilities to construct large central receiver generating plants despite the inherent technical and economic risks associated with first-of-a-kind systems. (Note that current laws exclude utilities--the largest market for electric applications--from taking advantage of tax credits for STES.) Additionally, with suitable Federal incentives, a number of utilities could pool their resources and build initial central receiver solar thermal plants. This "consortium buy" would reduce the risks to any single utility by spreading the financial capital requirements. Also, government involvement would ensure the consortium against potential anti-trust claims.

Any of these alternatives could encourage the development of a solar thermal industry. With increased production volume, industry would devote more resources to R&D, thus reducing the need for Federal R&D support. However, since private sector R&D commitments would be primarily funded out of the net income from system sales, the level of R&D investment would constitute only a fraction of federal expenditures. Therefore, increased federal expenditures substantially above the existing level will be required to maintain the current level of STES development efforts.

Another drawback to the alternative methods is that they only indirectly address the technology development needs (i.e., proof of the technical feasibility, reliability, and potential cost-effectiveness of solar-thermal subsystems and systems) that currently prevent industry from introducing products; that is, they require the private sector to focus on production, not research and development. As such, the current STES Program, with its direct emphasis on establishing a technology base that will be cost-effective without federal production subsidies, has a higher probability of leading to the earliest widespread adoption and use of STES.

III. Program Impacts (Questions 6,7,8,9,10 and 11)

Accomplishments (Question 6)

The program has made significant progress toward achieveing the objectives established by P.L. 95-473, but a substantial amount of work remains before all of the objectives are met.

To produce electricity from power plants on the order of 1-10 MWe each, the program has constructed or is constructing a variety of facilities. A 500-kWe parabolic trough system was constructed near Coolidge, Arizona, and has been producing electricity reliably for two years. A central receiver test facility (CRTF) was constructed in Albuquerque, New Mexico, to test heliostats, receivers, and storage components under development. Hardware that has been tested at the CRTF will be utilized in the 10-MWe solar thermal power plant under construction near Barstow, California (see Table III-1 for details). This plant, the largest of its kind in the world, will start operation in 1982. Several years of successful continuous operation will constitute a significant step toward the achievement of commercial-scale solar thermal power plants.

Production of synthetic fuels in commercial quantities is still a long-term objective. Solar thermal technology has been used to produce fuels and chemical feedstocks on a laboratory scale. In particular, the program has examined 1390 potential processes, completed feasibility experiments, and identified a number of candidate processes. Establishing the technical feasibility of commercially interesting processes, however, is at least five years away, and actual commercial production is still further away (see Table III-1).

A total energy project utilizing parabolic dish technology is under construction at Shenandoah, Georgia, and will be completed in 1982 (see Table III-1). This project is the first solar thermal facility to both generate electricity and produce process heat.

The program has completed a preliminary design for a 0.25-MW to 1-MW electric system, aimed at demonstrating parabolic dish technology in a solar thermal electric system for small community applications. The development of hybrid (solar-fossil) systems is also important for small community and remote power applications. To that end, versions of both Brayton and Stirling engines that can be used with parabolic dishes in a solar/fuel hybrid mode are well along in the development cycle.

Large-scale utilization of solar energy for direct heating in the 93° (200°F) to 260°C(500°F) temperature range has been accomplished in more than a dozen experimental installations using parabolic troughs. Several of these installations have a capability similar to standard industrial boilers, i.e., 10,000,000 Btu per hour (see Table III-1). Central receiver systems needed to achieve higher temperatures in large-scale applications have been designed, but the testing of major components lies ahead.

In addition to these specific accomplishments, the program has succeeded in involving the private sector in solar thermal technology development. In particular, 100 industrial process heat users, 44 small communities, and 5 large utilities recently responded to opportunities to share in the program.

Table III-1. SOLAR THERMAL ENERGY SYSTEMS PROGRAM ACCOMPLISHMENTS

GOALS/OBJECTIVES	OTHER PROGRAMS (duplicative)	BUDGET DATA ($millions) STATUS FY 78 104.1	FY 79 117.2	FY 80 143.2	FY 81 138.3	DEGREE ORIGINAL OBJECTIVE MET
PRODUCTION OF ELECTRICITY FROM A NUMBER OF POWER PLANTS ON THE ORDER OF 1-10 MWe EACH:						
o 80-100 mills/kWh by 1990's - Central Receivers o System capital cost \$1000-\$2300/kWe o Heliostat cost \$86/m^2 for glass o Receiver cost \$50/kWe - Parabolic Troughs	o European Economic Community, Japan, Israel and USSR central receiver programs. o EPRI central receiver/Brayton technology development (complementary to STES Program effort).	o Central Receiver Test Facility (CRTF) construction completed. o Shallow-well parabolic trough project in operation.	o Heliostat design with \$200/m^2 cost in production tested. o Confirmed performance of first-of-a-kind heliostats and EPRI/Boeing receiver at 1MWe.	o Heliostat field at CRTF maintained at or above 95% operational level. o Confirmed performance of 10-MWe receiver panels. o Deep-well parabolic trough project in operation for 1 year. o Distributed focus (bowl) collector in operation.	o Completed construction of 10-MWe Barstow Pilot Plant. o Tested small scale molten salt receiver and storage concepts, and heliostat design with \$100/m^2 cost in production.	Engineering feasibility of several options will be completed within next two years. If present rate of progress continues for next five years all objectives can be met.
PRODUCTION OF SYNTHETIC FUELS IN COMMERCIAL QUANTITIES:						
o Identify feasible processes o Prove commercial feasibility processes	(none)	o Fuels and chemicals project at Georgia Institute of Technology in operation.	o Completed experiments on oil shale retorting and coal gasification using solar. o Developed conceptual designs for solar thermal production of hydrogen.	o Demonstrated conversion efficiency of 50% for Solchem receiver. o Examined 1390 potential processes. o Completed feasibility experiment for fuels and chemicals production.		A number of candidate processes have been identified. Program is on track to achieve technical feasibility by 1986.
UTILIZATION OF THERMAL AND ALL OTHER BY-PRODUCTS OF SOLAR FACILITIES:	(none)		o 4 thermal dish collectors for Shenandoah tested.		o Shenandoah total energy project construction completed	Ready to operate system for a number of years.
DEVELOP HYBRID AND SMALL COMMUNITY POWER SYSTEMS:						
o 80-100 mills/kWe by 1990's - Parabolic Dish o system efficiency 20-30% o system life 30 years o concentrator cost \$80-120/m^2 o receiver cost \$24-45/kWe o power conversion cost \$120-230/kWe	(none)			o Confirmed performance of steam receiver. o Constructed parabolic dish test site (PDTS). o Test bed concentrators at PDTS achieved energy flux equal to 14000 suns.	o Completed development of an ORC parabolic dish power module. o Confirmed performance of dish Stirling concept at PDTS. o Confirmed performance of solarized Brayton engine. o Confirmed performance of air receiver.	Concentrators in development. 20% efficiency possible with 3 engine options 30% efficiencies using either a Brayton or Stirling engine with ceramic components.
LARGE-SCALE UTILIZATION OF SOLAR ENERGY FOR DIRECT HEATING:						
o \$5-\$7/MMBtu by 1990's o 4.0 MMBtu/m^2-yr o average annual efficiency 45% o system life 20 years	o GRI/IPH Program (complementary to STES Program effort)		o Confirmed performance of trough made of sheet-molding compound.	o Peak efficiency corresponding to 1995 target met. o Commercial collectors demonstrated 1986-1985 objective.	o Seven IPH projects in operation for one year. o Five new IPH projects in operation.	1980 objectives have been accomplished. Program is progressing towards future objectives.

Annual Activity (Question 7)

CENTRAL RECEIVERS

The Central Receiver (CR) Technology is in the middle stages of development. A number of conceptual designs for electric power generation, repowering and industrial process heat (IPH) applications have been completed. The 10-MWe pilot plant near Barstow, California, is near completion and scheduled for operation in 1981. First-generation heliostats and receivers have been tested successfully at the CRTF in Albuquerque, New Mexico. Second-generation heliostats, receivers, and storage components are currently under development. The CR program has assisted other programs including the Department of Interior solar-hydro integration and the IEA 500-kWe central receiver plant in Spain which will be operational in 1981. The following summary highlights the central receiver accomplishments between 1978 and 1981.

