**Institutional Applications
of Solar Total-Energy Systems
Draft Final Report – Volume 1**

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From March 1977 to May 1978, Resource Planning Associates, Inc., and InterTechnology/Solar Corporation conducted a study of the institutional applications of solar total-energy systems for the Department of Energy and Sandia Laboratories. In this study, we developed conceptual system designs and analyzed the institutional-sector market for those systems.

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Introduction

The projected long-term decline in the world's fossil-fuel energy resources is of major concern to policymakers both in the United States and abroad. To address this concern, the Department of Energy (DOE) has undertaken a dual-faceted effort aimed at (1) reducing the demand for energy, primarily through the development and implementation of conservation measures, and (2) increasing the supply of energy. A major thrust of the latter aspect of DOE's effort is the development of renewable energy sources such as the sun, the wind, and biomass.

In many respects, the sun is the ideal energy source: it is abundant, widely available, nonpolluting, and "free." Despite these attractive characteristics, capturing and using the sun's energy for practical purposes (for example, space heating and cooling, electrical generation) has proven to be a complex technological, economic, and institutional challenge. To date, the conversion of solar energy into other forms of energy has required capital investments that render it uneconomic for most potential end-users. Recently, however, dramatic rises in the price of fossil fuels, concern over their dwindling supply, environmental considerations, and the political uncertainties of dependence on foreign sources have combined to force a re-examination of the solar option and its role in meeting our long-term energy needs.

Working with Sandia Laboratories, DOE has defined a major research, development, and demonstration program to explore the various aspects of solar total-energy (STE) systems, which convert solar energy directly into both electrical and thermal energy. The basic component of an STE system is a concentrating collector; the energy collected heats a fluid, which in turn operates a turbine to generate electricity. The waste heat released in the generation process is then used to provide space heating, cooling, and hot water. An STE system does not necessarily provide 100 percent of a

building's total energy requirements, but may rely on the utility grid or conventional fuels as a supplement or for backup.

To investigate the potential market for STE systems and to identify barriers to their widespread adoption, Sandia Laboratories has sponsored a series of studies to explore applications in the industrial, commercial, institutional, and residential market sectors. Resource Planning Associates, Inc. (RPA), with the assistance of InterTechnology/Solar Corporation (ITC), has conducted the applications analysis in the institutional sector.

At the onset of our study, we realized that no consistent definition of the "institutional" sector is widely accepted. In energy-related analyses, the sector is most often treated as a subset of the commercial sector, which in turn is defined as anything other than industrial, residential, or transportation. For the purposes of this study, we defined the key characteristics of the institutional sector that not only distinguish it from the commercial sector, but that may affect the attractiveness of STE systems.

The general characteristics of institutional organizations that we considered important in evaluating the economic viability of STE systems include their tax-exempt status, relatively low capital costs, and guaranteed operating costs. In addition, they may be publicly or quasi-publicly owned, stress noneconomic or public-service goals, and be closely regulated. To identify the types of organizations that exhibit these characteristics, we performed a preliminary market segmentation. Based on a review of existing classification systems, we first identified the market segments that could be defined as "institutional" according to the key characteristics we defined. We eliminated those segments that are obviously unsuitable for STE systems because of their irregular load patterns (e.g., weekend use only -- churches, stadiums). As a result of this analysis, we decided to focus our study on eight subsectors of the institutional market:

- Colleges and universities
- Military installations

- Elementary and high schools
- Hospitals
- Public-administration buildings
- Post offices
- Airports
- Prisons.

Having defined these subsectors, we structured our analysis to meet four major objectives:

1. Develop conceptual designs for thermal and photovoltaic STE systems, and optimize their performances based on projections of energy prices and system-component costs
2. Analyze and characterize the institutional market in which these systems will be introduced
3. Estimate potential system sales and resultant energy savings
4. Formulate guidelines for the planned federal demonstration program to encourage market development.

Working within certain technical and economic parameters, we have designed thermal and photovoltaic STE systems that will be cost-effective for large institutional-sector buildings (specifically, colleges and military installations) located in the sunbelt area of the southwest, particularly in California. These systems will operate in a "peak-shaving" mode, supplemented by a conventional electric-utility system.

Several characteristics of the institutional market in which the STE systems will be introduced are likely to slow their rate of penetration. The major limitations stem from (1) the criteria (both financial and nonfinancial) that decision-makers in the institutional sector will apply in evaluating an STE system, and (2) the attitudes of participants external to the institutional sector (e.g., electric utilities, component manufacturers).

To estimate system sales and resultant energy savings, we developed a market model that integrates many of the data we compiled in the course of the conceptual-design and market-analysis aspects of our work. The outputs of the model indicate that the national potential market for STE systems is relatively small; sales of thermal STE systems will approach 0.3 million square feet of collector area per year by 2015, resulting in energy savings of 3.5 trillion Btu per year; and sales of photovoltaic STE systems will approach 7 million square feet of collector area per year by 2015, resulting in energy savings of 45 trillion Btu per year.

Sandia Laboratories is planning a program to demonstrate the technical and economic viability of STE systems in all market sectors. As part of our applications analysis, we have developed guidelines for selecting sites and conducting the demonstration program that are aimed at encouraging market development in the institutional sector.

Our findings are discussed in detail in the following chapters, and their analytical bases are presented in Volume 2, Appendixes. First, in Chapter 1, we present conceptual designs for thermal and photovoltaic STE systems optimized to have the lowest possible life-cycle costs. In Chapter 2, we present our analysis of the market for STE systems, synthesizing the results of interviews we conducted with institutional-sector decision-makers and representatives of utilities, component manufacturers, architect/engineers, contractors, and labor unions. The operation and outputs of the market model we developed to estimate potential STE system sales and resultant energy savings are presented in Chapter 3. Finally, in Chapter 4, we outline our preliminary guidelines for selecting sites and conducting the planned federal demonstration program.

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DEVELOPING CONCEPTUAL SYSTEM DESIGNS

A major objective of our study was to develop conceptual system designs that could be optimized to meet the energy requirements of institutional-sector buildings. Working within certain technical and economic parameters, we designed generic STE systems based on both thermal and photovoltaic technologies. We then selected and optimized the major system components to match the specific electrical and thermal energy requirements of each building type and size in each region of the United States, under alternative modes of utility interface. Our final step was to evaluate the cost-effectiveness of the STE systems by comparing their life-cycle costs with those of conventional systems.

Based on our simulations of system performance and estimates of cost-effectiveness, we have determined the optimal STE system design to be a hybrid solar/fossil system that draws on the conventional utility to meet energy requirements during off-peak hours (8 p.m.- 8 a.m. for most utilities) and presents a flat profile -- in effect, "shaving" the building's peaks -- during peak hours (usually 8 a.m.-8 p.m). The optimal thermal system we designed uses a small central receiver sized to provide 25-50 percent of a building's peak electrical requirements and 100 percent of its thermal requirements. The optimal photovoltaic system is a conventional diesel total-energy system assisted by a photovoltaic array. The diesel provides 50 percent of a building's peak electrical requirements and 100 percent of its thermal requirements; the photovoltaic array provides the remaining 50 percent of peak electrical requirements.

Large institutional-sector facilities such as colleges and military installations in the southwestern United States offer the highest potential for cost-effective

performance of the optimized STE systems. Our analyses indicate that the systems will generally not be cost-effective in other regions of the country.

Recognizing that much of the economic advantage of STE systems stems from their "total energy" rather than their "solar energy" aspect, we also evaluated the performance of conventional total-energy systems operating in a similar peak-shaving, or baseload, mode. We determined that these systems will be competitive with conventional-utility systems in the Boston, Madison, and Los Angeles areas. Only in the Los Angeles area will a "photovoltaic assist" to a conventional total-energy system prove economic.

In the following sections, we first discuss the technical and economic parameters that provided the framework for our system-design efforts. We then present the conceptual designs we developed for thermal and photovoltaic STE systems. For each system design, we discuss the methodologies followed and the engineering trade-offs made in developing and optimizing the systems to meet the specific requirements of institutional-sector buildings. We then present the performance and cost estimates we developed for each optimized system design.

ESTABLISHING DESIGN PARAMETERS

As a basis for developing STE system designs, we first established technical design parameters that account for regional climatic conditions, building energy-load profiles, and alternative modes of utility interface. We then investigated and established parameters for two economic variables: the costs associated with competing energy systems, and the discount rates applied by the various subsectors of the institutional market. These technical and economic parameters provided a framework that was useful first in developing conceptual system designs, and then in comparing the performances and costs of the STE systems with those of conventional systems.

Technical Parameters

The paramount consideration in designing an STE system is that it meet a building's energy requirements. Recognizing that the performance of STE systems is highly dependent on the region of the country in which the systems operate, we developed a regional-climate model. To simulate electrical and thermal energy requirements for institutional-sector buildings in each region, we then developed a building-load requirements model. Our final step in establishing technical parameters was to investigate several modes of utility interface to evaluate their implications for, and effects on, system configuration and operation.

Developing a Regional-Climate Model

As the basis for developing a regional-climate model, we adopted the regionalization scheme defined by General Electric Company (GE) in its Phase-0 study of Solar Heating and Cooling of Buildings.¹ In that study, GE assigned each of the 171 Bureau of Economic Analysis regions in the continental United States to one of 12 base cities that has the most similar climatic (e.g., heating degree days, insolation) characteristics (see Exhibits 1.a and 1.b). We used long-term statistical measurements of average regional temperatures and insolation to generate a "typical" year, on an hour-by-hour basis, for each of the solar regions (see Exhibit 1.c for annual insolation data and Appendix A for a discussion of the methodology and equations we used). Similar buildings within a region can be expected to have similar energy requirements and therefore similar STE system performances.

Developing a Building-Load Requirements Model

Once hourly temperatures and insolation were determined, we developed building energy-load profiles

1. Solar Heating and Cooling of Buildings, Phase 0 - Feasibility and Planning Study - Final Report,
General Electric Company, NSF-RA-U-74-021A.

Exhibit 1.a
Solar Climatic Regions

SOURCE: General Electric Co.

