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# ENVIRONMENTAL EFFECTS OF SOLAR THERMAL POWER SYSTEMS

TITLE

## COMMUNITY APPLICATIONS OF SMALL SCALE SOLAR THERMAL ENERGY SYSTEMS

FEBRUARY 1981

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# Community Applications of Small Scale Solar Thermal Energy Systems

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## CREDITS

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# ABSTRACT

Rapid technological development of small scale solar thermal energy systems (STES) may bring them "on line" before communities are adequately prepared for them. This report contains information for analyzing and siting STES, along with discussions of community applications, impacts and incentives. By providing this information to community planners, it is hoped that barriers to STES utilization can be anticipated and mitigated.

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# SUMMARY

Significant barriers remain in the path of community small scale thermal energy system (STES) programs. Research on successful community solar programs indicates that strong community support is necessary for success (Hamrin, 1979; Senauke, et al., 1980). Communities must be adequately informed, enthusiastically supportive, and possess sophisticated, experienced energy planning capabilities to implement and maintain STES programs. However, potential industrial or community users of STES are poorly informed about the nature, capabilities and limitations of these technologies (McDonnell-Douglas, 1977; SERI, 1979; Whitney, et al., 1980). Although the public is supportive of solar energy as a future source of energy (CEQ, 1980), these attitudes are not yet manifested in consumer purchasing behavior, especially for the more "advanced" solar thermal energy systems (Whitney, et al., 1980).

Communities, in general, lack the resources (capital, labor and information) necessary to successfully plan and implement a community STES program. The first step of defining community energy goals and needs has been accomplished by only a few communities throughout the United States (although interest and activities are increasing rapidly). The variable forms of energy output and sensitive load patterns of STES require thorough analysis and matching with energy demand patterns. Careful analyses are also required to properly site the systems because of their sensitivity to physiographic conditions (topography, geology, soils, and adjacent land uses). In addition, local agencies will have to comply with complex regulatory requirements in providing and protecting solar access, protecting health, safety and the environment, interfacing with utilities (rates, backup wheeling and excess power purchase) and in siting, designing, building and operating the systems.

Further technical development and cost reductions are necessary before STES are competitive. However, escalating fuel prices, technological development and government incentive programs may bring these systems to a point of economic competitiveness within the next decade (DOE, 1980). Engineering codes and performance standards are needed to protect consumers from poorly engineered or sited systems and to protect workers and the public from potentially serious health, safety and environmental problems (Ullman, et al., 1979). These codes and standards are currently being developed for large scale solar systems (Riley, et al., 1979). In addition, complex operation and maintenance requirements may necessitate on-site operation and maintenance personnel.

Early application concepts limited STES to electric power production. However, STES may also be used to obtain process heat, or in total energy systems to produce both power and useful heat. While thermal applications are appropriate for industries, integration of small scale STES into existing urban patterns to provide heat for low temperature applications (e.g., space heating and cooling) will be difficult and probably uneconomical (Boobar, et al., 1978). Thus even small scale STES, by nature, appear best suited for centralized applications by industries

(including agribusiness) and small utility systems ammenable to community ownership.

## References

Boobar, M.G., et al. Commercial Applications of Solar Total Energy Systems. Rockwell International, Atomics International Division, Canoga Park, California (1978).

Council on Environmental Quality (CEQ). Public Opinion on Environmental Issues. Resources for the Future (1980).

Hamrin, J. "Energy Saving Homes: Don't Bet on Technology Alone." Psychology Today (April, 1979).

McDonnell Douglas Aeronautics Company. Industrial Applications of Solar Total Energy. Final Report, SAN/1132-2/1 (1977).

Riley, J.O., et al. Standards, Building Codes, and Certification Programs for Solar Technology Applications. Solar Energy Research Institute, Golden, Colorado (July 1979).

Senauke, S., et al. Survey of Successful Community Applications of Solar Technologies. Master's Thesis Project, School of Architecture and Urban Planning, University of California, Los Angeles (1980).

Solar Energy Research Institute (SERI). Organized Labor and Solar Energy. SERI/TR-62-148 (1979).

Ullman, A.Z., et al. Worker Health and Safety in Solar Thermal Power Systems. Volumes I-V, UCLA 12-/1210-1215 (1979).

U.S. Department of Energy (DOE). A Guide to the Solar Thermal Program: FY 1980. Division of Central Solar Technology, Solar Thermal Branch, Washington, D.C. (1980).

Whitney, S., et al. Solar Augmented Applications in Industry. Final Report Phase I. Gas Research Institute (February 1980).

# 1.0 INTRODUCTION

## 1.1 Background

This report contains information for the evaluation of community applications, impacts, barriers and incentives of small scale solar thermal energy systems (STES). STES are defined as solar technologies, less than 10 megawatts electrical (MWe) or 50 megawatts thermal (MWt) rated capacity, that concentrate or reflect radiant energy from the sun to produce thermal energy, electrical and/or mechanical power. This definition is intended to exclude solar flat plate collector systems, solar photovoltaic systems, and large facilities that would likely be managed by conventional utilities.

The current legislative and technological drive to develop and promote STES may bring several "on line" before communities can adequately plan for their successful introduction and utilization. To date, energy planning activities have primarily been the responsibility of large energy corporations and utilities. Small scale systems, however, do not by nature require centralized management and control. Thus, communities and individual end users of STES may be confronted with complicated planning and administrative procedures to implement individual programs. These requirements represent a significant barrier to the utilization of STES systems. Thus, this report is intended as a source of information on the major issues, impacts and problems of community STES applications. Table 1-1 summarizes the purpose, objectives and assumptions of this report.