FY 1978

- Completed site surveys and soil analysis for the 10 MWe Pilot Plant, Barstow, California.
- Completed liquid sodium and molten salt conceptual design studies for alternate central receivers.
- Completed construction and initiated testing operations of the Central Receiver Test Facility (CRTF) near Albuquerque, New Mexico.
- Completed second-generation heliostat conceptual designs with projected production costs near goals.

FY 1979

- Tested the McDonnell Douglas 70-tube panel subsystems Research Experiment Receiver at the CRTF and completed three improved water/steam receiver designs.
- Completed fabrication and initiated testing of preproduction heliostats for the 10-MWe Pilot Plant.
- Completed testing of the EPRI/Boeing 1-MWe bench model solar receiver at CRTF at 1500°F.

FY 1980

- Testing of the MDAC receiver at CRTF was completed. Testing of a Martin Marietta molten salt receiver at CRTF was initiated. Three improved water/steam receiver designs were completed.
- The heliostat field at CRTF was maintained at or above 95% operational level.
- Testing of the 10-MWe Pilot Plant receiver panels was completed and construction of the receiver was started.
- The 10-MWe Pilot Plant preliminary design work was finished and the production heliostat supplier selected. The heliostat foundation was laid and installation of the heliostat begun.
- Concept development for internally insulated thermal storage containment for molten salt receivers and for an organic fluid maintenance unit were completed.
- Completed eight conceptual designs for electric repowering and six designs for process heat repowering/retrofit.

FY 1981

- Completed field construction of the 10-MWe Pilot Plant.
- Continued operation of the Central Receiver Test Facility in support of receiver development and heliostat characterization.

PARABOLIC TROUGHS

Parabolic trough technology has made tremendous advances in component development, testing, and potential manufacturer involvement. Peak efficiency measurements are approaching 70% compared to 45-55% efficiency of the first-generation systems, with collector costs reduced from $\$1000/m^2$ in 1978 to $\$300/m^2$ in 1981. Several application projects employing parabolic trough collectors are in operation, under construction, or in design. Examples are a 150-kWe deep well irrigation pumping experiment at Coolidge, Arizona, operational in 1979, and several projects in IPH applications. The major accomplishments for the parabolic troughs during the period 1978-1981 are summarized below:

<u>FY 1978</u>

- Prepared thin-glass reflector laminate and completed preliminary design of an engineering prototype advanced parabolic trough.
- Completed construction and put into operation two industrial process heat projects (270 m^2 Acurex system, 770 m^2 Honeywell system).
- Completed construction and put into operation the Shallow Well Project at Willard, New Mexico, and Gila Bend, the solar Irrigation Project in Arizona.
- Completed system design and initiated site construction for the deep well project (150 kW) at Coolidge, Arizona.

<u>FY 1979</u>

- Designed and analyzed a sheet-molding compound parabolic trough with integrally molded glass mirror and conducted wind-tunnel tests of scaled troughs.

- Completed and put into operation two heating and cooling projects (1900 m^2 Honeywell plant, and a 520 m^2 Solar Kinetics).
- Proved reliability of Solar Kinetics and Acurex collector fields at the Shallow Well Irrigation Project.
- Completed checkout and start-up operations at 150-kW Deep Well Irrigation Project at Coolidge, Arizona.

<u>FY 1980</u>

- 63% thermal efficiency at an output temperature of 315°C was obtained from a nonevacuated tube line-focus receiver.
- Demonstrated commercial collectors to have greater than 70% peak efficiency at Midtemperature Solar Systems Test Facility (MSSTF) in Albuquerque, New Mexico.
- In the industrial process heat technology area, seven projects were operated using low-temperature hot water/hot air, with collector efficiencies ranging from 12 to 30%. Four projects were in operation or under construction using low-temperature steam. Four systems designed in FY 79 were under construction using intermediate temperature steam.
- Five industrial process heat projects were operational or in the final construction phase. (1040 m^2 Acurex system, 600 m^2 Jacobs-Del system, 930 m^2 Suntec system, 880 m^2 Solar Kinetics system, 800 m^2 Suntec system).
- Field operation exceeded 70% of possible time and greater than 200 hours of turbine time at the Shallow Well Irrigation Project, Willard, New Mexico.

- At the Deep Well Irrigation Project in Coolidge, Arizona, the facility was completed and dedicated; the system was operated more than 85% of "good weather" time; approximately 108,000 kWeh was supplied to the grid.

FY 1981

- Completed detailed design and initiated construction of a large-scale, low-temperature IPH project.
- Initiated operation of 940 m2 grain drying operation.

PARABOLIC DISH

The Parabolic Dish Program has brought all of the major subsystems of a dish electric module to the point of establishing the feasibility of the concept. Several receivers have been successfully tested under a variety of conditions; the first-generation concentrator is developed; and industry, with funding from the program, is developing the components needed to build parabolic dish electric modules using organic Rankine, Brayton, and Stirling cycle engines. An historical element of this program is the retrofitting of a knitwear factory in Shenandoah, Georgia (started in 1977) which is scheduled to commence operation in 1982. A series of engineering experiments that will help to establish the requirements for dish systems to become economically competitive are in different stages of development. The following are the major accomplishments for the Parabolic Dish Program from 1978 to 1981.

FY 1978

- Completed design for a high efficiency turbine for a total energy parabolic dish project at Shenandoah, Georgia.

FY 1979

- Developed a first-generation design for a parabolic dish concentrator capable of producing temperatures in the 540-815°C range and completed conceptual design studies that identified candidate Rankine and Brayton cycle engines in parabolic dish electric modules.
- At the Shenandoah Total Energy Project, completed grading and erosion control modifications and finalized final design parameters.

FY 1980

- Cost-effective, lightweight, reflective glass for advanced parabolic dishes was developed.
- Two test bed concentrators were installed and tested at the Parabolic Dish Test Site.
- Completed system design for the Shenandoah Total Energy Project and testing of four prototype collectors at MSSTF.
- Selected the concentrator, receiver, power conversion unit, and six candidate sites for the Small Community Solar Thermal Power Experiment.

FY 1981

- Completed testing of a steam Rankine and two air Brayton receivers on the test bed concentrator.
- Fabricated and tested first article collectors for the Shenandoah Total Energy Project and initiated installation.
- Completed development and qualification of receiver, control and transport subsystems for the Small Community Solar Thermal Power Experiment.

- Completed testing of the United Stirling of Sweden P-40 solarized engine and initiated testing of the engine/receiver assembly at the Parabolic Dish Test Site.
- Completed design and initiated fabrication of first Power Kinetics Inc. concentrators, one for verification testing and one for application at Capital Concrete in Topeka, Kansas.
- Completed retrofit of the Omnium-G modules at the PDTS and the Southern New England Telephone Company and generated electricity.
- Completed structural design of the Acurex concentrator.
- Completed design of the solarized automotive air Brayton engine and initiated fabrication.

TECHNOLOGY BASE

For solar-thermal energy systems to become competitive, the program must stress continued research for lower cost, more durable and more efficient materials, components, and subsystems. Several polymers, cellular glass, and foam glass have been developed as structural materials for optical systems. Transport, storage fluids and selective coating materials for high temperature applications have also been developed. Feasibility experiments have been conducted to demonstrate the potential for solar thermal energy to promote fuels and chemical production. Major accomplishments are listed below for the 1978 to 1981 period.

FY 1978

- Demonstrated stable black-chrome selective coating in laboratory and completed silicone heat-transfer oil test for 1800 hours.
- Conducted tests of advanced receivers at Georgia Institute of Technology and initiated the fuels and chemicals project.

- Identified the potential of foam glass as a low-cost structural material and conducted high-temperature optical stability tests.