Exhibit 1.b**Regional Climatic Characteristics**

Base City	Insolation (Btu/ft²/day)	Heating Degree Days	Cooling Degree Days
Boston	1,361	5,634	661
Washington, D.C.	1,605	4,211	1,425
Madison	1,617	7,863	460
Los Angeles	2,192	2,819	1,063
Charleston	1,825	2,033	2,078
Bismarck	2,087	8,851	487
Nashville	1,665	3,394	1,367
Fort Worth	2,125	2,621	2,250
Omaha	1,851	6,218	1,148
Seattle	1,419	5,145	200
Phoenix	2,750	2,310	2,888
Miami	1,976	214	4,038

SOURCE: InterTechnology/Solar Corporation.

Exhibit 1.c
Annual Insolation Data

Region	Beam Insolation* (Btu/ft ² /yr)	Total Insolation** (Btu/ft ² /yr)
Boston	496,900	473,300
Washington, D.C.	586,000	534,100
Madison	590,200	528,600
Los Angeles	799,900	674,100
Charleston	666,000	606,000
Bismarck	759,500	620,500
Nashville	607,900	550,300
Fort Worth	775,700	665,600
Omaha	675,600	589,600
Seattle	517,900	453,100
Phoenix	1,003,600	791,600
Miami	721,200	656,500

SOURCE: InterTechnology/Solar Corporation.

* On a two-axis tracking collector

** On a south-facing flat-plate collector tilted at the latitude angle.

for use in designing STE systems and optimizing their performances (see Appendix B). Institutional-building load profiles can be divided into heating, ventilation, and air-conditioning (HVAC) loads, non-HVAC electrical loads (primarily lighting and machinery), and hot-water requirements. HVAC and hot-water requirements are highly dependent on regional and seasonal climatic differences; non-HVAC electrical profiles are essentially independent of region and season. All, however, are dependent on building type.

To determine the distribution of building types in the institutional sector, we first divided the types into four representative categories: colleges, hospitals, offices, and 10-month schools. We then distributed these types according to size (see Exhibit 1.d).

As an example, we ran an energy-demand profile for a large (1.21-million-square-foot) college located in Los Angeles (see Exhibit 1.e). We then determined the monthly thermal requirements for a college of that size located in various regions of the country (see Exhibit 1.f).

Comparison of the electrical and thermal demands of typical institutional buildings indicates that all building types in all regions generally have much greater electrical requirements than thermal requirements. The larger the institutional building, the less it is influenced by climatic factors and the more sensitive it is to internal heat gains from the occupants, lighting, and equipment; space-heating requirements are usually limited to the perimeter of the building.

Because a typical total-energy system provides two to four times as much usable thermal as electrical energy, the waste heat released in generating the needed electricity will exceed the building's thermal requirements. This implies that an STE system will not be efficient if it is the building's sole source of electrical energy. The mismatch in loads is not as severe as it first appears, however, because the thermal requirements are concentrated in the peak winter and peak summer months. In the northern regions, the waste heat released in the peak months is reasonably close to the thermal requirements. Furthermore, the mismatch can be minimized if the electric utility supplies the electrical energy needed to balance net electrical demand and total thermal demand.

Exhibit 1.d**Building Types and Sizes**

Type	Sizes (10 ³ ft ²)	Other Applications
Colleges	220; 1,210; 2,200	Military bases; prisons
Hospitals	40; 90; 140; 190	
Offices	7; 50; 125	12-month schools; post offices; college classrooms
10-month schools	50; 100	

SOURCE: InterTechnology/Solar Corporation based on distributions developed from the **Dodge Digest of Building Cases and Specifications**, F.W. Dodge Division, McGraw-Hill Information Systems Company, New York.

Exhibit 1.e

Sample Energy-Demand Profiles

(Los Angeles College, 1.21 million ft²)

Exhibit 1.f

Comparison of Monthly Energy-Demand Profiles
(College, 1.21 million ft²)

SOURCE: InterTechnology/Solar Corporation

— Water
 Heating
 - - - - - Cooling

Investigating Modes of Utility Interface

Recognizing that the relationship with the local electric utility will have important implications for STE system design, we examined four possible modes of interface between an STE system and a conventional utility (see Exhibit 1.g). In the "supplemental" mode, the STE system draws on the utility whenever the solar energy available is insufficient to meet the building's electrical requirements. In the "baseload" mode, the STE system is used to "shave" the building's peak electrical requirements, resulting in a flat profile to the utility during its peak hours. In the "off-peak" operating mode, the STE system draws on the utility only during off-peak hours. Finally, in the "independent" mode, the STE system provides the building's total electrical and thermal requirements, and has no interface with the utility.

In all regions, the lowest life-cycle costs associated with the independent and off-peak interface modes were higher than those associated with the baseload and supplemental modes for thermal STE systems (see Exhibit 1.h). Baseload operation appears to be the lower-cost option in almost all cases. However, the actual choice between baseload and supplemental interface for a particular building will depend largely on the local electric utility's pricing policies.

Economic Parameters

Economic considerations also provided some important ground rules for our system-design efforts. We determined that the major economic parameters affecting system design are the costs associated with competing systems and the discount rates applied to investments by decision-makers in the institutional sector.

Costs of Competing Systems

We considered the major competing systems to be conventional electric-utility and fossil-fuel (primarily distillate-oil) boiler systems, and conventional diesel total-energy systems. In developing and optimizing the

Exhibit 1.g
Modes of Utility Interface

SOURCE: Resource Planning Associates, Inc.

Exhibit 1.h

Life-Cycle Costs Associated with
Baseload and Supplemental Interface Modes*

Region	Baseload				Supplemental			
	A_c^{**} (ft ² /it ²)	Turbine (kW/peak)	Absorption (tons/peak)	LCC [†] (\$/ft ²)	A_s (ft ² /ft ²)	Turbine (kW/peak)	Absorption (tons/peak)	LCC (\$/ft ²)
Boston	0.61	0.54	0.4	40.05	0.61	0	0.4	45.77
Washington, D.C.	0.43	0.26	0.4	29.35	0.43	0	0.4	31.21
Madison	0.63	0.31	0.4	34.99	0.63	0	0.4	39.31
Los Angeles	0.23	0.33	0.4	34.79	0.23	0	0.4	39.22
Charleston	0.31	0.30	0.4	32.12	0.31	0	0.2	32.94
Bismarck	0.56	0.28	0.4	26.70	0.56	0	0.4	29.01
Nashville	0.39	0.31	0.4	31.95	0.39	0	0.4	33.18
Fort Worth	0.25	0.20	0.0	23.77	0.25	0	0.2	22.68
Omaha	0.47	0.25	0.4	23.52	0.47	0	0.4	24.71
Seattle	0.57	0.33	0.4	26.40	0.57	0	0.4	24.59
Phoenix	0.21	0.23	0.4	28.51	0.21	0	0.4	29.51
Miami	0.22	0.25	0.0	33.93	0.22	0	0.2	33.37

SOURCE: InterTechnology/Solar Corporation.

* For 1.21 million ft² colleges with moderate collector area.

** A_c = ratio of collector area to facility area.

† LCC = life-cycle cost.

STE system designs, we used projected estimates of the capital costs associated with these systems, as well as projections of 1990 electricity and distillate-oil prices.

We assumed that electricity would be priced on a "time-of-day" basis, which involves a peak demand and usage charge, and an off-peak usage charge. In developing the projections, we used the DOE Project Independence Evaluation System (PIES) model Base Case and escalated the rates to 1990 based on a sample of current time-of-day pricing schedules (see Exhibit 1.i; Appendix C presents a detailed discussion of the fuel-price scenario we used). The component costs we used in our system designs were developed by McDonnell-Douglas and Atomics International in previous studies of STE systems² and represent estimates of installed-system costs in the 1985-1990 time frame (see Exhibit 1.j).

Institutional-Sector Discount Rates

Finally, we applied a 3-percent real (i.e., net of inflation) discount rate in determining system life-cycle costs. Based on interviews, we determined this rate to be the minimum acceptable to decision-makers in the institutional sector.

DESIGNING OPTIMAL SYSTEMS

Working within the framework of these technical and economic parameters, we developed conceptual designs for both thermal and photovoltaic STE systems. Our general approach was to (1) postulate a conceptual system design, (2) develop design details by performing engineering trade-offs to determine which system configurations and components offer the potentially lowest life-cycle costs, (3) optimize the design to

2. Industrial Applications of Solar Energy, McDonnell-Douglas Astronautics Company, April 1977; Commercial Applications of Solar Total Energy Systems, Rockwell International, Atomics International Division, June 1977.

Exhibit 1.i

Projected 1990 Fuel Prices
(1977 dollars)

Region	Electricity Prices			Distillate-Oil Prices (\$/10 ⁶ Btu)
	Peak Demand (\$/kW/yr)	Peak Usage (¢/kWh)	Off-Peak Usage (¢/kWh)	
Boston	77.26	3.41	1.64	3.65
Washington, D.C.	70.50	1.57	1.25	3.77
Madison	71.38	2.33	1.17	3.62
Los Angeles	30.04	5.49	0.60	3.66
Charleston	40.61	2.65	2.65	3.77
Bismarck	51.78	1.30	0.54	3.77
Nashville	40.61	2.65	2.65	3.77
Fort Worth	40.93	1.42	0.95	3.66
Omaha	32.80	1.25	1.25	3.53
Seattle	23.05	1.28	0.45	3.66
Phoenix	48.61	2.42	2.42	3.66
Miami	40.61	2.65	2.65	3.77

SOURCE: Resource Planning Associates, Inc.

Exhibit 1.j**Component Costs**

Item	1990 Installed Costs (1977 \$)
Capital Equipment	
Heliostats/tower (central receiver)	\$13/ft ²
Collectors/piping (linear trough)	\$15/ft ²
Collectors/piping (parabolic dish)	\$17/ft ²
Photovoltaic cells/structure	\$10/ft ²
High-temperature storage (oil)	\$352 (volume ft ³) ^{0.515} + \$12 (volume ft ³)
High-temperature boiler	\$3,690 (lb steam/hr) ^{0.32}
Turbine/generator	\$3,815 (kW/unit) ^{0.66}
Diesel	\$100/kW > 150 kW \$175/kW < 150 kW
Low-temperature storage (water)	\$352 (volume ft ³) ^{0.515}
Absorption chiller	\$2,194 (tons/unit) ^{0.7}
Controls/miscellaneous	10 percent of sum of above
Yearly Operating and Maintenance Costs	
Collectors	0.02 x (collector capital costs)
Turbine/generator	0.04 x (turbine/generator capital cost)
Other components	0.02 x (remaining system capital costs)

SOURCE: McDonnell-Douglas Astronautics Company
Atonics International Division of Rockwell International
InterTechnology/Solar Corporation.

meet the specific requirements of each institutional building type in each climatic region, and (4) evaluate system cost-effectiveness.