Table 1-1

Report Purpose, Objectives and Assumptions

| | |
|---|---|
| Purpose: | To overview the major issues, problems and impacts of community STES applications. |
| Objectives: | Review pertinent research.<br>Assess potential community STES applications.<br>Overview the resource, socioeconomic and environmental impacts of community STES utilization.<br>Overview regulatory requirements and utility roles in community STES applications.<br>Evaluate economic incentive programs.<br>Produce readable report overviewing the major issues, problems and impacts of community STES applications |
| Assumptions: | STES are technically viable, economically competitive and available for use. |

Since neither STES, nor the market are currently well defined, the establishment of detailed planning guidelines would be premature. However, on-going research in many public and private institutions is beginning to address many of the potential issues and problems associated with community STES applications (Marriott and Kiceniuk, 1979). Table 1-2 provides a summary of the general questions addressed in each major section of this report. A more specific list of pertinent site evaluation criteria is given in Section 1.3.

## 1.2 STES Evaluation and Siting

The potential problems of dispersed introduction of STES into the community setting necessitates a careful evaluation of physical and socioeconomic impacts. Many of the impacts from the introduction and use of STES will be different from those of conventional energy systems because of: 1) the novelty of the technology, 2) intermittent nature of the energy output, 3) variations in modes and temperatures of available energy, 4) electrical grid interface, and 5) dispersed nature of energy generation. Since neither the technology nor the market is well defined at present, a detailed evaluation manual has not been attempted. Rather, the criteria and a logical sequence of analysis for determining optimal end-uses and sites are presented.

This matching and siting process is based on two fundamental premises: 1) that the match of community energy needs with STES capabilities be as close as possible in energy form, load profile, economics and system operation, and 2) that the design, siting, construction and operation of STES must be compatible with the physical and socioeconomic resources and constraints of a host community.

## 1.3 Sequence of Analysis

A three step sequential evaluation process (Figure 1-1) is proposed to provide a logical sequence of analysis and indicate the nature and extent of energy supply and demand and site information necessary for proper STES evaluation (Ashworth and Neuendorffer, 1980).

### Step 1. Energy Compatibility Analysis

The unusual environmental sensitivities of STES severely limit their output capabilities and therefore applications. Before resources are allocated for site or design analyses, the nature and extent of potential applications should be carefully researched. The three major steps in this process are: 1) to profile the community energy goals, 2) to analyze community energy demand patterns, and 3) to profile STES energy output capabilities.

A priority list of community energy program goals that accurately reflect community attitudes and expectations should be established. If a community strongly supports renewable energy programs, it will be more likely to allocate the resources, time and effort necessary to make such programs successful.

The energy demand of the target community or individual end users should be profiled in terms of the quality, form, load characteristics, delivery

## Table 1-2

## Issues and Questions Addressed in this Report

| Report Section | Issues/Questions |
|---|---|
| 1.0 | What is the proper sequence of activities to be taken by the community in assessing its STES potential?<br>What information is required for this analysis and where may it be found? |
| 2.0 | What are small scale solar thermal energy systems?<br>How do they function?<br>What are the various subsystems?<br>How do they compare?<br>Are there serious resource constraints on STES development?<br>What are the physical limitations on siting?<br>What are the major planning problems of STES? |
| 3.0 | What are the potential community applications of STES? |
| 4.0 | What are the on-site and off-site health, safety and environmental impacts of STES?<br>What environmental parameters should be studied and monitored? |
| 5.0 | What roles could regulatory considerations play in the commercialization of STES?<br>What effect will recent federal legislation have on STES commercialization? |
| 6.0 | What federal, state and local ordinances, codes and regulations apply directly to STES siting and utilization?<br>What institutional and/or regulatory tools may be used to properly site and develop STES facilities? |
| 7.0 | How can STES be integrated into the urban setting? |
| 8.0 | What are peoples' attitudes toward solar systems in general and STES in particular?<br>Do potential consumers have sufficient information to adequately analyze the applicability of STES?<br>What, if any, impacts will STES commercialization have on lower income energy consumers? |
| 9.0 | What are the advantages and drawbacks of various types of economic incentive programs?<br>What federal, state and private incentive programs are currently available for community solar programs that could be applied to STES?<br>Where may additional information be obtained on STES? |

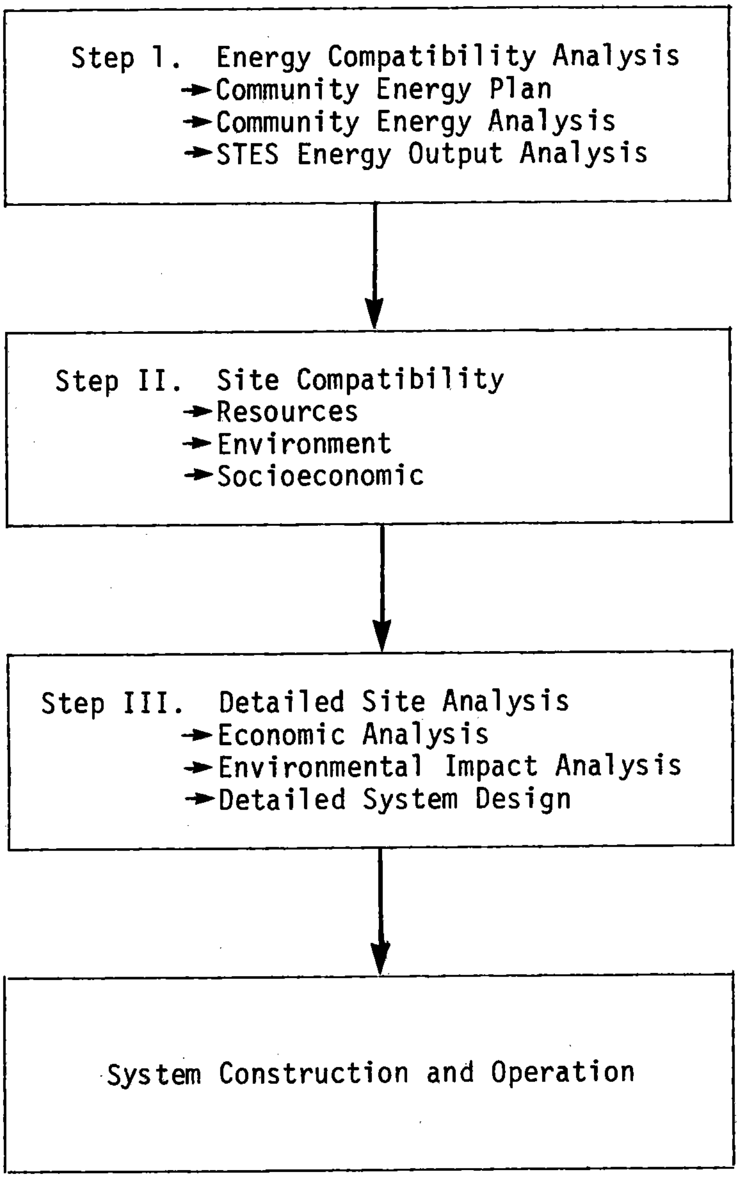


Figure 1-1 STES Evaluation and Siting Sequence (modified from Ashworth and Neuendorffer, 1980)