FY 1979

- Completed two hemispherical bowl receivers and performed receiver solar tests.
- Conducted experiments on solar retorting of oil shale and solar coal gasification. Conducted conceptual design studies for solar thermal production of hydrogen.
- Tested the Sanders Associates 250-kWe Ceramic honeycomb receiver at 1065°C (1950°F) and ambient pressure at Georgia Institute of Technology.

FY 1980

- A Solchem receiver containing a CO_2-CH_4 reforming convector-heat exchange coil was tested with conversion efficiencies greater than 50%. Westinghouse completed fabrication of an SO_3 receiver module.
- Design information for use of cellular glass as a structural material in optical systems was published. The technical feasibility of sag-forming cellular glass was demonstrated.
- Feasibility experiments were conducted to demonstrate the potential for solar thermal energy to promote fuels and chemicals production. Experiments include solar thermal coal gasification, retorting of shale, pyrolysis of biomass, production of calcium carbide, feedstock for acetylene production, and thermochemical splitting of water.

FY 1981

- Completed construction of the 500-kWe central receiver and 500-kWe line-focus distributed receiver experiment at Almeria, Spain, as part of the IEA program.
- Completed Rankine storage subsystem second-generation test.
- Tested the Sanders receiver to 1426°C (2600°F) at the Parabolic Dish Test Site.
- Tested a solarized Stirling engine for 460 hours in various attitudes prior to solar tests.

Beneficiaries (Question 8)

The beneficiaries of the STES program can be classified into two categories: direct and indirect. Direct beneficiaries include all suppliers and customers directly involved in the production and utilization of STES. On the supply side, this will include all firms producing STES components for both domestic and export markets, as well as those firms involved in integrating and installing these systems. On the demand side, the beneficiaries will include all customers purchasing an STES. Preliminary studies indicate that early STES customers (1990 installations) will include, among others: municipal electric utilities and rural electric cooperatives, which currently rely on a high proportion of petroleum as a fuel source; investor-owned electric utilities in high insolation and/or high fuel price regions; industries using industrial process heat in high insolation and/or high fuel price regions; agricultural producers currently using diesel power for irrigation purposes; and petroleum extraction companies currently using diesel fuel for enhanced oil recovery. In the long-run, if real fuel prices continue to increase and STES costs decrease, the number of beneficiaries will expand as both penetration in the high insolation/high fuel price regions increases and STES becomes economically competitive in less favorable regions of the country.

The size of each of these beneficiary classes is impossible to estimate at this time. As described in the following section, "Economic Impacts," STES penetration, and hence the number of beneficiaries in each category, depends critically on the actual future energy prices and STES costs. Due to the overwhelming uncertainties surrounding estimates of these future values, an accurate assessment of STES penetration in 1990 is impossible at the present time. All that can be said with certainty is that the total market can range from very small to quite significant.

The second category of beneficiaries served by the STES program is that of indirect beneficiaries. As discussed elsewhere in this review, successful development of STES will tend to impose a ceiling on the petroleum price which can be extracted by the OPEC cartel. Those receiving the largest benefit from this attribute of the STES program, however, will include firms and customers of electric utilities that have a high reliance on petroleum (i.e., fertilizer manufacturers, farmers, customers of small municipal electric utilities, etc.). Furthermore, since the domestic rate of inflation is extremely sensitive to changes in energy prices, this ceiling will help stabilize the domestic price level and benefit the U.S. economy as a whole. Finally, since STES provide an alternative means of power production, they both reduce U.S. dependence on imported petroleum and natural gas, and increase the flexibility of response to future oil embargoes. These considerations provide an additional benefit to the U.S. domestic economy.

Economic Impacts (Question 9)

The economic impacts accruing from the Solar Thermal Energy Systems Program can be divided into two broad categories: impacts which are reflected in market transactions, and impacts which are not. The primary impact in the first category is the savings in energy-related costs that consumers will realize as utilities and industrial users replace conventional generating capacity with economically competitive solar thermal energy systems. Secondary impacts in this category include considerations such as net changes in employment levels and the effect of lower energy costs on other sectors of the domestic economy. The second category of impacts, those which are not captured through the pricing mechanism or market transactions, include benefits attributable to the presence of a solar thermal option and positive environmental impacts, as well as increases in the level of competition in the energy market, economic stability, and national security. (For a summary of these impacts see Table III-2.)

As mentioned above, the primary benefits of the Solar Thermal Energy Systems Program, which are reflected through the market pricing mechanism, result from using cost competitive STES to supply a portion of utility and industrial energy demand. The energy cost savings attributable to the installation of an STES will include displacement of conventional fuel and generating capacity, as well as potential savings in operations, maintenance, transmission and distribution costs. Furthermore, while an STES is expected to displace a variety of fuel types, the primary impact will be on the most expensive alternative fuel, petroleum. The actual solar thermal penetration and corresponding fuel displacement will depend, of course, on the price of an STES relative to the future price of conventional fuels and other alternative technologies. Due to uncertainties associated with predicting these prices,

Table III-2. EFFECT OF STES PROGRAM ON NATIONAL ECONOMY

COMPETITION	ECONOMIC STABILITY	PRODUCTIVITY	EMPLOYMENT
o Positive Impact from creation of potentially viable substitute energy system. o Flexibility in size and application increases the range of purchasers considering Solar Thermal Energy - Thermal as well as electric application - Central as well as decentralized application - Modular	Positive Impact from increased competition and enhanced independence of the energy sector from cartel pressures.	(Effects are not currently assessible.)	o Net employment effects minimal. o Minimal dislocational effects (production material requirements similar to existing industries).

Reference: Solar Thermal Energy Systems Program Draft Multi-Year Program Plan, April 1981.

it is impossible to obtain a reliable point estimate of either the STES penetration in 1995 or 2000, or the resulting energy cost savings, although ranges for these values can be obtained through a sensitivity analysis using alternative scenarios. The potential impact is significant, however, if oil prices continue to escalate.

Figure III-1 shows a typical "demand curve" of an individual utility for STES; it was derived by using a utility specific value analysis based on Fresno insolation, an EPRI Type E utility (summer peaking), and the NEP III