The results of this design approach indicate that the relative cost-effectiveness of both thermal and photovoltaic STE systems is highly dependent on regional climatic factors (see Appendix D). Only in the Phoenix and Los Angeles regions will either thermal or photovoltaic STE systems be more cost-effective than conventional utility fossil-fuel systems and conventional total-energy systems (see Exhibits 1.k and 1.l). In both cases, large colleges represent the most favorable application for STE systems, and baseload operation is the most cost-effective mode of interface with the electric utility (see Exhibit 1.m).

Los Angeles is the most favorable location for all total-energy systems, as a result of its high peak-usage electricity charge. In this region, the photovoltaic STE system represents the lowest life-cycle cost system, followed by the conventional total-energy system, and then the thermal STE system. The comparison between the photovoltaic and conventional total-energy systems indicates that most of the photovoltaic STE system's savings stem from its "total energy" rather than "solar energy" features.

In Phoenix, the thermal STE system is more cost-effective than the conventional or photovoltaic total-energy system. This region's high insolation and high summer-cooling requirement can be met effectively by the thermal system's absorption chiller.

Thermal STE System Design

In applying our design methodology to developing a thermal STE system, we considered only systems and components that will be ready for commercialization in the 1980s. This focus limited our selection of turbine cycles to Rankine; advanced Stirling and Brayton cycles still require significant development.

Exhibit 1.k

System Life-Cycle Costs by Region*

SOURCE: InterTechnology/Solar Corporation

Key to Solar Regions:

- Thermal STE System with Mid-Sized Collector
- Conventional Total-Energy System
- ⊙ Thermal STE System with Optimal Collector Area
- ▲ Photovoltaic STE System with Optimal Collector Area

- 1—Boston
- 2—DC
- 3—Madison
- 4—Los Angeles
- 5—Charleston
- 6—Bismarck
- 7—Nashville
- 8—Fort Worth
- 9—Omaha
- 10—Seattle
- 11—Phoenix
- 12—Miami

*Large colleges, $1.21 \times 10^6 \text{ft}^2$

Exhibit 1.1

System Performances by Region
(1.21×10^6 sq ft colleges)

Region	Conventional System			Conventional Total-Energy System		Thermal System			Photovoltaic System		
	First Cost (\$/ft ²)	Annual Energy Cost (\$/ft ²)	LCC (\$/ft ²)	First Cost (\$/ft ²)	LCC (\$/ft ²)	Coll. Area (ft ² /ft ²)	First Cost (\$/ft ²)	LCC (\$/ft ²)	Coll. Area (ft ² /ft ²)	First Cost (\$/ft ²)	LCC (\$/ft ²)
Boston	0.51	1.99	35.32	0.83	29.86	0†	0.55	34.98	—	—	—
Washington, D.C.	0.58	1.39	24.98	1.00	28.13*	0	—	—	—	—	—
Madison	0.50	1.61	28.74	0.85	25.41*	0†	0.57	28.54	—	—	—
Los Angeles	0.55	2.09	37.20	1.13	28.77**	0.46†	10.48	34.03	0.68	8.91	26.30†
Charleston	0.63	1.53	28.40	1.08	32.86*	0	0	—	—	—	—
Bismarck	0.47	1.09	19.69	0.85	20.48*	0	—	—	—	—	—
Nashville	0.62	1.56	27.93	1.06	31.86*	0	—	—	—	—	—
Fort Worth	0.65	1.04	18.93	1.09	25.37*	0	—	—	—	—	—
Omaha	0.58	0.94	17.06	0.99	21.64*	0	—	—	—	—	—
Seattle	0.45	0.74	13.48	0.75	16.00*	0	—	—	—	—	—
Phoenix	0.64	1.58	28.29	1.07	31.58*	0.25†	6.31	27.75	—	—	—
Miami	0.65	1.66	29.73	1.12	34.57*	0	—	—	—	—	—

SOURCE: InterTechnology/Solar Corporation.

* Diesel supplies 1/3 of peak electrical demand.

** Diesel supplies 2/3 of peak electrical demand.

† Diesel supplies total peak electrical demand.

‡ Absorption chiller supplies 40% of peak cooling demand.

Exhibit 1.m

Life-Cycle Cost Comparison
of Utility-Interface Modes

SOURCE: InterTechnology/Solar Corporation

— Supplemental
..... Off-Peak
- - - Baseload

Building: College
Size: 1.21×10^6 ft²
Region: Los Angeles
Conventional:
System LCC: $\$4.50 \times 10^6$

Postulating a
Conceptual Design

The conceptual design we postulated for a thermal STE system is a hybrid solar/fossil system that uses a small central receiver to collect solar energy, and a fossil boiler for backup when insufficient solar energy is available. Electricity is generated using an organic Rankine cycle turbine operating with toluene as the working fluid. The system uses a combination of absorption and vapor-compression refrigeration. The system interfaces with the conventional electric utility in a baseload mode, "shaving" the building's electrical peaks.

In our conceptual thermal STE system (see Exhibit 1.n), solar energy is collected in a concentrating collector and transferred via Therminol-66 to a rock-filled storage tank, where the heat is stored for future use. A separate pump extracts the heated oil from the storage tank, passes it through a boiler, and then returns it to the storage tank.

The turbine working fluid, toluene, is vaporized in the boiler, passes through the turbine, and is condensed in a low-temperature heat-storage unit in which water serves as the heat-storage medium. This water is then used to supply the heat required for space and water heating and air conditioning by the absorption chiller. If the low-temperature heat-storage system is fully charged (i.e., heat cannot be added), the toluene leaving the turbine is passed through a second turbine to be condensed by water from the cooling tower. The two-turbine system permits an increase in the efficiency of the electrical-generation system from 19 percent when heat is being recovered to 24 percent when heat is not needed.

Instead of relying on the utility to provide all the backup electrical energy, a fossil-fuel boiler is used to vaporize the toluene when insufficient solar energy is available. This configuration, in which the boiler serves to decrease the peak power demand on the utility, results in a lower life-cycle system cost than a design in which the utility serves as the total backup. A second boiler can be used to supplement the solar energy when necessary for space heating. This second boiler can be combined with the high-temperature boiler to lower system capital costs.

Exhibit 1.n

Thermal STE System Conceptual Design

SOURCE: InterTechnology/Solar Corporation

- * Can also be placed before the turbines.
- ** Can also be combined with high temperature boiler.

Developing Design Details

The major engineering trade-offs we performed in developing the design details of the thermal STE system relate to the collector system, turbine working fluid, storage type and size, and refrigeration system (see Appendix E).

Collector System

The solar collector system we selected for the thermal STE system is the small central receiver, or "power tower." Reasonable electric-power generation-cycle efficiencies can be obtained only at high temperatures, which in turn can be achieved only through the use of concentrating collectors. The major types of concentrating collectors we considered are linear trough (line-focusing), parabolic dish (point-focusing), and central receiver (a variation of point-focusing).

The economic performance of a collector system is a function of its relative costs and relative collection efficiencies. Installed costs include costs for the reflective structure, the piping, and (for the central-receiver system) the central tower. In mass production, the reflective-structure costs should be similar for all three systems; thus, system-cost differentials arise from the difference between the piping and tower costs. Our estimates of the relative costs of the systems are \$13 per square foot for the central receiver, and \$17 per square foot for the parabolic dish.

The efficiency of a collector depends on both optical and piping losses. The comparisons we performed show that the central-receiver system always has an annual collection efficiency equal to or better than any of the other alternatives. In Phoenix, for example, the central-receiver and parabolic-dish systems have a 68-percent efficiency, and the linear-trough system has less than a 50-percent efficiency.

The central-receiver system was determined to have the lowest cost per unit of delivered energy, and was therefore incorporated into our thermal system design.

Turbine Working Fluid

Although steam technology is further developed than toluene technology, significantly higher cycle

efficiencies can be obtained using toluene as the turbine-working fluid. The difference between the two fluids is most pronounced at high condensing temperatures:

<u>Working Fluid</u>	<u>Cycle efficiency (%) with</u> <u>condensing at:</u>	
	<u>70°F</u>	<u>200°F</u>
Steam	22	15
Toluene	24	19

In our conceptual-system design, the utility provides a significant portion of the electrical requirements, and the waste thermal energy therefore closely matches the building's heating and cooling requirements. As a result, the STE system must operate at the higher condensing temperature (200 F), where the differences in efficiency are significant, much of the time. Accordingly, we selected toluene as the working fluid for our thermal STE system.

Storage Type and Size

Storage at the high temperatures required to produce electricity efficiently is possible using oil, oil/rock, and high-pressure water.

Oil storage (using Therminol-66) was eliminated from consideration based on its high relative cost (\$6.50 per gallon, compared with \$2.50 per gallon for an equivalent oil/rock system). The use of high-pressure water requires system operation at relatively low temperatures (i.e., 400) to keep the pressures manageable; this not only reduces the power-generation efficiency, but also requires an expensive pressurized container. Oil/rock was determined to offer the most cost-effective storage.

The optimal size of high-temperature storage is a function of building energy-demand profiles, regional climatic conditions, and storage-system costs. Simulations were performed to determine optimal storage-system sizes for various building types in both high-insolation (Phoenix) and low-insolation (Bismarck) regions. Total system life-cycle costs for systems supplying 25 percent, 50 percent, and 75 percent of a building's annual energy requirements, and for storage amounts ranging from 1 to 40 pounds per square foot of collector area were determined by calculating initial capital costs and yearly operating and fuel costs.

We determined the optimal storage sizes for systems using the utility as a supplement to be:

<u>Portion of yearly electrical energy supplied by STE system (%)</u>	<u>Optimal storage- system size (lb/ft² of collector)</u>
25	3
50	5
75	21

The life-cycle costs were relatively insensitive to storage size. For example, varying the storage size from 6 pounds per square foot to 25 pounds per square foot for an office building using an STE system to meet 25 percent of its electrical requirements would increase the life-cycle cost by less than 10 percent.