patterns costs and availabilty of energy. The energy demand characteristics that would currently favor STES applications include: 1) combined electrical (or mechanical) power and higher temperature thermal energy demands, 2) load requirements that coincide with peak daily and seasonal variations in direct solar insolation, 3) energy demand relatively insensitive to interruption, 4) low energy conservation potential (that would offset the need for additional energy), and 5) high energy costs that are expected to escalate. The data from this demand analysis should be used to profile current and future energy demand characteristics by economic sector, subsector, and where warranted, by individual users.

Finally, the available technical information on STES design and output capabilities should be analyzed. STES energy output capabilities may change rapidly with technological development and a changing regulatory climate. Data from the energy demand and system output profiles should then be composed to eliminate incompatible energy applications.

### Step 2. Site Compatibility Analysis

The resource, environmental and socioeconomic impacts and demands of STES must be compatible with those of the target community setting to be fully accepted and integrated. The U.S. Department of Energy (1979) lists and discusses twenty-five social indicators that may be important in assessing community impacts of solar technologies. Table 1-3 contains a modified list of social and physical criteria important in the evaluation of site impacts and demands of STES, and indicates the location of discussion of each in this report. The relative importance of each criteria will vary by STES use and site, requiring individual analysis for each. For instance, the land requirements and land use impacts are far more important in densely populated areas than in rural areas.

The information provided by this analysis should be useful not only for selection and siting of STES, but will also provide baseline data for late evaluation of the community impacts of STES introduction and utilization. Once compatible energy applications and sites are identified, government incentive programs should be reviewed to determine the feasibility of reducing investment costs and risks.

### Step 3. Detailed Site Analysis

Once appropriate applications and sites are chosen, detailed economic, environmental and STES system design (including storage or backup systems) provide the information necessary for project construction and operation. These analyses are highly site and use specific and therefore beyond the scope of this report. The requirements for these analyses are well established and within the capabilities of any number of public and private research institutions.

Table 1-3

Site Specific Evaluation Criteria

| Evaluation Criteria | Report Location (Section) |
|---|---|
| 1. Resource availability | 2.2 |
| Capital | |
| Land | |
| Water | |
| Materials and labor | |
| 2. Physical siting limitations | 2.3 |
| Geological | |
| Meteorological | |
| 3. Health, safety and environmental effects | 4.0 |
| One-site impacts | 4.2 |
| Health and safety | 4.2.1 |
| Environmental | 4.2.2 |
| Off-site impacts | 4.3 |
| 4. Utility issues | 5.0 |
| Regulatory overview | 5.2 |
| Recent Federal legislation | 5.3 |
| 5. System regulation | 6.0 |
| Project assessment | 6.2 |
| Building codes and standards | 6.3 |
| Environmental regulation | 6.4 |
| Zoning | 6.5 |
| Solar access | 6.6 |
| 6. Urban design integration | 7.0 |
| 7. Social considerations | 8.0 |
| Consumer attitudes and behavior | 8.2 |
| Information and education | 8.3 |
| Community support | 8.4 |
| Equity considerations | 8.5 |
| 8. Economic assistance | 9.0 |
| Incentive evaluation | 9.2 |
| Incentive selection | 9.3 |
| Overview of current incentives | 9.4 |

## 1.4 References

Ashworth, J.H. and J.W. Neuendorffer. Matching Energy Systems to Village Level Energy Needs. SERI/TR-744-512 (June 1980).

Marriott, A.T. and T. Kiceniuk. "The Small Community Solar Thermal Power Experiment." In AS/ISES Proceedings of the 1980 Annual Meeting. G. Franta and B. Glenn (eds.), Vol. 3:1:519-523.

U.S. Dept. of Energy (DOE) and George Washington University. Social Assessments of On-Site Solar Energy Technologies. HCP/R4040-02 (April 1979).

## 2.0 TECHNICAL EVALUATION

This section of the report provides an overview of STES along with a review of the resource requirements and physical constraints of the systems. The intent is to explain how each of the four major small scale solar thermal energy systems work, and to overview possible physical and resource constraints that could limit system utilization. The descriptive nature of this section is due to the evolving nature of the technologies and the intent of the authors to present a non-technical overview of STES.

### 2.1 Technical Description

#### 2.1.1 Introduction

The purpose of this section of the report is to provide general information on STES technologies and applications. A more detailed technical discussion of STES is presented in Appendix A. An analysis of STES subsystems is given followed by a description and evaluation of the four major types of STES; central receivers, parabolic troughs, parabolic dishes, and fixed mirror hemispherical bowls.

The key elements, or subsystems of a solar thermal energy system are given in Figure 2-1. Radiant energy from the sun is collected by reflecting surfaces which redirect and/or focus it on a receiver. A "heat transfer" or "working" fluid is heated as it circulates through the receiver, then is transported to a heat engine where the heat is converted into mechanical energy. Some energy may be diverted and stored in an energy storage subsystem to buffer against fluctuations in insolation, thermal shock to system components, or to alter system energy load capabilities.