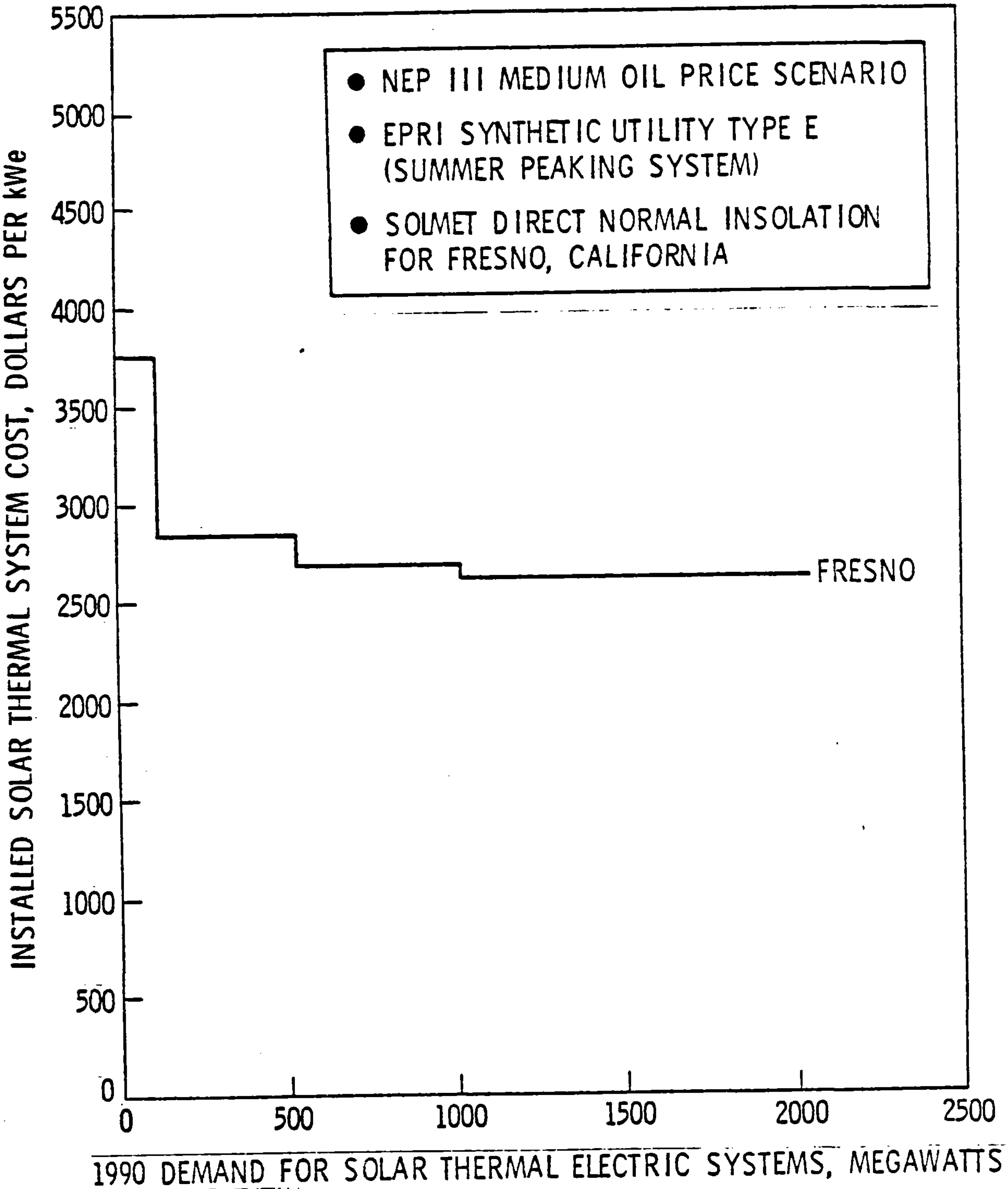

Figure III-1. 1900 Demand for Solar Thermal Electric System by an Investor-Owned Utility medium oil price scenario. Similar demand curves have been generated for two alternative insolation regions (Albuquerque and Fort Worth), which represent the higher and lower sides of the insolation band. As expected, the marginal values of STES are highest for small levels of market penetration, since initial STES installations will displace primarily peak load and relatively expensive fuel sources. These demand curves are somewhat conservative estimates for true values of STES, because they reflect only the fuel credits attributable to STES.

The aggregate national electric utility demand for STES is estimated by summing the individual utility demand curves. Figure III-2 shows these aggregate demand curves for three alternative future energy price scenarios, corresponding to NEP III high, medium and low world oil prices. The 1990 STES cost targets are superimposed on these curves to illustrate the potential level of penetration, and the net energy cost savings associated with each penetration level. These 1990 cost targets assume that the STES program is successfully completed, mass-production techniques are employed in manufacturing STES, and sufficient production capacity exists to satisfy the aggregate national demand.

Figure III-3 shows the aggregate national energy cost savings as a function of the cost of STES for the case of a medium oil price scenario: the lower the STES costs, the greater the energy cost savings attributable to STES, reflecting the larger level of STES penetration. The discounted net present value of solar thermal electric generation systems introduced in 1990, for the NEP III medium oil price scenario, is estimated to range between 15 and 25 billion dollars (in 1981 $). This range reflects the level of uncertainty associated with predicting the outcome of the STES program, since the degree of R&D success will determine future STES costs.

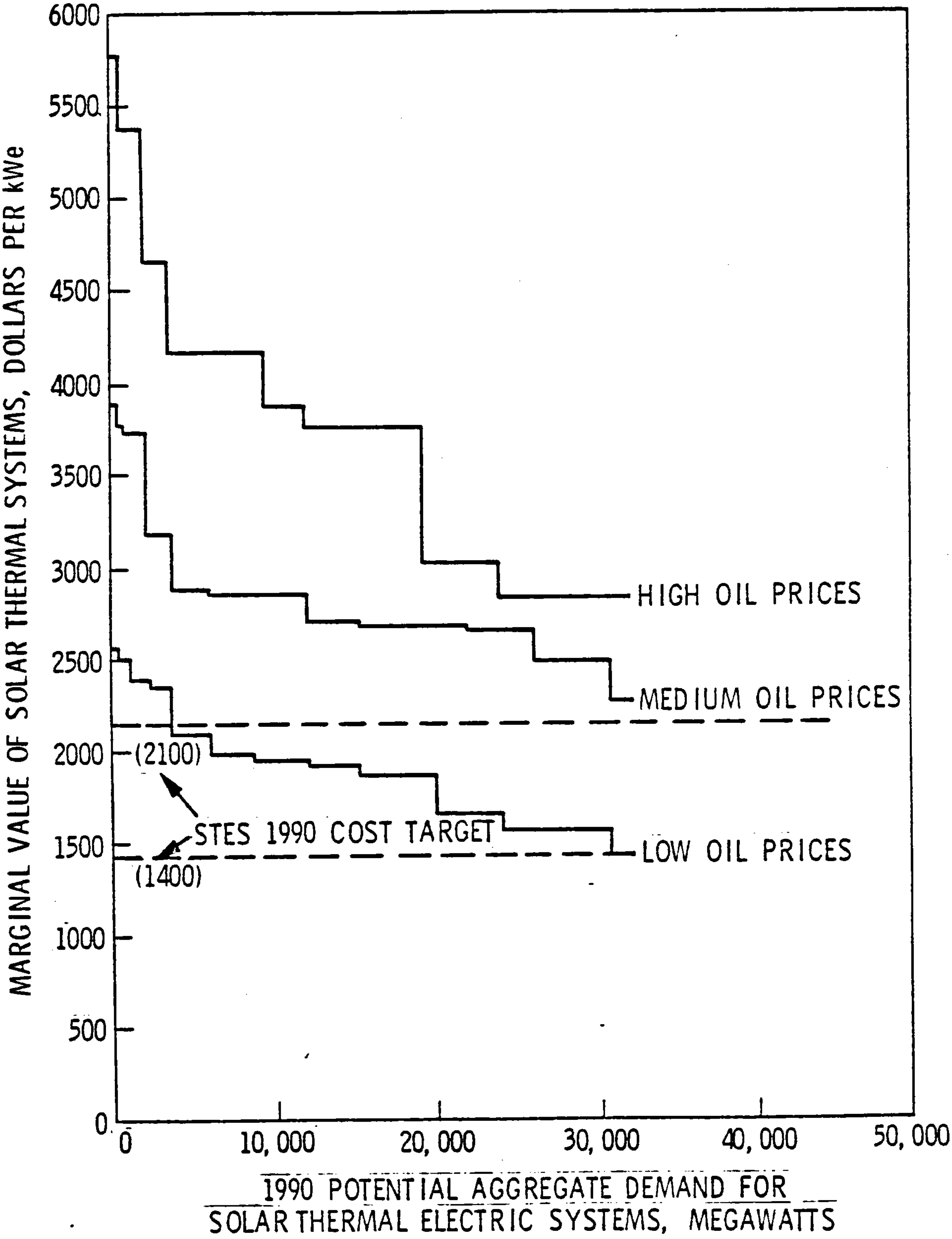

Figure III-2. 1990 Potential Aggregate Demand for Solar Thermal Electric Generation System