Refrigeration System

Refrigeration can be provided through an absorption or combined vapor-compression absorption system. Absorption refrigeration capitalizes on the considerable amount of waste heat released during the power-generation cycle. If most of the electricity is being supplied by the utility, however, it may not be possible to meet all cooling requirements using the waste heat from the turbine. A combined vapor-compression/absorption refrigeration system permits the STE system to draw on the utility to meet cooling requirements.

In optimizing the system, we treated the size of the absorption portion of the refrigeration system as an independent variable, to be selected to yield the minimum life-cycle cost for the system.

Optimizing the System Design

Once we had developed a detailed thermal STE system design, we optimized the major system components to minimize life-cycle costs. The fundamental step in the optimization procedure was to simulate system performance over a typical year. Nine combinations of collector and turbine sizes were chosen for each of

three absorption-chiller sizes, and system life-cycle costs were computed for each combination. A polynomial was fit to the nine points to estimate the combination of collector area and turbine size that yielded the minimum net present value. This tenth combination was again evaluated by the simulation. We defined the optimal design as the least-cost system combination among the 30 evaluated.

Evaluating System Cost-Effectiveness

The thermal STE system proved competitive with conventional systems in only two regions: Phoenix and Los Angeles (see Exhibits 1.o and 1.p). In all other regions, the optimal collector area was found to be zero, indicating that an STE system will not be cost-effective (see Appendix F).

Using the performances of the thermal STE system having the lowest life-cycle cost with a nonzero collector area, we estimated the level to which the STE system's fuel savings would have to rise in 1990 before the system become competitive in each region (see Exhibit 1.q). We determined that savings must rise 50-100 percent (in real terms) in most regions (see Appendix G).

Photovoltaic STE System Design

We followed the same general approach in developing a photovoltaic STE system design that we did in developing the thermal STE design.

Postulating a Conceptual Design

The photovoltaic system we postulated (see Exhibit 1.r) is a hybrid solar/fossil system that uses flat-plate silicon photovoltaic arrays to provide electricity and a conventional diesel generator to provide both electrical and thermal energy. The system uses a combination of electrical and absorption refrigeration, and a furnace for thermal backup, but no electrical storage. The conventional electric utility is again relied upon to supply baseload requirements, and the STE system is used to "shave" the building's electrical peaks.

Exhibit 1.o

Thermal STE System Costs

(Los Angeles college, 1.21 million ft²)

Item	Size	Cost (\$/10⁶)	Fractional Cost (percent)
Collector	560,000 ft ²	7.3	57
High-temperature storage	105,750 ft ³	1.4	11
High-temperature boiler	150,000 lb/hr	0.2	1
Turbine/generator	4 x 1,400 kW	1.8	14
Low-temperature storage	246,000 ft ³	0.2	2
Chillers	3,300 tons	0.6	5
Other	—	1.2	9
Total Capital Cost		12.7	100
Yearly Operating and Maintenance Cost (\$10⁶/yr)		0.29	

SOURCE: InterTechnology/Solar Corporation.

Exhibit 1.p

Thermal STE System Savings
(Los Angeles college, 1.21 million ft²)

Energy Type	Amount Saved (Extra Usage)	Value (\$000)
Electricity		
Peak demand	6.8 x 10 ³ kW	\$ 204.5
Peak usage	2.2 x 10 ⁷ kWh	1,204.5
Off-peak usage	1.3 x 10 ⁶ kWh	8.0
Fossil fuel	4.7 x 10¹⁰ Btu)	227.2
Net Savings		1,187.7

SOURCE: InterTechnology/Solar Corporation.

Exhibit 1.g

**Ratio of Actual/Estimated 1990
Fuel Prices for Thermal STE
Systems to be Competitive**

Region	Actual/ Estimated Price
Boston	1.44
Washington, D.C.	1.58
Madison	1.63
Los Angeles	0.84
Charleston	1.68
Bismarck	1.88
Nashville	1.58
Fort Worth	2.04
Omaha	1.88
Seattle	
Phoenix	0.96
Miami	1.49

SOURCE: Resource Planning Associates, Inc.

Assumptions:

DOE PIES Base Case and time-of-day fuel prices

Central receiver heliostats, and tower cost = \$13/ft²

Discount rate = 3%

Exhibit 1.r

Photovoltaic STE System Conceptual Design

SOURCE: InterTechnology/Solar Corporation

When sufficient solar energy is available, the photovoltaic array generates electricity and a separate thermal array supplies heat for space heating and cooling. The silicon photovoltaic cells used in the design operate at a 15-percent conversion efficiency. When the available solar energy is insufficient, a diesel engine is used to drive an electrical generator; the waste heat is used for space heating and cooling. The diesel electrical-conversion efficiency was determined to be 28 percent at full load (25-percent average), and its useful thermal energy, 50 percent.

When the diesel is providing the cooling, it is also cost-effective to have some of the electricity the diesel generates drive a vapor compressor to provide additional cooling. If heating is needed when electricity is not, the thermal energy is supplied by a furnace. A coolness-storage unit is used to reduce the losses associated with cycling the absorption unit and to store the excess cooling available from the vapor compressor, should excess electrical energy be available. Finally, a furnace is used to provide thermal backup.

A key to the economic success of the photovoltaic system is its integration with the electric-utility system. As in the thermal system, a least-cost design is obtained when the photovoltaic STE system operates in a baseload-interface mode with the local utility.

Developing Design Details

The major engineering trade-offs we performed in developing the design details of the photovoltaic STE system relate to the array type, storage type, and refrigeration system (see Appendix H).

Array Type

The photovoltaic STE system can use either a combined array, in which the photovoltaic cell is placed on the front of the thermal collector, or separate arrays, in which the thermal and photovoltaic arrays are independent. For our system, we chose the independent flat-plate arrays, as suggested in studies by General Electric and Spectrolab.³

3. Conceptual Design and Systems Analysis of Photovoltaic Systems, General Electric Space Division, ALO3686-14; Photovoltaic Systems Concept Study, Spectrolab, April 1977.

Storage Type

We considered two types of storage for the photovoltaic system design: storage in batteries, and hot- and cold-water thermal storage.

Both General Electric and Spectrolab found that electrical storage is not cost-effective for a photovoltaic system, because inefficiencies of storage and withdrawal result in a 25-percent energy loss. Furthermore, the short life of batteries significantly increases system costs. In many applications, because STE electrical requirements are limited to peak hours, operation without storage does not waste significant amounts of electricity.

Both hot- and cold-water storage are used in the system we designed. Hot-water storage, which is charged by the heat from the thermal solar arrays, and waste heat from the diesel, is used to drive the absorption-cooling system, as well as to meet space-heating and hot-water requirements. Cold-water storage is used to enhance the performance of the photovoltaic cells. Any excess solar-provided electrical energy is used to drive the vapor-compression refrigeration system. The coolness that is produced is stored as cold water for later use in the air-conditioning system.

Refrigeration System

As in the thermal STE system, combined vapor-compression/absorption refrigeration is used in the photovoltaic STE system. In performing trade-off analyses, the sizes of the two chillers need not be specified because both have the same installed costs. Some overcapacity is required in the vapor compressor to ensure sufficient backup (about 3 tons per thousand square feet of thermal solar collector). We added this additional capacity in the systems simulation.

Optimizing the System Design

To optimize the photovoltaic system design, we performed a direct search of 27 points generated

by three thermal-collector areas, three photovoltaic collector areas, and three diesel sizes. The performance of each of the 27 combinations for each building type in each region was computed by simulating system operation. The combination having the lowest life-cycle cost was considered to be the optimal system.

Evaluating System
Cost-Effectiveness

Los Angeles is the only region in which the photovoltaic STE system will be cost-effective. The most cost-effective application is a large (1.21-million-square-foot) college (see Exhibits 1.s and 1.t).

The conventional and photovoltaic total-energy systems have very similar life-cycle costs, primarily because our conceptual design evolved into a "photovoltaic-assisted" conventional total-energy system. The photovoltaic array acts as a "fuel saver," reducing the amount of fossil fuel needed to power the diesel, and allowing the system to supply a larger amount of the total electrical load before some of the thermal energy provided must be discarded. Our optimizations showed that the thermal array is not cost-effective in any case, because the diesel usually provides more than enough thermal energy to meet a building's needs.

Conventional total-energy systems generally start to become competitive with conventional-utility systems when peak-period energy costs (demand and usage charges) reach 5 cents per kilowatt-hour (kWh). The photovoltaic-assist becomes cost-effective when its delivered energy cost is less than the peak utility-usage charge. We calculated the level to which electricity prices must rise above those postulated in the DOE Base Case scenario before the photovoltaic-energy cost in each region equals the peak-usage cost (see Exhibit 1.u and Appendix G). The photovoltaic arrays will become cost-effective in regions other than Los Angeles if prices increase by 20 percent (in Phoenix and Miami) to 180 percent (in Seattle).

Exhibit 1.s**Photovoltaic STE System Costs****(Los Angeles college, 1.21 million ft²)**

Item	Size	Cost (\$/10⁶)	Fractional Cost (percent)
Photovoltaic collector	826,000 ft ²	8.26	77
Diesel generator	4 x 2,250 kW	0.90	8
Chillers	3,300 tons	0.64	6
Other	—	0.98	9
Total Capital Cost		10.78	100
Yearly Operating and Maintenance Costs (\$10⁶/yr)		0.23	

SOURCE: InterTechnology/Solar Corporation.

Exhibit 1.1

Photovoltaic STE System Savings
(Los Angeles college, 1.21 million ft²)

Energy Type	Amount Saved (Extra Usage)	Value (\$000)
Electricity		
Peak demand	1.17 x 10 ⁴ kW	\$ 350.6
Peak usage	3.71 x 10 ⁷ kWh	2,034.6
Off-peak usage	0	0
Fossil fuel	1.6 x 10¹¹ Btu	780.8
Net Savings		1,604.4

SOURCE: InterTechnology/Solar Corporation.