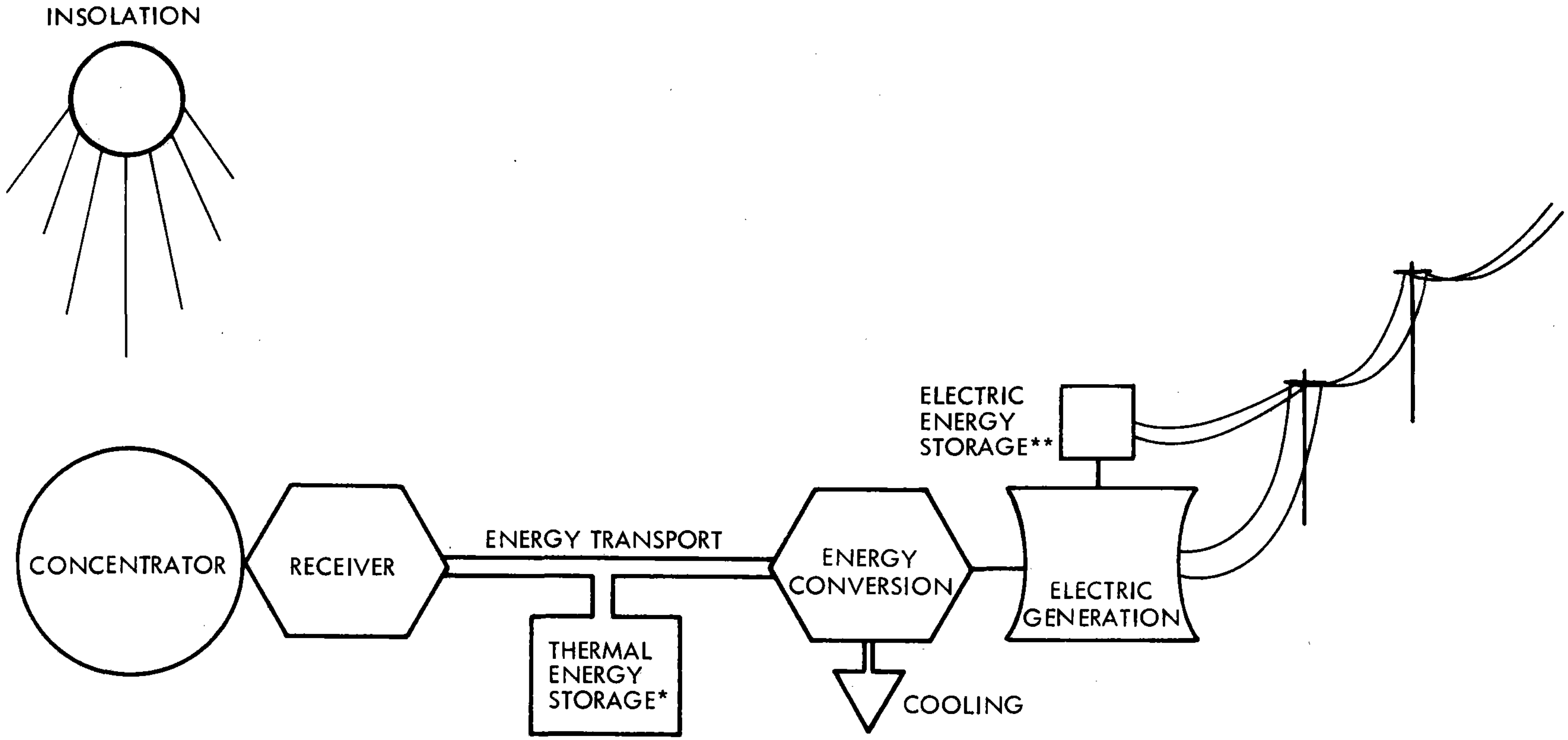
There are two basic approaches to solar thermal energy systems; central receiver and distributed receiver systems (Figure 2-2). Central receiver systems consist of a large field of tracking heliostats (i.e., mirrors) which reflect and concentrate solar radiation onto a centralized elevated receiver. Distributed systems collect and concentrate sunlight on separate modules, each with a self contained collector and receiver. Thermal energy collected at the receiver can either be transported by a working fluid to a central electrical generating facility, or can be converted to electricity at each module through the use of a small heat engine.

#### 2.1.2 STES Subsystems

The subsystem options for central receiver and distributed receiver systems are given in Figure 2-3. The collector and receiver subsystems distinguish the major types of STES and will be discussed in greater detail.

##### Tracking Subsystems

To properly focus incident solar radiation on a receiver, a solar thermal energy system must adjust to daily and seasonal variation in the relative position of the sun. Parabolic trough and fixed mirror



*Storage prior to conversion may be either thermal or chemical
**Storage after conversion may be either electric or mechanical