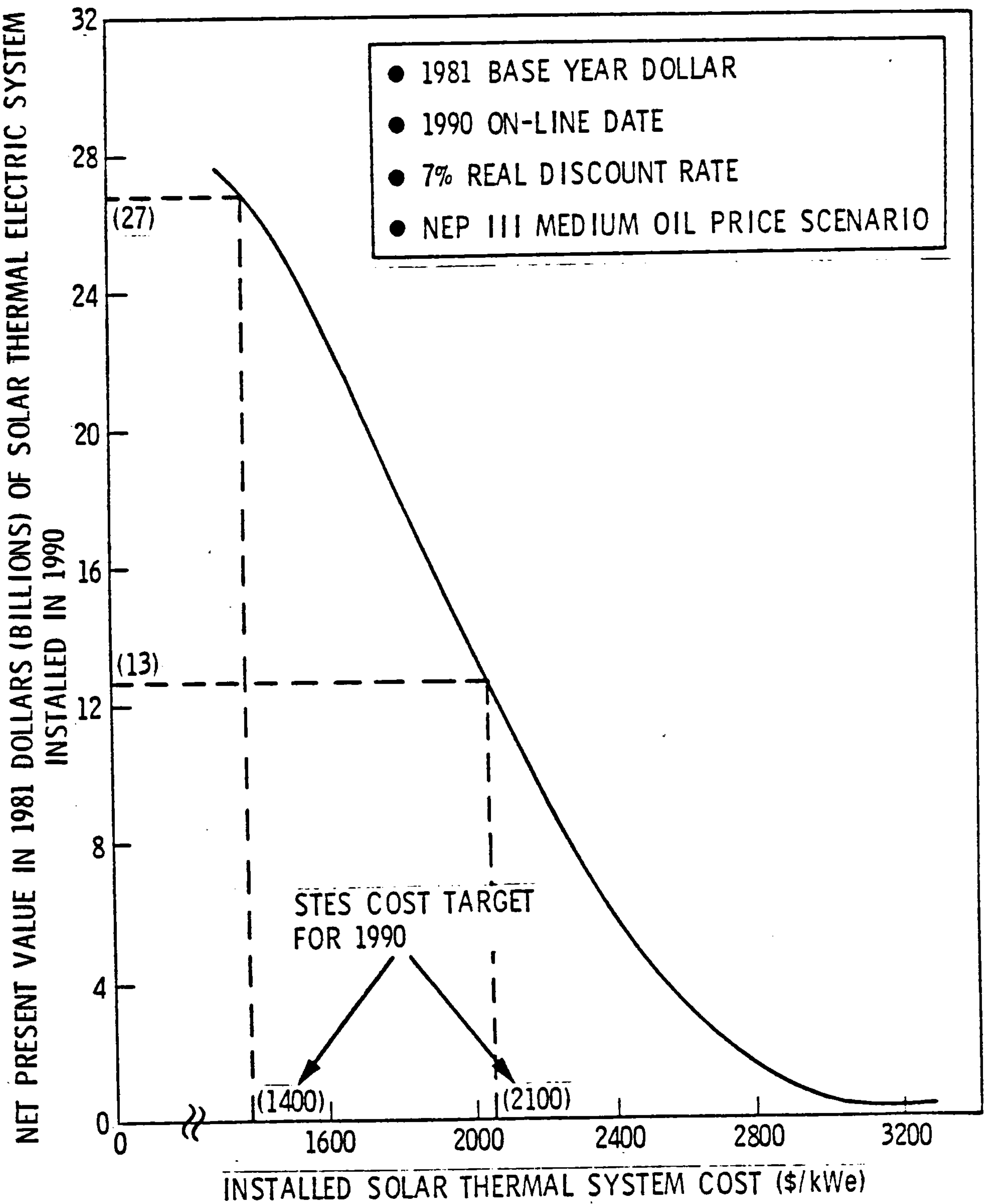

Figure III-3. Net Present Value in 1981 Dollars of Solar Thermal Electric Systems Installed in 1990

For the NEP III high oil price scenario, the potential discounted net present value of the aggregate national energy cost savings is expected to exceed 25 billion dollars. In contrast, for the NEP III low oil price scenario, the net benefit is estimated to range from zero to six billion dollars. Because of the wide variation in expected net benefits, and the sensitivity of these benefits to the unpredictable price-setting policies of the OPEC cartel, private investment sufficient to achieve the required cost reductions in STES related R&D is not anticipated without federal support.1/ Thus, the entire net benefit of successful STES development can be attributed to the federal STES program. If sufficient private R&D occurred without federal intervention, the federal STES program will merely speed the development process. In this case, the benefits attributable to the federal program would be limited to the value of obtaining cost-competitive STES at an earlier date. In particular, if the federal program increased the rate of STES development by 20 years, the present value of the expected net energy cost savings would range between zero and 15 billion dollars, depending on the oil price scenario. If the federal program only increased the rate of development by 10 years, the upper value of this range would decrease to 8.5 billion dollars. It must also be stressed that these estimates consider only the electric utility market. Neither IPH, agricultural applications, nor the impacts of storage have been included yet, though they will be considered in future benefit assessments. To this extent these net benefit estimates represent a lower boundary.

In addition to reductions in the cost of energy, development of cost-competitive solar thermal energy has other potential impacts on market transactions. In the labor market, for example, new jobs will be created by a growing solar thermal industry. However, the production requirements of STES are similar to existing industries. Therefore, the net (or new) employment and related dislocational effects will depend on whether there is excess supply or demand for labor in these industries when the employment demands of the solar thermal industry become significant.

Lower energy costs will also affect the economy as a whole. Experience over the past decade has shown that continually rising real energy costs exert strong inflationary pressures on the domestic price level. Therefore, expansion of a cost competitive solar thermal industry, which delivers energy at a relatively constant cost over the life of the solar thermal system, will reduce the inflationary pressures on the entire U.S. domestic economy.

The second category of impacts, which are not reflected through market transactions, include a variety of considerations. In the first place, any oil displaced due to the installation of cost competitive STES will reduce the dependence of the U.S. on foreign sources of petroleum, which will have a positive impact on the national security of the U.S.2/ The magnitude of this impact again depends on the level of solar thermal penetration, which in turn depends primarily upon the cost of the solar thermal system and the fuel price scenarios. Given any of the future oil price scenarios, the lower the STES cost the higher the level of STES penetration, and hence the greater the oil displacement.

The relationship between future oil prices and the potential oil displacement attributable to STES is more complicated. As petroleum prices increase, utilities are expected to adopt more aggressive conservation measures and to switch to alternative fuel sources in order to reduce their oil consumption. Thus, the potential for oil displacement by STES is smaller under high oil price scenarios, because less oil is being consumed. Therefore, even though an increase in oil prices will increase the level of

STES penetration, the total level of oil displacement attributable to STES may either increase or decrease. In fact, as STES costs fall and the level of penetration increases, the reduced oil displacement potential of STES due to increased utility conservation and fuel switching are expected to dominate the increased oil displacement potential due to increased STES penetration. For high STES penetration levels, smaller total oil displacement by STES is expected if oil prices are high.

Secondly, solar thermal energy will provide a renewable and reliable alternative to oil and natural gas, which can be used by either electric utilities or for industrial applications. Thus, these systems will provide the United States with flexibility in terms of response to both OPEC price increases and supply disruptions. If the price of oil and/or natural gas rises above the price of an STES, or these fuels become unavailable, solar thermal energy will be used to displace oil and/or natural gas-fired systems. Therefore, the price of solar thermal energy will represent a ceiling on what utilities and industry would have to pay for oil or natural gas-fired systems in applicable regions of the U.S. (e.g., Southwest and Southcentral). Obviously, the lower the cost of solar thermal energy, the greater this benefit.

An added benefit results from the fact that solar thermal energy can be supplied by modular systems ranging in size from tens of kilowatts to hundreds of megawatts. An STES can also be used to produce transportable fuels and chemical feedstocks. Thus, STES can meet the requirements of all energy markets, and can be installed in virtually any industry or electric utility to satisfy their particular energy demands. This flexibility will increase the level of competition characterizing the U.S. energy market.

Additionally, as oil prices rise and domestic demands increase, foreign countries will increase their search for indigenous energy sources. As a result, the potential export market for STES can be expected to grow.3/,4/ Thus, as solar thermal energy completes the R&D process, a substantial export market for STES can be expected to exist. This will both increase the size of the domestic STES manufacturing industry, this will also contribute to the U.S. balance of payments position.

Finally, since solar thermal energy systems are highly modular, it is possible to operate solar thermal generating facilities while adding additional capacity.5/,6/ This diminishes the level of capital investment for STES facilities (relative to other renewable energy technologies), since operating revenues can partially offset cash flow requirements during construction.