Exhibit 1.u

**Ratio of Actual/Estimated On-Peak
Electricity Prices for Photovoltaic
STE Systems to be Competitive**

Region	Actual/ Estimated Price
Boston	1.4
Washington, D.C.	2.4
Madison	1.7
Los Angeles	0.6
Charleston	1.3
Bismarck	2.6
Nashville	1.4
Fort Worth	2.3
Omaha	2.8
Seattle	3.5
Phoenix	1.2
Miami	1.2

SOURCE: Resource Planning Associates, Inc.

Assumptions:

DOE PIES and time-of-day fuel prices

Photovoltaic costs - \$0.50/peak watt

Discount rate = 3%

2

ANALYZING THE MARKET

The second fundamental objective of our study was to analyze and characterize the institutional market in which STE systems will be introduced. Through a series of interviews and independent research, we identified two major components of the institutional market for STE systems: decision-makers at all levels within the sector; and participants external to the sector. The various requirements of both these groups will have to be satisfied if STE systems are to compete for a share of the market currently held by conventional utility and conventional total-energy systems.

DECISION-MAKERS WITHIN THE INSTITUTIONAL SECTOR

Within the institutional sector, two types of decision-makers are usually involved in the selection of an energy system: those who set policy, arrange for funding, and review and approve the recommendations of technical evaluators; and those who actually evaluate and choose among alternative energy systems. The policymakers/approvers (generally legislative committees, boards of trustees, city councils, or high-level administrators) are primarily interested in ensuring that (1) the system is needed, and (2) sufficient funds are available or can be raised. The evaluators (which include facility engineers, business managers, and architect/engineers) are interested primarily in the costs and performances of the alternative systems. They are responsible for making specific recommendations to the approvers, who usually accept and follow those recommendations without serious questioning.

Through interviews with both types of decision-makers, we determined that the decision process followed and the criteria applied in selecting an energy system are more a function of the level of government involved than the type of institution. Appendix I describes the federal, state, local, and private decision processes in detail.

Institutional-sector decision-makers at all levels consider both financial and nonfinancial criteria in evaluating an energy system. As in all sectors, these criteria are not hard-and-fast rules, but are flexible depending on the investment climate, social and economic priorities, and the particular features of a proposed project.

Financial Criteria

The major financial factors likely to influence an STE system decision are the subsector's investment requirements and the availability of sufficient capital to make the STE system investment.

Investment Requirements

By installing and operating an STE system, an institutional user is in effect substituting a large initial capital investment for lower operating costs. Accordingly, the user's investment requirements will have an important influence on the decision whether or not to install an STE system. Decision-makers in the institutional sector generally use some combination of three techniques to evaluate a potential investment: initial cost, payback, and life-cycle costing.

"Initial cost" is by far the most widely followed approach to making investment decisions in the institutional sector, especially at the state and local levels. Under this approach, a facility's detailed design is specified in advance, and bidders compete for lowest cost. The decision-maker is often required by law to accept the lowest bid meeting the initial design specifications; accordingly, for innovative features or systems with higher capital costs to compete, any

financial trade-offs would have to be incorporated in the initial specifications. Until the engineers developing the specifications, the administrators approving the funds, and the contractors bidding on the design are fully educated regarding more sophisticated financial-analysis techniques, initial-cost analysis will work against the serious consideration of STE systems by state and local governments.

"Payback" is the best-understood and most widely used financial-analysis technique for comparing a capital cost with future savings. It simply represents the number of years required to recoup an initial investment. Payback techniques are applied primarily by the larger, more sophisticated, private, local, and state institutions. Most sector decision-makers require a payback period of 3-5 years. Decision-makers in large colleges and universities consider a 5-7 year payback period good, and a 10-year period acceptable. Based on our discussions with institutional-sector decision-makers, we estimate that one-fourth to one-third use "payback" criteria in evaluating HVAC systems.

The military uses a variation of payback in its energy-conservation programs. A threshold energy saving of 22 million Btu per year per \$1,000 invested is required, which represents approximately a 14-year payback at current prices. The programs currently funded by the military save an average of 59 million Btu per year per \$1,000 invested, which is equivalent to a 5-year payback.

We developed estimates of the market potential in the institutional sector for energy systems having various payback periods (see Exhibit 2.a), based on our discussions with institutional-sector decision-makers and an examination of expected returns on investment (ROIs) on large, recently purchased HVAC systems (e.g., conventional total-energy systems, waste-to-energy systems). The payback periods can be used to derive an implied discount rate by assuming the inverse of the payback period to be the capital-recovery factor.* A reasonable estimate of the discount rate used in large institutional-sector buildings such as colleges is 7 percent, net of inflation.

* Capital-recovery Factor = $1/(\text{payback period}) = k/[1 - (1+k)^{-N}]$, where k is the discount rate and N is the system life.

Exhibit 2.a

Market Potential as Percent of Payback

SOURCE: Resource Planning Associates, Inc.

The final and least-understood financial-analysis technique is life-cycle costing. In this method, the yearly cash flows of alternative systems are discounted to their present value, based on the ROI required, and the lowest-cost alternative is selected. The federal government is the largest institutional-sector user of this technique. It applies a 10-percent real discount rate to its usual investment decisions, and a 7-percent rate to real property (e.g., new buildings).

Only five states (Connecticut, Maine, Massachusetts, Rhode Island, and Wyoming) currently require life-cycle costing in all their building-system analyses. Seven states (Alaska, Colorado, Florida, Massachusetts, New Mexico, North Carolina, and Washington) require life-cycle cost analyses to establish the feasibility of alternative energy systems (e.g., solar wind) in state-owned buildings. Several other states have legislation pending to adopt life-cycle costing, often as part of a comprehensive energy-conservation plan. The discount rates used (or proposed) generally range from 7 percent to 12 percent, net of inflation. At the present time, we estimate that approximately 10 percent of the nonfederal institutional-sector decision-makers use life-cycle cost techniques.

Lack of experience, however, has to date resulted in the inconsistent application of those techniques. In particular, state officials have encountered difficulties developing acceptable assumptions for fuel-price escalation rates and distinguishing between "constant" and "inflated" dollars. Consensus among the decision-makers we interviewed was that these problems would be solved in time, but possibly not for 10 or 20 years.

Capital Availability

A crucial factor affecting the market potential of STE systems will be the ability of the various institutional subsectors to finance their purchase. An STE system could represent as much as 5-20 percent of a building's initial capital cost; accordingly, financing issues will have to be addressed early in the decision process.

The source of construction funds in the institutional sector generally depends on the level of government involved. The federal government and many state and

local governments rely primarily on tax appropriations, which are sometimes augmented by "general-obligation" borrowings not specifically tied to a particular project. Other state and local governments issue bonds for specific projects (e.g., airports, hospitals, school dormitories) and use the revenues generated by the facilities constructed to repay the notes. Private institutions receive their construction funds through bonds, both tax-free and taxable; conditional loans; and government-insured loans.

Traditionally, lenders do not become involved in the details of an energy-system choice, but rely on the evaluations performed by architect/engineers. The general credit-worthiness of the borrower, which depends on far many more factors than the estimated costs and savings of various energy-system alternatives, is the major factor considered in the decision to lend funds. The lenders we interviewed emphasized that their only concern regarding the choice of a particular system is that it will not affect the institution's ability to meet its debt payments (as determined through analysis of the borrower's cash flows over a 5-year period). Only if there were general disagreement among engineers on system reliability, or if initial installations performed poorly, would lenders seriously begin to examine an STE or any other type of energy system.

Nonfinancial Criteria

The major nonfinancial criteria that decision-makers within the institutional sector will consider in evaluating an STE system are system reliability and land availability. In the military subsector, which offers the highest potential for STE system adoption, funding and manpower limitations also represent important considerations for decision-makers. Several other, relatively minor factors (e.g., immunity from power cutoffs, public relations, vandalism) will also contribute to an STE decision to varying degrees in the institutional subsectors.

System Reliability

The technical reliability of an STE system is a major factor which will be considered by all participants in the decision process. For some of those participants (e.g., architect/engineers, contractors, operating and maintenance personnel), reliability may be more important than the system's economic performance; although they do not necessarily share in any future savings, their reputations may be damaged or substantial extra work required if a system experiences undue downtime.

In general, the decision-makers are waiting for a system to be installed and operated for a significant period of time (1-3 years) that demonstrates that an STE system is at least as reliable as a conventional HVAC system. Several noted the need for a "system integrator," who will not only design and package the systems, but will warrant all parts, as a significant factor influencing system acceptance.

Land Availability

A prerequisite for STE system installation is the availability of sufficient land for solar collectors. Our optimization of the STE system designs indicates that the lowest life-cycle cost systems have collector-area/floor-area ratios on the order of 0.25-0.50 for a thermal system, and 0.50-0.90 for a photovoltaic system. If we assume a collector-field/collector-area ratio of 5:1 for a thermal system, and 2:1 for a photovoltaic system, approximately 1.25-2.5 times the facility's floor area will be required for collectors. As an example, a Los Angeles college that is 1.21 million square feet in size will require 65 acres (a square area one-third of a mile long on each side) for the optimally sized thermal collector field, and 38 acres for the optimally sized photovoltaic collector field. In Phoenix, 35 acres will be required for the optimally sized thermal field, and 32 for the optimally sized photovoltaic field.

To estimate the effects of land-area constraints on the market potential for STE systems, we conducted a nationwide survey to determine the ratio of a facility's

total area (including the building site, parking, recreation, etc.) to its floor area. The sample included 39 colleges and universities, 41 elementary and high schools, and 70 nonfederal hospitals. The results of the survey (see Exhibit 2.b) indicate that colleges and schools generally have substantial amounts of land; over 60 percent have total-area/floor-area ratios of 10.0 or more. Hospitals, on the other hand, tend to be located in more heavily populated areas and thus have less land available for collectors.

Although we did not conduct formal surveys of land availability in the remaining subsectors, we did speak with many knowledgeable subsector personnel and inspected plans for some specific facilities. Based on this investigation, it appears that military installations, airports, federal prisons, and federal hospitals (primarily Veterans Administration) generally have total-area/floor-area profiles similar to those of colleges and schools. Public-administration buildings and post offices, on the other hand, are usually located in urban areas and thus show profiles similar to nonfederal hospitals.

Total-area/floor-area ratios do not necessarily indicate the amount of land available for solar collectors, however. For example, land used for recreational facilities or parking may not be available for collectors. In retrofit situations, only a portion of the roof area may be available.