Figure 2-1 Solar Thermal Energy Subsystems

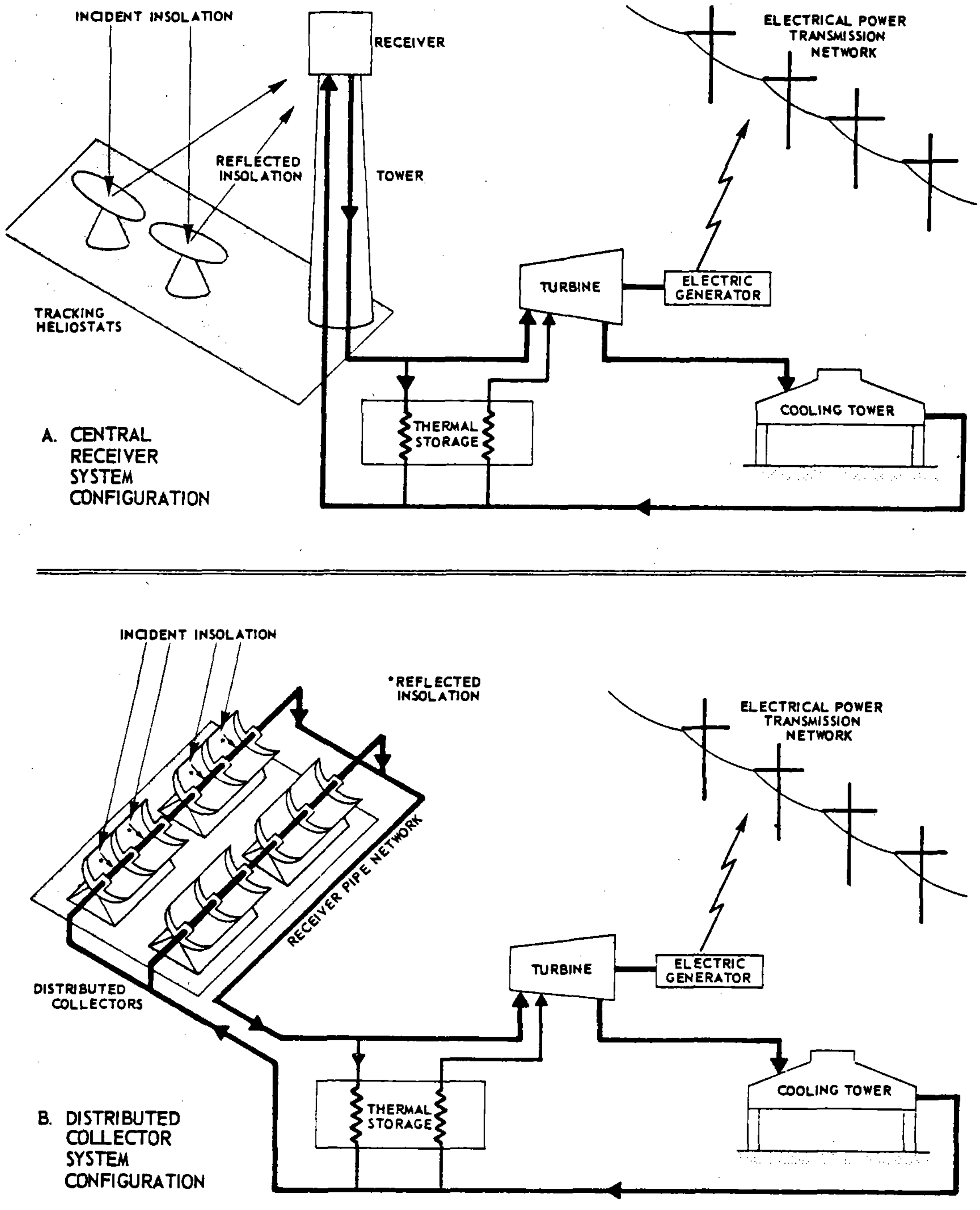
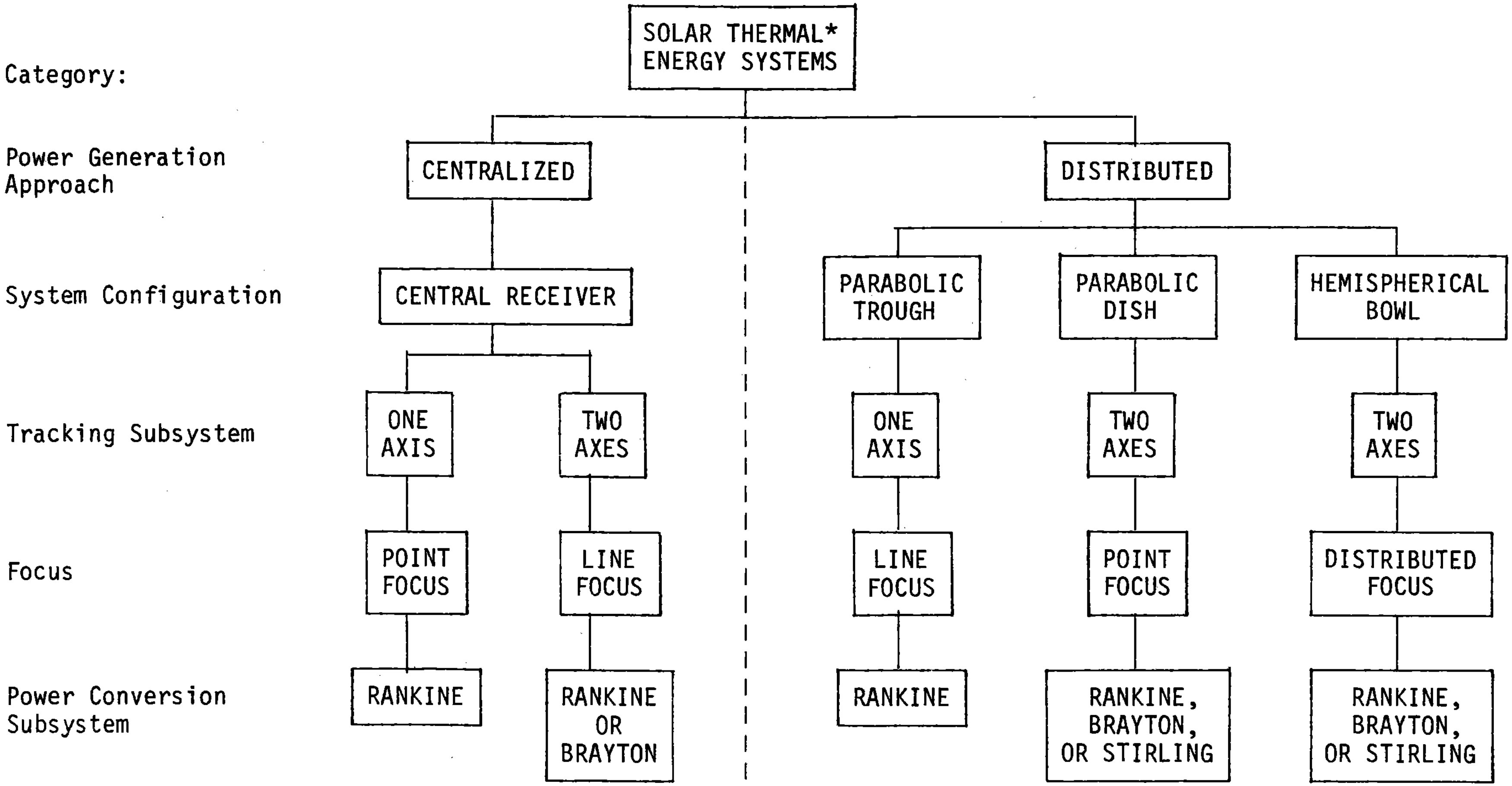


Figure 2-2 Solar Thermal Power System Configuration



* Subsystem option information from SERI, 1979 and JPL, 1979

Figure 2-3 Subsystem Options Within the Central Receiver and Distributed Collector System Approaches hemispherical bowl systems do not require accurate sun tracking mechanisms, but are limited in their capabilities to concentrate solar energy. These collectors have large solar incident radiation acceptance angles, have a simple single curvature design, and can achieve concentration ratios of 10 by orienting their axis of rotation perpendicular to the seasonal north-south path of the sun (Kreith and Kreider, 1978).