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Environmental Impact (Question 10)

When analyzed as a replacement for conventional fossil fuel-fired systems, STES improve environmental quality in the short term by reducing air pollutants (SO_x and NO_x); in the long term STES improve environmental quality by mitigating concern for CO_2 build-up in the atmosphere and by not requiring mining, drilling or transport of fuel.1/ Preliminary studies indicate that a 1-quad total energy displacement by STES in the electric utility sector, a level of potential penetration which is consistent with the 1990 cost goals for STES, will result in the following levels of effluent reductions:

EFFLUENT	REDUCTION tons/year
CO_2	$75\text{-}80 \times 10^6$
SO_x	$10\text{-}13 \times 10^3$
NO_x	$45\text{-}50 \times 10^3$

Of course, the potential level of STES penetration and corresponding effluent reductions will depend on future fuel costs, STES costs, and general economic conditions. Furthermore, actual STES penetration will probably be less than the potential level in 1990 due to expected bottlenecks in establishing the required STES industry infrastructure. Since future values of these factors cannot be accurately estimated, ranges of pollution reductions rather than point estimates have been given.

There are a number of potential environmental, health, and safety impacts associated with the production and utilization of STES. While it is important to consider these impacts, in most cases they are negligible, easily mitigated, or specific to the unique characteristics of a particular site. For example, occupational health and safety hazards do not differ substantially from those experienced in common industrial practice.2/ Public health issues appear to be limited to concern about accidental or mismanaged off-site releases of thermal transfer and storage fluids, or solid waste from solar ponds1/ and the possible nuisance of glare from misdirected solar radiation. These health and safety concerns can be mitigated by reasonable operation and maintenance procedures.1/,3/,4 Potential ecological and micrometeorological impacts are associated with land requirements of large-scale STES in undeveloped areas, but tend to be site-specific and keyed to the fragility of desert eco-systems.1/,3/,4/,5/ Regional and/or local climatic changes are not anticipated. Since STES are material intensive, secondary impacts are associated with processing, manufacture and transport of components and subsystems. These are judged minor.1/

An inescapable requirement of STES is the need for large areas to collect sunlight. Solar energy, although free, is also diffuse (a 100-MWe STES is estimated to require 2-3 km^2 of land in areas of high insolation). Since solar collectors and land are the highest cost elements for an STES, it is assumed that economic considerations will dictate that large facilities be located in the southwest where land is relatively inexpensive and solar insolation is two to three times greater than is other regions of the country.6/

Available water is a common constraint to any development in the arid southwest. STES water requirements depend on both the type of system and the type of energy produced. STES water requirements can be much less than, similar to, or slightly greater than water requirements for comparable fossil fuel systems. The potential for water quality degradation from fluid and/or solid waste disposal can be mitigated by reasonable management procedures. Small STES will require proportionately less land, and in the case of air-cooled dish electric systems, almost no water. These small systems, however, are likely to be located near areas already developed for industry and agriculture. The primary siting constraint will be institutional barriers associated with land use, zoning, and utility interface. While STES are judged land-intensive, they are no more so than coal-fired systems if coal mining and transportation over the 30-year life of a power plant are included in the comparison.1/

Uncertainties in these projections arise from lack of operating and maintenance experience with commercial-scale STES; the diversity of STES, that is, the variety of hardware configurations which can be scaled from a few kW thermal to several hundred MW electric; the variety of applications; and the variety of potential ecological settings. Nevertheless, none of the environmental concerns or uncertainties identified to date pose any obstacle to accelerated STES development. Several environmental factors will constrain site selection.

Environmental, Health and Safety Impact Matrix

ENVIRONMENT	HEALTH	SAFETY	OTHER
Positive impact through low atmospheric emissions; no fuel mining or transport. Negative impact from land requirements and ecological effects of large systems.	Positive impact through improved air quality. Negative impact from disposal of fluids and wastes.	Positive impact from no fuel mining or transport. Negative impact from reflection and misdirected solar radiation; management of fluids.	Low negative impact - material intensive.

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IV. PROJECTED PROGRAM REQUIREMENTS (Questions 5, 12 and 13)

Budget Justification (Question 5)

The mission of the program is to conduct solar thermal R&D that will result in a high pay-off in the longer term. The mission retreats from specific demonstration goals originally established in PL 93-473 for solar thermal technology, but not from research goals. At this point all of the research goals in PL 93-473 are worth pursuing and are deemed to be achievable.

The program plan for pursuing the goals includes energy cost targets and consideration for the appropriate role of the private sector. In this plan, programmatic objectives specifically linked to the work prescribed by PL 93-473 have been established (see Table IV-1, column 1). The dates by which the objectives can be accomplished and the work which needs to be done have been identified (see Table IV-1, column 3). The 1983 to 1988 STES Program emphasizes: (1) research and development on material components and subsystems for producing electricity and heat, as well as fuel and chemicals; (2) consolidating the state-of-the-art knowledge gained from pilot-scale systems in user environments and completed projects; and (3) obtaining

Table IV-1. NEEDED ACCOMPLISHMENTS TO ACHIEVE PROGRAM OBJECTIVES

PROGRAMMATIC OBJECTIVE	ALTERNATIVE METHODS***	ANTICIPATED NEEDS	BUDGET JUSTIFICATION AND SERVICE PROVIDED IN FY83
			FY 82 = $44M; FY 83 = $46.0; 5 out-years = $306M
FOR UTILITY-SCALE ELECTRIC CENTRAL RECEIVER (CR) SYSTEMS:			
o Proof of technical feasibility of heliostats, receivers and storage subsystems with potential to meet cost targets.	By 1985	o 2-year or more testing of prototype subsystems; o Material compatibilities research; and o Confirmed subsystem cost projections.	o Central receiver technology development. o Materials research, applied research and advanced thermal storage.
o Proof of feasibility of the CR concept based on Barstow Pilot Plant and foreign experiments.	By 1984-87	o 2- to 5-year testing; and o 100-MW system cost projection linked to experience at 10-MW and 1-MW.	o Systems test and evaluation of Barstow 10-MW electric pilot plant.
FOR SALT-GRADIENT SOLAR POND ELECTRIC POWER PLANTS:			
o Proof of large-scale solar ponds operated efficiently, reliably and economically.	By 1988	o 2-year operation of 5-MW (50 acre) power system at Salton Sea and 4-year operation at Dead Sea; o Cost estimates for full-scale 20- to 50-MW modules for Salton Sea Power Plant; and o Regional tests of 500-kW to 1-MW ponds.	o Development of components and subsystems for solar ponds. o Initiate Salton Sea power plant construction
FOR LARGE-SCALE DIRECT HEATING SYSTEMS AND THOSE USING THERMAL BY-PRODUCTS:			
o Proof of feasibility of systems using parabolic dish technology at low temperature.	By 1983	o 1-year testing of solar total energy system at Shenandoah and PKI collector design at Capitol Concrete in Topeka, Kansas.	o Systems test and evaluation of Shenandoah. o Develop low-temperature parabolic dishes.*
o Technical readiness of IPH compatible receivers, storage for use with central receiver	By 1984	o Tests of 5-MW class subsystems at CRTF.	o Develop receivers for IPH.
FOR SOLAR FUELS AND CHEMICALS:			
o Proof of technical feasibility.	By 1986	o Test of fuel or chemical production at CRTF.	o Systems requirements for Sunfuels.
FOR SMALL-COMMUNITY ELECTRIC HYBRID FUEL/SOLAR POWER SYSTEMS:			
o Establish feasibility of 20-kW modules at 20% solar-to-electric efficiency.	By 1984	o Extended testing of ORC, Brayton and Stirling engines with high-temperature parabolic dishes.	o Develop parabolic dish technology, including organic Rankine and Stirling engine test.**
o Establish feasibility of 28-kW modules at 30% solar-to-electric efficiency.	By 1988	o Success in the Automotive Program with either Brayton or Stirling engine improvement programs; and o Tests of adapted versions of advanced automotive engine with parabolic dish.	o Develop solarized version of Brayton engine with ceramic components.*

*Included only at the "incremental" level.
**Deleted at the "decremental" level.
***Massive Federal Purchase and Tax Credits (see text of Program Objectives).

experience at the 5-MWe scale to verify the design and operating principles applicable to larger scale (20-50 MWe) solar ponds. This emphasis is supported by over 80% of the respondents in a recent survey of STES suppliers; however, these same suppliers feel that additional Federal support is needed for full-scale system tests and user applications.