Investigation of site plans for some specific large facilities indicated that the portion of the land area suitable for collectors can range from 25 percent to 75 percent of total land area. Assuming that 50 percent of the land area is available for a collector field, a land-area/floor-area ratio of at least 5:1 is required for a thermal STE system, and 2:1 for a photovoltaic system. This requirement limits STE system potential in the college and university, school, military, airport, and prison subsectors to 70-80 percent, and in the remaining subsectors to 25-40 percent.*

* It may, of course, be possible to construct a system that is smaller than the optimal size, with some reduction in ROI.

Exhibit 2.b

Cumulative Distributions of Total-Area/Floor-Area Ratios

SOURCE: Resource Planning Associates, Inc.

--- Elementary and secondary schools

— Colleges and universities

..... Hospitals

RPA

Furthermore, although a particular facility may have sufficient land for an STE system, its administrators may be planning future development on that land. The administrators of approximately two-thirds of the large colleges and universities surveyed indicated that available land could be used for STE systems (depending of course, on the system's expected ROI, projected fuel availability, and estimated future enrollments). In the military subsector, approximately 90 percent of the decision-makers in installations with sufficient land available indicated willingness to devote the land to an STE system. In other subsectors, including hospitals and schools, only about 50 percent of those currently having sufficient land available would be willing to devote it to an STE system.

Interestingly, most of the institutional-sector decision-makers we interviewed indicated that they would not explicitly consider the cost of the land in evaluating the economics of an STE system. There are some exceptions, of course. For example, the University of California campus at Irvine imputes a value of \$65,000 per acre to its land.

We estimated the possible impacts of including land costs in STE system capital costs based on a survey of regional land costs on a dollar-per-square foot basis. In general, land costs of \$1.30-\$90.00 per square foot (the equivalent of as much as several million dollars per acre) will make the STE systems uneconomic in urban areas, land costs of \$0.15-\$1.40 per square foot may have a small effect in suburban areas, and land costs of \$0.01-\$0.20 per square foot (the equivalent of as little as several hundred dollars per acre) will have a negligible effect in rural areas.

Military Funding and Manpower Limitations

Military installations appear to offer the greatest potential for STE systems, based on their size, investment requirements, and land availability. However, certain funding and manpower limitations could seriously constrain this potential, regardless of system cost-effectiveness.

Currently, a base commander must weigh the future savings associated with an investment against other uses of capital (e.g., housing, recreational facilities)

that will upgrade the quality of life at the base. In recognition that the "quality-of-life" investments will win in most cases, a portion of the military construction budget (approximately \$100-\$150 million out of \$4 billion) is set aside for energy-conservation projects such as insulation and total-energy systems. However, at that level, it is not likely that sufficient funds will be available to install many STE systems, especially considering their marginal economic performance.

An additional factor adversely affecting STE market potential in the military subsector is manpower ceilings, which limit the total personnel the military has available to carry out all its responsibilities. Forced to work within these limitations, military decision-makers generally seek to place as many of their nonmilitary functions (e.g., maintenance, utilities) as possible with private contractors, reserving their manpower for directly military purposes. It seems likely, therefore, that military decision-makers may resist the installation of STE systems -- with their large manpower requirements and indirect military value -- unless (1) the systems are owned and operated by private contractors, or (2) Congress specifically provides additional funds and manpower for system construction and operation.

Other Contributing Factors

Solar-industry representatives and government planners consider the "insurance value" of an STE system, which could offer a building immunity from power cutoffs, a major selling point for any type of solar system. The institutional-sector decision-makers we interviewed, however, do not consider this factor very important -- certainly not to the extent that they would be willing to pay a premium for a system that might provide this benefit. College and university representatives noted that they can simply send their students home during temporary blackouts. Military-base commanders have emergency powers to requisition available energy supplies, which they feel are adequate under reasonable extrapolations of future energy conditions. Decision-makers in hospitals, which are highly susceptible to energy-supply shortages, are confident that they would be among the last to be cut, and hence are not willing to pay a significant amount to insure energy supply.

The public-relations aspect of solar systems is a more significant factor. Most decision-makers are quite concerned about their institutions' image and prestige, partly as a result of their public-service orientation, and partly because they rely on the goodwill of the public for tax advantages, appropriations, and contributions. At present, solar systems have an excellent public image as energy-conserving and environmentally benign. In fact, many of the solar heating and hot-water systems currently being installed in hospitals and colleges are intended as much to attract favorable publicity as to save energy. Over the long term, however, the critical factor will be system cost-effectiveness, especially if public interest begins to wane as solar technologies are adopted more widely.

Vandalism is considered a potential problem in all subsectors, especially for urban facilities. Rocks, guns, and paint may take a significant toll on collectors, increase operating and maintenance costs, and possibly require that collector fields be fenced in. The vandalism problem will probably be particularly acute during the early years of commercialization, until the novelty of the systems wears off.

PARTICIPANTS EXTERNAL TO THE INSTITUTIONAL SECTOR

The general attitudes and specific criteria evaluated by decision-makers within the institutional sector will clearly be the fundamental determinants of STE market penetration. Those decision-makers do not act independently, however. STE market potential will also be influenced significantly by the attitudes and actions of "external" factors, particularly the local electric utilities. We interviewed a number of utility and regulatory-commission representatives to determine the service arrangements they would be willing to establish with STE systems users. We also interviewed collector manufacturers, architect/engineers, contractors, and representatives of labor unions to learn their attitudes toward STE systems.

Electric Utilities

The market penetration of STE systems in the institutional sector will depend to a significant degree on utility attitudes and arrangements. Most important will be the type of interface established between the STE system user and the utility grid, and the electricity-pricing schedules adopted by the utility to provide supplemental or backup service to the STE system.

Alternative Interface Modes

Through a series of interviews, we obtained the reactions of utility representatives to the three alternative modes in which the STE system can interface with the utility grid. The 20 utilities we sampled were in agreement about most aspects of the alternatives.

The supplemental mode, in which the STE system is used whenever possible, is currently the basis for most utility planning with respect to solar systems of any type. The utility representatives generally feel that a customer who invests in a solar system will want to use that system at maximum capacity for the maximum amount of time. However, this alternative involves the highest degree of uncertainty; because demand for supplemental service is dependent upon unpredictable factors, such as the weather, a utility would have no control over load levels. To maintain the reliability of the supplemental service, the utility would have to build excess capacity equal to the highest anticipated level of customer demand. The cost of this capacity would be reflected in high rates (e.g., standby charges, ratcheted demand charges), particularly during peak periods.

The utility representatives feel that the second option -- using an STE system only to meet electricity needs over a certain baseload level -- is somewhat impractical for a total-energy system, in which heating and cooling requirements may influence the periods and amount of electrical generation. Although the baseload option would enable utilities to plan accurately to meet customer demands, STE system users would still be consuming some peak energy and would thus be required to pay peak rates at times. One utility representative

suggested the possibility of entering into a contract with a customer for a guaranteed-baseload level of service provided at a flat rate. He qualified this suggestion, however, by noting that such an option would only be considered in the case of a very large customer, who might otherwise choose to operate completely independent of the utility grid.

The best option from the utility perspective is the off-peak mode, in which the STE system user would draw energy from the grid only during off-peak hours. The major concern expressed by utility representative relates to whether an STE system would be able to expand sufficiently to meet its user's growing demand without having to rely on the utility during peak periods.

In general, the utility representatives indicated that they could easily incorporate the load profiles of new customers using STE systems into their future planning. Large-scale installations of STE systems by existing customers, which would significantly alter load profiles, would be more difficult to accommodate, particularly in periods or regions of slow service growth.

Electricity- Pricing Schedules

Electricity costs represent the major component of fuel costs for most institutional-sector buildings. Consequently, the electric utility's pricing schedules will have major impacts on STE system design and economics.

As closely regulated monopolies, electric utilities are required to charge "just and reasonable" rates that are in some way related to costs. Currently, utilities charge customers both for the actual amount of energy used and for standby capacity, which may or may not be used. Three techniques are commonly used to price the energy actually used:

Declining block, in which each successive block of kWh per month is charged at a different, generally declining rate.

Demand/usage, in which the peak kW demand and kWh usage are priced separately. The kW demand charge is based on either the monthly peak or the highest peak during the previous year (a "ratcheted" charge).

Time-of-day, in which charges are applied during the peak portion of the day (e.g., 8 a.m.- 8 p.m.), and a usage-only charge is applied during the off-peak portion.

Declining-block schedules are the least favorable to an STE system, which will always displace the lowest-priced electricity first. Demand/usage schedules are more favorable, provided the STE system is able to displace some of the peak demand.

Time-of-day rates will probably be most favorable to STE systems; because the solar energy will be available during the peak hours, it will tend to displace the most expensive peaking capacity. Although utilities do not use any one formula to develop rates, we found, through a sensitivity analysis, that their rates generally reflect regional differences in capacity costs and fuel prices (see Exhibit 2.c).^{*} Nationally, the trend is toward instituting time-of-day rates for all large industrial and commercial users; we therefore used these rates in developing our system designs and performing our market analysis.

In addition to actual usage, utilities also impose charges for backup or standby service. Utilities generally either use a ratcheted demand charge, or assess a standby charge equal to the customer's potential requirements (based on the amount of on-site power-generation equipment installed). Although we assumed that a ratcheted demand charge would be used in developing our market estimates, we also examined the impacts that standby charges would have on STE system economics.

The major concern of utilities is the possibility that all solar customers might come on line for supplemental electricity at the same time (for example, on a cloudy day), greatly increasing the utility's peak demand and lowering its load factor. Accordingly, we developed hypothetical rates that reflect the full marginal cost of providing backup in the case of "synchronous failure." We estimated that the demand, or capacity, component of backup charges by DOE region would be as follows (see

^{*} Some of the ratemakers we interviewed indicated that their rates are promotional; that is, they are designed to encourage users to shift to off-peak usage, and thus do not necessarily reflect the actual costs incurred.

Exhibit 2.c**Time-of-Day Electricity Rates**

Region/City	Peak Rate		Off-Peak Rate
	Demand (\$/kW/yr)	Usage (¢/kWh)	Usage (¢/kWh)
New England	72.00	3.18	1.53
New York/New Jersey	84.00	3.01	1.79
Middle Atlantic	63.00	1.40	1.12
South Atlantic	36.00	2.35	2.35
Midwest	61.20	2.00	1.00
Southwest	29.76	1.03	0.69
Central	28.80	1.10	1.10
North Central	43.44	1.09	0.45
Phoenix	40.20	2.00	2.00
Northwest	18.00	1.00	0.35
Los Angeles	24.84	4.54	0.50

SOURCE: Resource Planning Associates, Inc.