The more complex collectors of parabolic dish or central receiver systems track the sun along two axes and can achieve concentration ratios of over 20. Thus, sophisticated tracking systems allow for greater concentration of sunlight, but are more costly and technically complex.

### Power Conversion Subsystems

Power conversion subsystems convert thermal energy into mechanical or electrical energy. Central receiver systems convert thermal energy to electrical energy in one large heat engine (generator) unit. In distributed systems, smaller heat engine (generator) units are located in close proximity to the collectors. Both approaches to power conversion may use the same types of heat engines.

Heat engines have been developed to operate at a wide variety of temperatures. Low temperature systems (130 to 180°F) which rely on organic fluids (such as freon) can be extremely dependable but are relatively inefficient. Higher temperature engines (similar to gas turbines in aircraft engines) are more efficient and can be used for temperatures of over 1400°F. The active circulation of large amounts of extremely hot fluids may increase system health and safety problems (Section 4).

The principle heat engines under consideration for STES are Rankine, Brayton and Stirling cycle engines. These engines can be used interchangeably. Energy conversion efficiences depend on the types of engine, working fluids used, the size of the engine and the type of heat recovery system employed. Complete descriptions of these engines, along with a comparative overview of conversion efficiencies can be found in Appendix A (OTA, 1978).

### Energy Storage Subsystems

STES facilities may require energy storage capacilities to buffer against fluctuations in insolation, thermal shock to system components, or to alter system energy load capabilities. Power output may be buffered or extended by use of thermal or non-thermal (mechanical, electrical or chemical) storage systems, fossil fueled back-up systems, or the use of a conventional electrical utility grid system.

Thermal energy storage systems store energy prior to the conversion to electricity as sensible heat (heating with no phase change), latent heat (heating with a phase change) or in a thermochemical reaction which will release heat when the reaction is reversed (Table 2-1). The latter two systems are still in a preliminary design stage.

## Table 2-1

## STES Energy Storage Systems Concepts

| THERMAL STORAGE | NON-THERMAL STORAGE |
|---|---|
| 1. Sensible Heat<br>-oil rock<br>-oil<br>-oil/salt<br>-salt<br>-steel ingot | 1. Mechanical<br>-pumped hydro<br>-compressed air<br>-flywheel |
| 2. Latent Heat<br>-pressurized water<br>-eutectic salts | 2. Electric<br>-lead acid battery<br>-hydrogen fuel cell<br>-redox batteries<br>-superheating conducting magnet |
|  | 3. Chemical<br>-heat of dehydration<br>-chemical reactants with high enthalphy of reaction<br>Example:<br>$CH_4 + H_2O \overset{\text{heat}}{\underset{\text{catalyst}}{\rightleftarrows}} Co + 3H_2$ |

Reference: Ullman & Sokolow, 1979

In comparing storage systems and media characteristics of the total solar process such as temperature requirements of the heat engines, collector capabilities, load requirements and insolation availability should be considered (Duffie and Beckman, 1974). Higher temperature systems, such as parabolic dish systems may require non-thermal storage systems such as flywheels, advanced batteries or electrolysis (Caputo and Truscello, 1976). A more detailed discussion of energy storage systems may be found in Appendix A.

### 2.1.3 Major Types of STES

There are four major types of small scale solar thermal energy systems; central receiver, parabolic trough, parabolic dish and hemispherical bowl. This section will briefly describe and discuss the important subsystems of each system. A more detailed discussion and examples of each system are presented in Appendix A.

#### Central Receiver

A central receiver system consists of a field of tracking mirrors (or heliostats) that reflect solar radiation into an elevated central receiver (Figure 2-4). Major components of a central receiver system include:

- Heliostats - arrays of flat or slightly focused tracking mirrors which reflect incident sunlight into a receiver. The heliostats are continually focused on the receiver during operation. At night, or in adverse physical conditions they may be defocused in a more protected position.
- Tower - a tower is used to elevate the receiver in full view of the heliostat field.
- Receiver - A centralized receiver absorbs the energy reflected from the heliostats. The receiver transfers thermal energy to a working fluid for transport to a turbine for conversion to electrical or mechanical power.
- Heat transfer media - Media choice varies with power conversion cycle selected. Steam, air and helium are best suited for Rankine, open cycle Brayton and closed Brayton respectively.

The Barstow Central Receiver Pilot Plant is capable of generating 10 MWe net directly from insolation and 7 MWe net from a duel media rock and oil sensible heat storage subsystem. The primary working media are water and steam. A 12.5 MWe (gross) Rankine cycle turbine generator (with a 2.5 MWe minimum output) provides electrical power.