The Program foresees two private sector milestones: proving that systems are ready for marketing during the 1988 to 1994 interval; and having in place a hardware production capacity of 200 MW year, the amount needed to satisfy the projected market demand four years later (1992-1998). At least one privately funded utility-supplier group is moving forward with plans to get the one-year of operating experience on a 100-MWe central receiver plant needed to meet the first private sector milestone.

In spite of significant progress in improving the performance characteristics of solar thermal systems and in fostering an industrial base, continuing Federal support for research and development is needed. The technical and, to a greater extent, the economic uncertainties associated with STES preclude a sufficiently large R&D investment by potential suppliers or by the utilities. The risks are too high in relationship to the cost of introducing solar thermal technology on a commercial scale. The Solar Energy Industries Association has said that "...significant Federal involvement is needed for the technical validation of solar thermal technology and the fulfillment of its potential in the market place. The supply industry cannot afford both the investment in trained personnel and capital equipment, and the funding for this long-term R&D." In a recent survey of industry,* 61% of the responding

* In the summer of 1981, JPL surveyed 67 purveyors of solar thermal energy systems, 54 of whom are involved in the STES Program. The results are contained in the remainder of this report.

suppliers said that they will reduce their R&D commitment to solar thermal technology if the Federal program is discontinued; 39% would discontinue STES development altogether. If Federal spending is reduced, less sharable technical information is generated. This increases the cost and risk to any single firm of introducing STES products, but the chance for any one company to profit stays the same.

The best theoretical basis for justifying federal support for STES R&D, and for alternative energy technology R&D in general, lies in analysis of the existing imperfections in the international energy market. Distortions or imperfections introduced into the U.S. economy by the presence of the OPEC cartel are numerous, but the most important with respect to energy alternatives is that petroleum and petroleum product prices are not market-determined. In fact, the general perception exists that OPEC can and will undercut the price of developing technologies, thereby rendering them uneconomical relative to petroleum. This imperfection alone inhibits socially optimal allocation of private U.S. resources to the development of STES, and energy alternatives in general, and hence Federal involvement is required to achieve a socially optimal rate of development.

The recent contractors' survey included questions dealing with specifics of continued Federal R&D support. When asked how long Federal R&D funding should continue, answers ranged from 3 to 20 years with a median of 9. When asked to identify areas most needing continuing support, 93% identified "testing of prototypes at the system level," and 84% identified "development of components and subsystems." In third, fourth and fifth place were "full-scale system tests in user applications," "development of conceptional designs" and "basic research on fundamental phenomena," respectively.

Implications of discontinuing the Program are discussed in more detail in the following Section (Discontinuation Requirements), but when asked how long completion of development of STES would be delayed if the STES Program was discontinued, the median survey reply was six years and the maximum 20 years.

Finally, the survey indicated that the firms contacted favored STES Program budgets at or somewhat above the FY 1981 level: The most frequent answer, when asked to identify the appropriate level of Federal spending, was $200 million, with an average of $167 million and a median of $141 million.

Expected Results and Alternative Budgets (Questions 12 & 13)

The expected results of the STES Program will depend on the level of future Federal funding. Three levels for FY 83 funding are postulated: the "request level," and "incremental" and "decremental" levels at ±10% of the "request level." For all of the levels the nature of the research and development which can be conducted by the program in FY 83 is indicated in Table IV-1, under "services provided in FY 83."

The impact of the STES R&D Program on industry's penetration of various energy markets with solar thermal systems can never be fully quantified. However, with the proper level of funding, the STES technological concepts can be developed to meet the required cost targets of one or more of these markets. Therefore, the size of the markets which are economically addressable by the technologies being developed by the Program gives a simple indication of payoff potential.

At the "decremental" funding level, the program sponsors development of central receiver technology for electrical, IPH, and fuels and chemical applications, and solar ponds for electric applications. Since the fuels and chemicals work is pointed at applications beyond the year 2000, the economics are too uncertain to even suggest the size of the economically addressable markets at this time. But in the case of the electric and IPH applications, the Program can be expected to provide the technological basis for industry to address 2.2 quads of energy markets with economically competitive central receiver systems. The nature and location of the markets is described in Table IV-2. The program will also study the economic potential of salt-gradient solar ponds. In 1981, an estimate of the technical potential for salt-gradient solar ponds was set at 6 quads, based solely on an assessment of the availability of the essential constituents (i.e., land, salt, and water) for salt-gradient solar ponds. The degree to which the 6-quad technical potential can be addressed with economically competitive solar pond electric power systems is still unknown. For process heating, technical potential is limited to less than 1 quad by the requirement for a coincident use for the 37.7°C (100°F) to 93°C (200°F) energy produced by a solar pond.

At the "request" level, expanded support for university research could accelerate building the pool of talent needed to ensure the ultimate success of central receiver technology. At this level, the technology base for 0.1-MWe to 10-MWe parabolic dish systems could be advanced. Autonomous power modules at the 20 kW scale capable of solar-to-electric conversion at 20% efficiency could be tested. Continued support at this level could put industry in a position to address the remote (e.g., island power, certain irrigation, and stripper well applications), military, and small community market sectors in the late 1990s.

At the "incremental" level the technology for 30% solar-to-electric parabolic dish systems could be developed. This program would put industry in a position to introduce products into the remote, military, and small

TABLE IV-2. Size of the Initial STES Markets in Quads/Year

Period	Application	Location	Total Size (Quads/Year)
ELECTRIC POWER GENERATION			
1985-1990	Oil and gas peaking units	11 states*	0.50 (± 30%)
1990-2000	Oil and gas peaking units	All states	1.2 (±50%)
	Oil and gas intermediate-load units	4 states**	
LARGE SCALE-DIRECT HEATING			
1985-1990	Enhanced Oil Recovery	California	0.15 (-50%+10%)
1990-2000	Industrial Process Heat	11 plus a few in the midwest	1.0 (±80%)

* AZ, HW, CA, NV, NM, CO, UT, KS, OK, TX, AND AR
**CA, NM, AZ, AND TX

communities market on the time schedule of the current program's objectives. In aggregate, these markets represent an economically addressable potential of about 0.5 quads. In addition, the Program would support development of parabolic dishes applicable to process heating in the 200°F to 750°F temperature range.

For STES R&D budgets in the range of $40 to $50 million per year, the program benefits are proportional to the budget. The point of diminishing benefits relative to increased budget levels is above this range.

While the completion of the Program's R&D objectives is a necessary condition for the introduction of commercially viable systems by industry, it is not sufficient. Industry must put substantial amounts of private capital at risk to develop production, marketing and distribution capacity when and if technological uncertainties are eliminated. While many factors will influence decisions to put necessary capital at risk, it is expected that if technological uncertainties are resolved (with the program's help) and if conventional energy costs rise as anticipated, sufficient capital will be forthcoming.

It is appropriate, however, to test this assumption. If, for instance, there is no evidence of private investment to date, or if order-of-magnitude estimates of capital requirements are not many times smaller than estimates of potential revenues, then continued federal expenditures for R&D are difficult to justify.

When respondents to the contractors' survey were asked to estimate how much of their own (including borrowed) funds had been invested to date in STES, 79% indicated that they had invested private funds in STES. The total dollar amount was approximately $64 million. The total cumulative value of DOE contracts received to date was reported to total approximately $281 million; hence to date industry has provided about $1 for every $4.4 provided by DOE.

Survey respondents were also asked to estimate how much capital would be needed to bring their STES products or services to the point of commercial viability without government subsidy. Responses are shown in Figure IV-1. The total of all answers is approximately $4.3 billionn including one firm's estimate of $3 billion.*

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* The extremely wide range of answers presumably reflects the widely differing aspirations of the various firms. No clear-cut correlations with questions relating to firms' future plans have been identified as yet, however.