Appendix J for a detailed description of the methodology we followed in developing these estimates):

<u>DOE REGION</u>	<u>Hypothetical Demand Charge (\$/kW/year)</u>
I - New England	\$58.39
II - New York/New Jersey	62.71
III - Middle Atlantic	58.91
IV - South Atlantic	56.27
V - Midwest	69.06
VI - Southwest	50.31
VII - Central	70.33
VIII - North Central	57.16
IX - West	76.14
X - Northwest	85.83

Assuming these standby charges, our sample Los Angeles college would incur additional costs of \$430,000 per year -- or more than one-third of its estimated fuel savings -- if it operated a thermal STE system with 5.6 megawatts of on-site generating capacity. The standby charges would thus negate any economic advantages the STE system might offer.

It is also possible, however, that a state regulatory commission could direct its electric utilities to offer backup rates that encourage the use of STE systems; that is, rates that do not reflect the full costs the utilities incur to provide backup service. These "promotional rates" might be ordered if the commission regards STE systems as an effective energy-conserving technology and decides to encourage conservation actively as a worthy social goal whose costs should be borne by utility customers.

An alternative that might resolve some pricing and regulatory problems is for utilities to own the STE systems, and sell the energy generated. This arrangement is currently being explored for many cogeneration systems. Although a specific analysis of this option was beyond the scope of our study, estimates we developed of the costs of utility ownership indicate that STE-generated electricity costs can be competitive with gas-turbine peak electricity costs (see Exhibit 2.d and Appendix K).*

* Detailed calculation of the true costs to a particular utility would require hour-by-hour simulations for a year of an STE system optimized to interface with that utility.

Exhibit 2.d

**1990 STE Electricity Costs (¢/kWh)
for Utility Ownership (1977 \$)**

Region	Thermal STE System	Photovoltaic STE System	Range of Gas-Turbine Peaking Costs
Los Angeles	9.6	8.5	9.6-19.8
Phoenix	8.3	7.3	9.6-19.8

SOURCE: Resource Planning Associates, Inc.

Assumptions:

1.21 million ft² college

Baseload operation

Utility fixed charge rate = 15%

Central-receiver, heliostat, and tower costs = \$13/ft²

Photovoltaic costs = \$0.50/peak watt

Thermal energy is valued at \$3.66/MBtu

Under declining-block pricing schedules, STE systems will probably not be competitive with conventional utility systems for the average user. Under time-of-day pricing schedules that fully reflect the utility's marginal costs of providing the energy, STE systems may be competitive with peak electricity costs in some regions (e.g., Phoenix, Los Angeles).

Utilities that do not institute time-of-day pricing may find it economical to own the STE system and incorporate any additional costs into its rate base, which would be reflected in a small increase for all customers. The resulting increase would be less than that associated with the utility adding the extra capacity needed to serve the user with conventional generating techniques.

Utility ownership offers several other important advantages. First, the utility will be able to make trade-offs in system design and operation that will optimize the system's interface with the conventional grid. Second, standardization of design, centralized purchasing and distribution, and centralized operating and maintenance may help reduce system costs. Third, and most important for some institutional subsectors (e.g., military), utility ownership will relieve users of the responsibility for operating and maintaining the system.

Utility ownership is not without disadvantages, however. Many technical, financial, management, legal, and regulatory issues would have to be clarified and resolved before a utility would seriously pursue the possibility of STE system ownership. For example, an STE system optimized for the grid interface may not be optimized to meet a building's energy requirements; some utilities may have difficulty raising the capital needed for an STE system; the management problems associated with coordinating a large number of relatively small, dispersed power-generating facilities (from contract negotiation to maintenance) can be formidable; utilities attempting to sell both electrical and thermal energy may encounter franchise difficulties; and political problems may arise related to allowing regulated utility monopolies to compete with private enterprises attempting to sell STE systems.

Collector Manufacturers

The projected costs we used to optimize our STE system designs are based on the assumption that collector manufacturers will lower prices through mass production; accordingly, the attitude of manufacturers toward the STE market development is extremely important. We interviewed a number of manufacturers of concentrators, heliostats, and photovoltaic cells to determine what critical signals/events they will be looking for before they commit resources to expansion and production.

All manufacturers seem to be looking for increased demand as a signal to commit additional resources. Uncertainty about whether existing market demand is being generated by the federal government or actual market forces is having a direct impact on investment decisions. As one collector manufacturer noted: "We are selling 100 collectors a month but we are not sure there is a viable market. We need assurance of a true market."

Many manufacturers indicated that substantial sales will have to be made to private customers operating without government grants and not on an experimental basis before they feel confident enough to expand production. In addition to increased demand, they need to have a clear understanding of the most cost-effective applications for STE systems. Before they commit resources to production, they insist that system-design trade-offs and performances be better defined, costs and benefits to the potential user readily apparent, and federal policies on regulation and price controls clarified.

Most manufacturers feel that the government should encourage the market development of STE systems in the early years by providing financial incentives such as tax credits and accelerated-depreciation allowances. Such incentives would help STE systems compete with conventional energy systems, whose prices are lowered artificially through controls and depletion allowances. Other manufacturers support legislative forms of state intervention and encouragement. (For example, legislation recently passed in New Mexico requires all state

and local buildings to meet 60 percent of their heating needs through solar systems within 5 years, beginning June 1, 1978.) Quite a few manufacturers feel that DOE should continue and increase its purchasing for testing and demonstration purposes.

Once the STE technologies become sufficiently mature that adoption requires only the application of well-understood design principles, manufacturers expect system-distribution patterns to follow those of conventional HVAC equipment. Generally, a manufacturer works through sales representatives or a field sales force to persuade architects, engineers, and mechanical contractors to specify its products for construction jobs. In reaching a decision, these personnel evaluate the equipment in terms of cost, performance, reliability, and promised delivery, relying heavily on previous experience with the manufacturer. Once specified, the equipment is generally ordered directly by the owner/operator, and delivered directly to the construction site. Commissions on these sales are generally 5-10 percent.

In view of the size and complexity of STE systems, it is likely that the "manufacturer" will become a "system integrator" who manufactures a major system component (e.g., heliostat, photovoltaic cells), combines it with components produced by other manufacturers into a packaged unit, and warrants on all components. During the first few years of STE system commercialization, the system integrator will probably also assume responsibility for system installation and maintenance, primarily to ensure proper operation and reliability.

ARCHITECT/ENGINEERS, CONTRACTORS, AND LABOR UNIONS

Other external groups that will affect STE system market development include architect/engineers, contractors, and labor unions. To determine the factors these groups consider important to system acceptance, we

interviewed personnel in a number of firms and trade organizations, concentrating on those involved in institutional-sector work and having experience with solar and conventional total-energy systems.

Architect/engineers are important to STE system development for two reasons. First, together with the manufacturers, they represent an important source of innovative ideas in the construction of institutional facilities. Second, even if they do not originate the idea, they will be called in to evaluate STE system costs and performances. Architect/engineers tend to be conservative in their evaluations, and often emphasize system reliability more than cost. They feel that the development of packaged systems with well-understood performance and cost characteristics is crucial to widespread adoption.

The contractors who will be installing the systems foresee no major difficulties, largely because the systems are constructed of materials they are accustomed to working with: concrete, metal, and glass. Furthermore, they welcome the increased on-site labor requirements associated with system installation and maintenance. Many contractors noted, however, that because they will have to assume liability for the system's mechanical performance, they will probably increase their normal fees substantially in the initial years of market development, until the "bugs" have been worked out and procedures are well-understood.

Similarly, labor unions foresee no problems in installing and operating STE systems. Possible jurisdictional disputes can be handled by existing arbitration procedures. Union representatives noted, however, that these should be initiated prior to actual construction, because procedures are difficult to change once established. For example, if certain portions of the heliostat or collector are assembled in the field initially, attempts to replace the field work by factory preassembly may be resisted.

3

ESTIMATING SYSTEM SALES AND RESULTANT ENERGY SAVINGS

In the final analysis, the development of STE systems can be justified only on the basis of their potential energy savings, which are a function of actual sales and performance.

As a basis for estimating potential STE system sales and resultant energy savings, we developed a market model (see Appendix L) that integrates many of the data compiled in the course of the conceptual-design and market-analysis phases of our work. Operation of the market model involves four basic steps: defining the total market, determining the potential market, calculating expected sales, and calculating energy savings.

For each year, the "total market" (i.e., both current inventory and new construction in an institutional subsector) was defined based on regional-inventory data (see Appendix M). The total market represents the greatest potential market for STE systems, expressed in square feet of facility space.

Next, the "potential STE market" was determined using life-cycle costs. We developed STE system capital costs, operating and maintenance costs, and supplemental-fuel requirements for each building type in each region of the country.

Yearly cash flows were then calculated for both STE and conventional systems over their lifetimes (generally 25 years), using regional-fuel price projections. To determine life-cycle costs, the model discounted the yearly cash flows according to discount rates identified in our interviews with decision makers in the various institutional subsectors. To simplify the calculation procedures and ensure meaningful results, all inputs were presented in constant 1977 dollars.

Once the life-cycle costs of the STE and conventional energy systems were developed, the portion of new-construction and replacement systems that represents part of the potential STE system market was determined: the regional-price data were used to determine the proportion of the market in which STE systems will offer the lowest life-cycle cost. For example, if the life-cycle costs of the STE and conventional systems are exactly the same, variations in fuel prices and discount rates mean that the STE system will be the lowest-cost choice for half the market; that half was considered part of the "potential" market.

Once the potential market was identified, we estimated actual sales using a Bass diffusion model, which simulates the delays in acceptance by the marketplace from initial introduction to full market penetration. To establish parameters for the Bass model, we examined the diffusion of a number of other energy-system innovations (e.g., heat pumps, conventional total-energy systems).