#### Parabolic Dish

Parabolic dish systems (also known as point focusing, distributed receiver systems) employ two-axis tracking parabolic dish collector and receiver modules to generate temperatures from 200 to 3000°F to produce heat

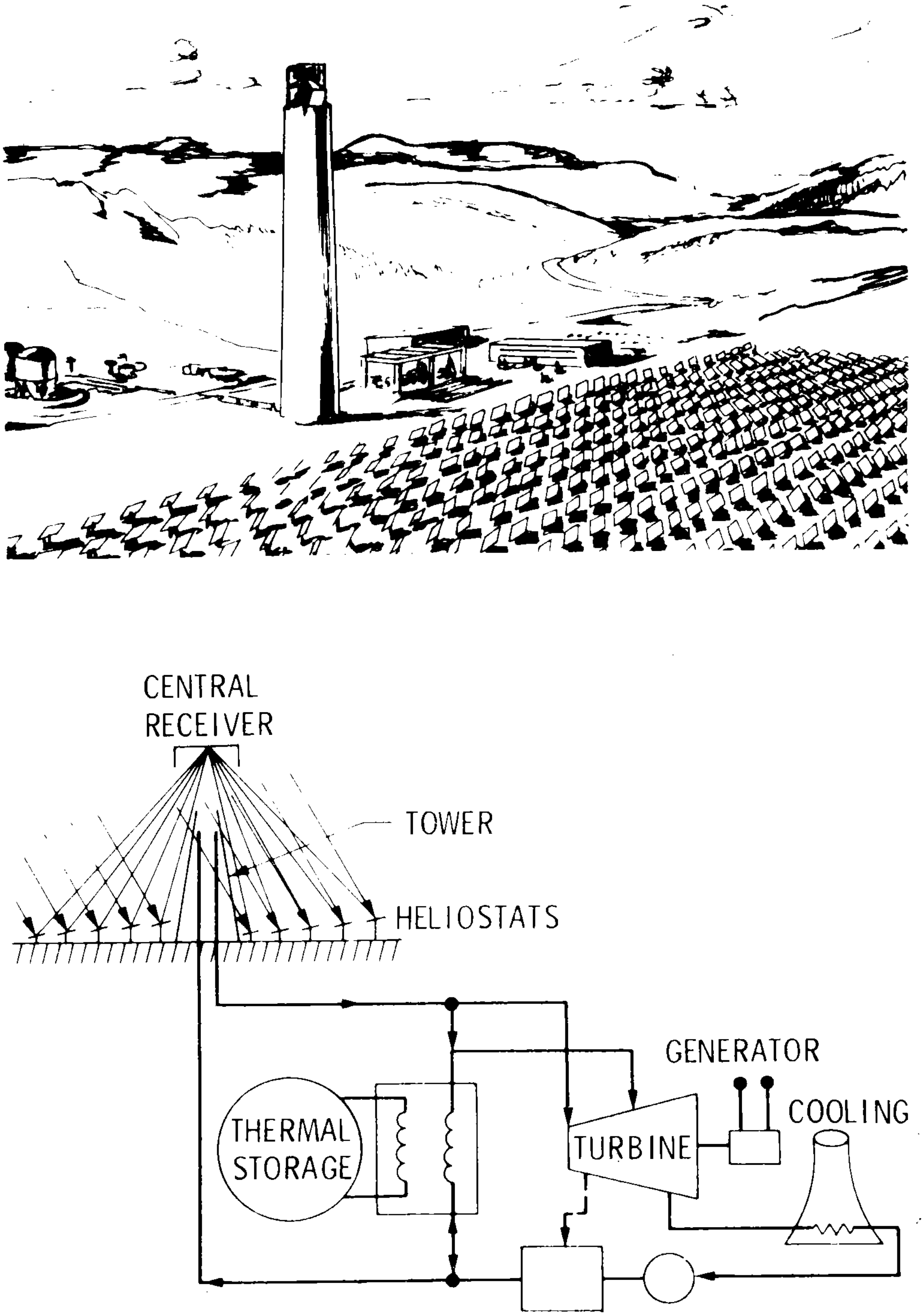


Figure 2-4 Point Focus Central Receiver Concept

energy, electrical and/or mechanical power production (Figure 2-5). Electrical generating modules consist of a parabolic dish concentrator, a receiver and a power conversion unit. A typical module generates electricity in the range of 20-30 KWe. Process heat applications require a heat transport subsystem to transfer the heated working fluid to the area of use.

A 2 MWe small community parabolic dish system distributed system (with an organic Rankine cycle engine) is currently being planned by the U.S. Dept. of Energy (Marriott and Kicenuik, 1980). The parabolic dish collector is being developed by General Electric and the Jet Propulsion Lab is managing power plant design and development. A site should be selected and the system operational by 1983. The system will be connected to the utility grid of the selected community. The objective of this experiment is to determine the feasibility of using STES for small community utility applications.

### Line Focus Parabolic Trough

Parabolic trough systems reflect and concentrate incident solar radiation onto a linear receiver, containing a heat transfer medium, located on the focal line of the trough (Figure 2-6). Parabolic trough collectors (with single axis tracking) can concentrate solar radiation up to 40 times with a possible temperature range of from 600-900°F. A cylindrical receiver configuration is most commonly used for higher operating temperatures (OTA, 1978).

A 150 KWe line focus parabolic trough systems is currently in operation near Coolidge, Arizona, to power a deep well irrigation system in the summer (Anonymous, Solar Thermal Report, 1980). The system consists of a 23,040 ft$^2$ Acurex parabolic trough collector field. The working fluid (Caloria-HT-43) is heated to 450°F and passed through a heat exchanger where toluene is heated to drive an organic Rankine cycle turbine. The system has a 6-hour storage capacity and is used to irrigate 200 acres of cotton. About 70 percent of the annual electrical requirements for a 100-home community could be provided by this system.

### Fixed Mirror Hemispherical Bowl

using a fixed reflectors along the circumference of a circle, onto a movable receiver which follows the focal line coincident with the position of the sun (Figure 2-7). The world's largest hemispherical bowl is currently under construction near Crosbyton, Texas. The fixed, hemispherical 65 foot dish collector reflects and concentrates solar radiation onto a movable cyclindrical receiver. The concentration ratio of 600 will generate temperatures up to 1300°F to produce steam to drive a turbine generator at an overall system efficiency of 15 percent. Plans are in the making to build 10-200 foot dishes to provide 5 MWe for Crosbyton.