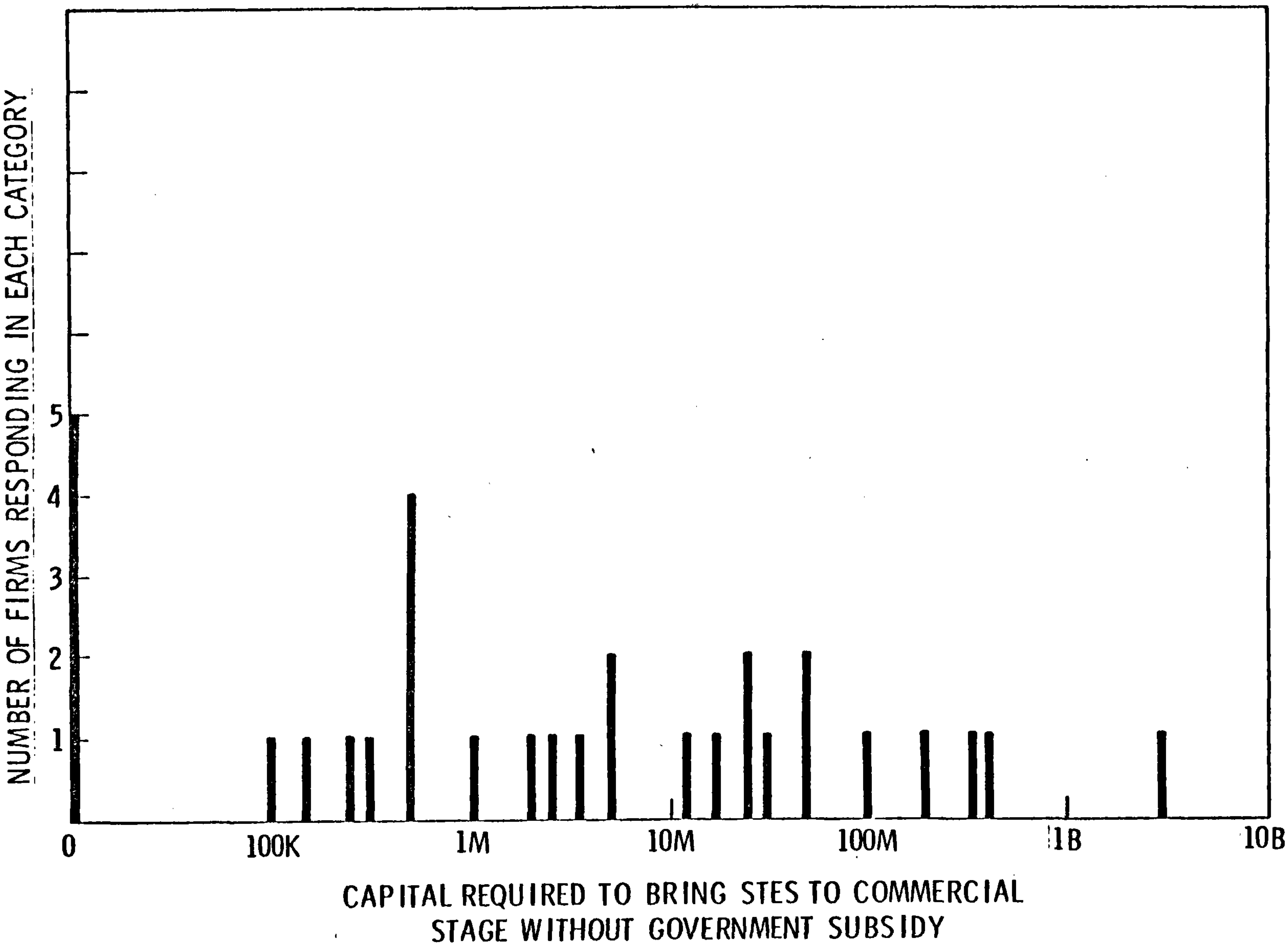

Figure IV-1. Survey Responses - Capital Required to Bring STES Products or Services to the Point of Commercial Viability without Government Subsidy

A very rough measure of the possibility that such capital will be forthcoming may be had by comparing this total to the gross revenues associated with potential sales (estimated separately by the STES Program).

Table IV-1 above indicated an addressable market totaling 2.2 quads/year in the 1990s for central receivers in electric power and IPH applications. The total revenues associated with sales at that level would be on the order of at least $100 billion.

No conclusions can be drawn with respect to the likely behavior of an individual firm or firms from these two order-of-magnitude estimates. Cash flow, timing, risk aversion, profitability and many other factors will affect such decisions. Potential revenues seem sufficiently greater than total industry capital requirements, however, so as not to preclude the possibility of positive investment decisions in the future.

V. DISCONTINUATION REQUIREMENTS (Question 14)

If a decision is made to terminate the Program in mid-FY 82, then to minimize both disruptive effects and future government costs, the administration should request an FY 83 appropriation of $50M to be available until expended. Approximately 60% of this sum would be used to meet existing obligations to U.S. companies who have shared in the cost of field experiments. These obligations include: (1) operation and evaluation of the 10-MW power plant at Barstow, the 500-kW total energy experiment at Shenandoah, the small solar power systems at Almeria, Spain, and (2) completion of miscellaneous obligations to IPH experiments. The remaining money would be used to terminate all R&D contracts in effect on the date of the decision and to close down research facilities at national laboratories and universities.

A survey of DOE STES Program contractors was undertaken during the summer of 1981 to collect information on status, plans and opinions regarding STES technology. Table V-1 displays some preliminary results that are pertinent to the question of disruptions caused by discontinuation of the STES Program.

Clearly, discontinuing the DOE STES Program would be disruptive to potential suppliers of STES technology. Although 57% of the firms contacted would continue STES work, only one company indicated that it was prepared to increase its own funding to take up slack caused by the disappearance of DOE support. Of the firms that were willing to estimate the delay in STES commercial viability associated with disappearance of the Program, the median answer was six years.

Cross correlations of survey results indicate that if the program was discontinued, the relative number of companies working on each major STES technology (central receiver, trough, etc.) would remain roughly the same. That is, the present estimate of companies that would discontinue STES work is about 40-50% in each technology. Cross correlations also reveal that the group of firms least likely to discontinue STES work if the DOE Program is discontinued are those who indicated that they are currently marketing systems and/or manufacturing subsystems or components. Only 23% of the former and 30% of the latter indicated that they would discontinue. It should be noted that the approximate non-DOE sales volume reported by all firms was $38 million; this covers 1980 sales to other than DOE projects, but probably includes some sales to DOE contractors.

Table V-1. DISTUPTIONS CAUSED BY PROGRAM DISCONTINUANCE PRELIMINARY RESULTS - STES CONTRACTORS SURVEY

A. Cumulative dollar ammount of DOE contracts for solar thermal: $280 million (43 companies)

B. Total dollar amount of own private funding in solar thermal: $64 million (40 companies)

C. Is your firm planning to market solar thermal products or services in the future? 83% said yes.

D. If DOE funding were discontinued in your solar thermal technology development area in 1982, would you increase/maintain same level/ decrease your own funding?

Increase:	2%
Maintain same level:	37%
Decrease:	61%

E. If DOE funding were discontinued next year, would your firm continue current solar thermal technology/change to another S.T. technology/ discontinue STES work altogether?

Continue same technology:	55%
Change to another:	2%
Discontinue altogether	43%

F. How many additional years would it take for you to complete development (to the point of commercial viability) without DOE support 6 years (median answer of 22 firms answering).

G. Without DOE support would you try to be first to enter solar thermal market/wait for competitors to open up initial markets/wait until market was fully developed before entering?

Enter first:	52%
Wait for competitors:	26%
Wait for developed market:	22%

Table V-2 summarizes the disruptions that might be caused by discontinuation of the DOE STES Program. There do not appear to be any practical ameliorative steps to be taken to maintain existing program goals in the event that the program is discontinued.*

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* Investment tax credits for STES R&D, sufficient to stimulate private investment of levels approaching current program funding, is not considered practical (see Section II under "Alternative Methods" for further discussion).

Table V-2. Summary of Disruptions

- Loss of approximately 40% of firms currently working on STES.

- Greater than four-fold decrease in total U.S. rate of R&D expenditure for STES.

- Delay of several years in availability of commercially viable STES.