The final step in operating the market model was to calculate the energy savings that will result from the use of STE systems. Estimated sales (in square feet of collector area) were multiplied by the difference in energy use between the STE and conventional systems, divided by the collector area of the STE system. Energy savings in electrical (kWh) units were then converted to Btu (12,000 Btu/kWh) and added to the thermal (Btu) savings to determine net energy savings.

The outputs of the market model indicate that the national potential market for STE systems is relatively small: sales of thermal STE systems will approach 0.3 million square feet of collector area per year by 2015, resulting in net energy savings of 3.5 trillion Btu per year (see Exhibit 3.a); sales of photovoltaic STE systems will approach 7 million square feet of collector area per year by 2015, resulting in net energy savings of 45 trillion Btu per year (see Exhibit 3.b).

Most of the projected sales of thermal systems (more than 90 percent) will be to federal and state governments

Exhibit 3.a

Thermal STE System Sales and Energy Savings

SOURCE: Resource Planning Associates, Inc.

Assumptions:

DOE Base Case fuel-price scenario
7% real discount rate

- Potential market
- - Collector sales
- Net energy savings

Exhibit 3.b

Photovoltaic STE System Sales and Energy Savings

SOURCE: Resource Planning Associates, Inc.

— Potential Market
- - Collector Sales
... Net Energy Savings

Assumptions:
DOE Base Case fuel-price scenario
7% real discount rate

for use in military installations and colleges located in the Phoenix area. About two-thirds will be in retrofit installations, installed as replacements for obsolete HVAC systems (see Exhibit 3.c).

The sales of photovoltaic systems will be concentrated in Los Angeles as well as Phoenix (see Exhibit 3.d), where those systems are expected to compete successfully with conventional total-energy systems. Elementary and high schools also represent a significant potential market for photovoltaic systems. Again, retrofit installations will predominate.

The outputs of the market model provide a reasonable indication of potential system sales and resultant energy savings. However, the data the model incorporated relate primarily to system costs and performances. Implicit in the model's focus on cost-effectiveness are assumptions about market conditions; for example, that military funding and manpower limitations will be eased, that no significant federal subsidies will be provided to STE system users, and that legal and regulatory barriers to system adoption will be removed. In sum, the results of the model are meaningful only when considered within the context of the overall market in which the optimal thermal and photovoltaic systems will be introduced.

To test the effects that a change in market conditions could have on the estimates of system sales generated by the model, we postulated various levels of federal capital subsidies, and then determined their impacts on collector sales and energy savings (see Exhibit 3.e). A 50-percent capital subsidy would increase sales of thermal STE systems to approximately 18 million square feet per year by 2010. The energy ROI, defined as the net Btu savings per dollar of federal expense, would decline significantly, to 22,000 Btu per year per dollar. A 50-percent capital subsidy would increase sales of photovoltaic STE systems to 20 million square feet per year by 2010, with an energy ROI of 50,000 Btu per year per dollar.

Exhibit 3.c

**Thermal STE System Sales Breakdown
(percent)**

Region	Phoenix	100
Building Type	Military	50
	Colleges	42
	Prisons	5
	Airports	3
Level of Ownership	Federal	51
	State	39
	Local	2
	Private	8
Installation Type	New	35
	Retrofit	65

SOURCE: Resource Planning Associates, Inc.

Exhibit 3.d

Photovoltaic STE Sales Breakdown
(percent)

Region	Los Angeles	92
	Phoenix	8
Building Type	Colleges	32
	Military	28
	Schools	24
	Airports	6
	Prisons	5
	Public-administration buildings and post offices	4
	Hospitals	2
Level of Ownership	Federal	31
	State	38
	Local	24
	Private	8
Installation Type	New	38
	Retrofit	62

SOURCE: Resource Planning Associates, Inc.

Exhibit 3.e

Impacts of Federal Subsidies on System Sales

SOURCE: Resource Planning Associates, Inc.

— Net energy ROI
 - - Annual sales

Assumptions:

7% real discount rate

DOE base case fuel-price scenario

Thermal system cost = \$18.10/ft² of collector in 2010

Photovoltaic system cost = 0.50/peak watt = \$10/ft² in 2010

Non-optimized systems

4

FORMULATING GUIDELINES FOR THE PLANNED DEMONSTRATION PROGRAM

As defined by Sandia Laboratories, the overall objective of the federal STE program is to demonstrate the technical, economic, and institutional viability of STE systems. An important vehicle for achieving this objective is the design, construction, and operation of STE system demonstrations in various market sectors throughout the United States.

Before the demonstrations take place, two large-scale STE experiments will be conducted. The purpose of these experiments is to move STE technology from the laboratory environment into the marketplace by reducing cost and performance uncertainties and ensuring adequate engineering capability and experience. These experiments are scheduled to begin in 1980 and 1981. The first demonstration is expected to be under way by the end of 1981, and the final demonstration to begin in 1984.

As part of our investigation of the institutional market for STE systems, we have formulated preliminary guidelines for selecting sites and conducting the planned demonstration program.

SELECTING SITES

Sandia Laboratories has developed a methodology¹ for selecting sites at which to conduct the STE large-scale experiments. The major site-selection criteria identified are based on technical, economic, insitutional, and social factors. To a large extent, the criteria for the STE experiments can be applied to the STE demonstrations. One criterion that is central to the selection

1. Robert W. Hunke, Methodology for Site Selection of a Solar Total Energy Large Scale Experiment (Springfield, Virginia: National Technical Information Service, March 1977).

of an STE demonstration site, however, is addressed only briefly in the criteria for selecting an experiment site: visibility to the potential market.

The high visibility of an STE demonstration will help speed the adoption of STE systems in several ways. First, a highly visible demonstration will inform both the general public and specific target audiences of the availability of STE systems. Second, it will make essential information on STE system applicability, performance, and costs readily available to potential adopters. Third, a highly visible demonstration will provide rapid feedback regarding target-audience attitudes, and thereby serve to identify potential barriers to widespread adoption early in the commercialization process.

Based on our interviews with institutional-sector decision-makers and energy-market professionals, we have identified three general categories of visibility criteria:

Subsector Characteristics

- The market subsector should be large and growing, in both numbers of buildings and energy use.
- Subsector decision-makers should be highly aware of energy usage and costs, and have indicated commitment to reducing energy use through an active energy-conservation program.
- An active, broad-based, credible network of professional organizations and trade journals should be in place to disseminate information on STE system performance.

Facility Characteristics

- The facility should have innovative features (e.g., architectural designs, unique services such as a hospital with a new burn center) that are already attracting public attention.
- The facility should be providing a perceived good or service to the community (e.g., mental health services, adult education courses).

Regional Characteristics

- The region should have a representative mix of both institutional decision-makers and the overall United States population (measured in terms of factors such as income distribution, employment, and educational background).
- The region should be receptive to energy-conservation measures, as indicated by state and local legislation, in the fields of energy conservation and solar energy.
- The region should be either growing or stagnating. (In the case of a stagnating region, the demonstration would symbolize newness, or revitalization, and thus gain media attention and public support.)
- The region must have sufficient capacity to host professional conferences and conventions, which will foster rapid, widespread dissemination of information, as well as permit on-site inspection.
- The area should have significant additional attractions to ensure effective, continuous, national-media attention.

CONDUCTING THE DEMONSTRATION PROGRAM

Experience in other federally funded programs² has indicated that demonstrations should be based on an explicit strategy comprising certain essential elements. These elements can be applied to the planned federal program to demonstrate STE systems as follows:

1. Develop explicit plans for follow-through after the demonstration. Demonstrations generally constitute only one part of a federal effort to stimulate commercialization. Accordingly, an explicit model of how

2. U.S. Department of Commerce, Analysis of Federally Funded Demonstration Projects: Final Report, 1976.

commercialization will proceed after the demonstration -- and a program staff with both market and technical expertise -- are essential.

2. Clearly distinguish between experimental and demonstration activities. The purpose of a demonstration should be to provide information about an existing technology. In the case of the STE demonstration program, enough time should be allowed for the large-scale experiments to establish the engineering capability of STE systems before the demonstrations begin. If this is not possible in view of planned milestones, the "demonstrations" should begin as "experiments," with as little publicity as possible. Only after engineering capability is established should they be called demonstrations.

3. Conduct the "demonstrations" on as small a scale and with as little initial visibility as possible. Many demonstrations encounter serious difficulties in their initial stages; consequently, too much visibility can cast the entire program in a poor light. A decision regarding the appropriate level of visibility for the STE system demonstrations should be made based on the success of the large-scale experiments in reducing cost and performance uncertainty. Major publicity efforts should be deferred until after the first few demonstrations are successfully under way.

4. Evaluate cost/performance/location trade-offs during the site-selection process. System costs and performances will be largely a function of the location of the demonstrations: a demonstration in areas with less-than-optimal climatic conditions will incur higher costs (for more collectors and land) and possibly perform less reliably (as a result of more cloudy days). On the other hand, a demonstration in less-than-optimal climatic conditions will be more credible to a wider audience. In fact, the decision-makers we interviewed stressed that the demonstration must be in a climatic region similar to theirs for it to be convincing. Interestingly, building type is not considered important. Even an industrial application would be acceptable; the decision-makers are confident that their engineers will be able to adapt an STE system to meet their buildings' specific requirements. The decision-makers did, however, express a preference for having the demonstration conducted in a retrofit rather than new application.

5. Identify and then specifically address the target audience. The target audience is the group of individuals or institutions whose decisions the demonstrations are seeking to influence. That audience should be clearly identified and its needs and concerns specifically addressed. The target audiences of most immediate concern in the STE demonstration are utilities, facility administrators and engineers, and architect/engineers. In addition, the public represents an important target group in the institutional sector; many public groups such as legislatures and school boards will be passing laws, appropriating funds, and establishing energy-system evaluation procedures that will affect STE market potential.

6. Include all potential participants, from manufacturers to potential users, in planning the demonstrations. A technical committee consisting of representatives of all decision-makers should be formed to ensure that important issues are addressed in the demonstrations, and to promote communications about the demonstration results through trade journals, regional conferences, and informal discussions.

7. Allow for innovations by the adopters. The experience of the Department of Housing and Urban Development's solar-energy demonstration program indicates that when potential adopters are provided precise specifications for a system, their response is lower than it is when they have the option to fit the system to their particular needs. The STE demonstrations should be sufficiently flexible to encourage innovation by potential system adopters.

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