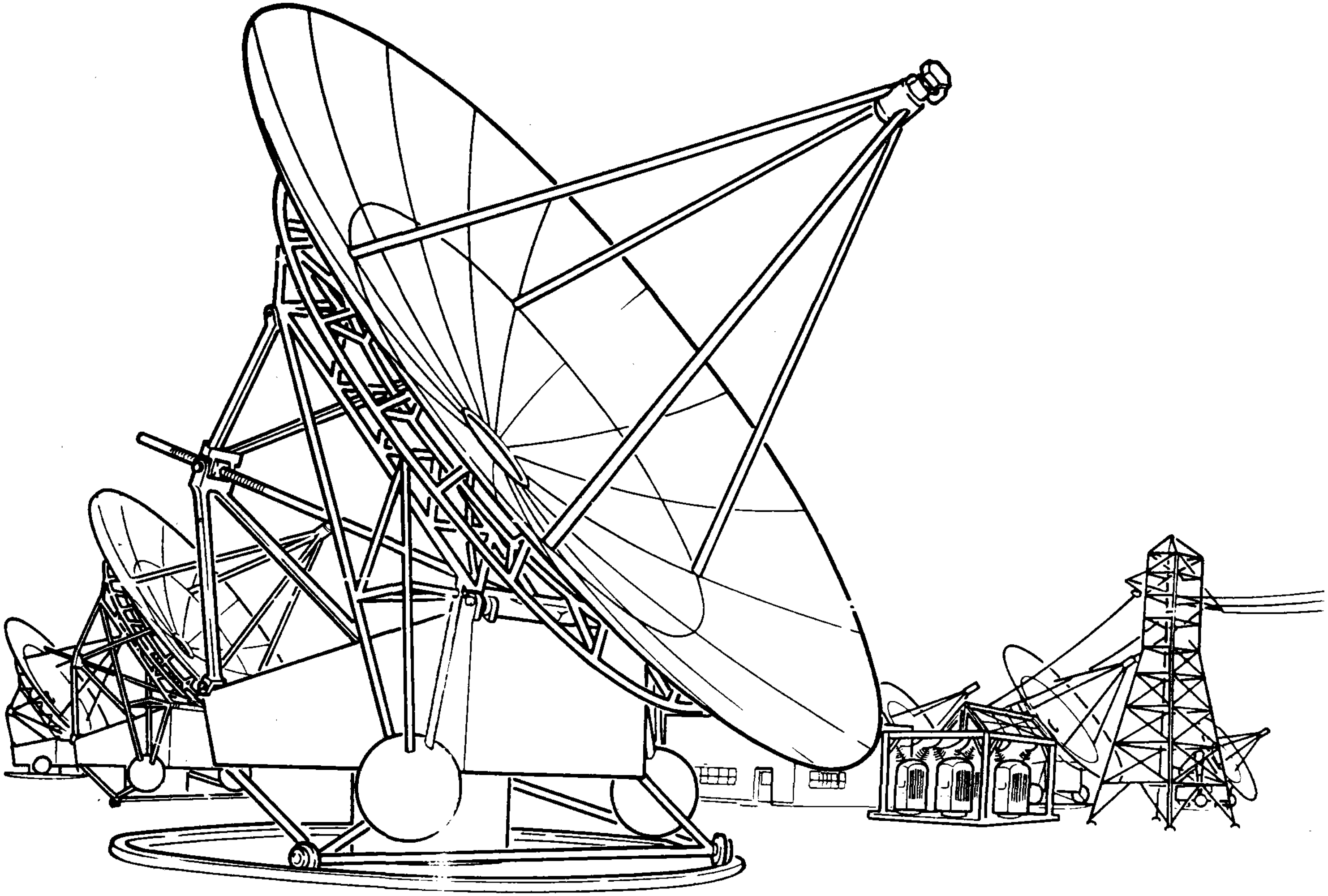


Figure 2-5 Point-Focus Distributed Receiver Concept
Reference: JPL, 1978

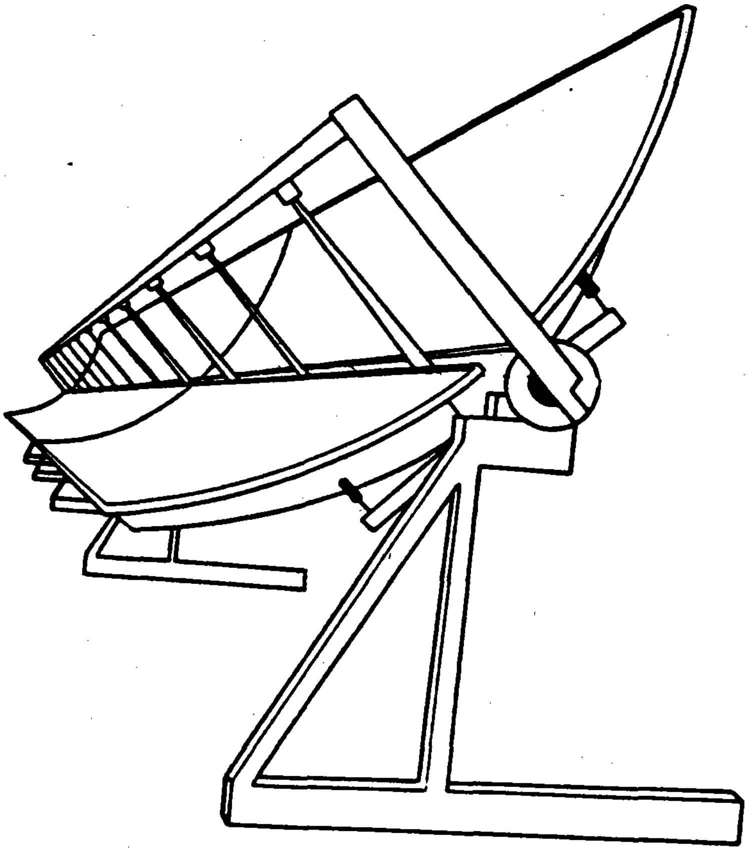


Figure 2-6 Line Focus Distributed Receiver Tracking Collector (Reference: SERI, 1980)

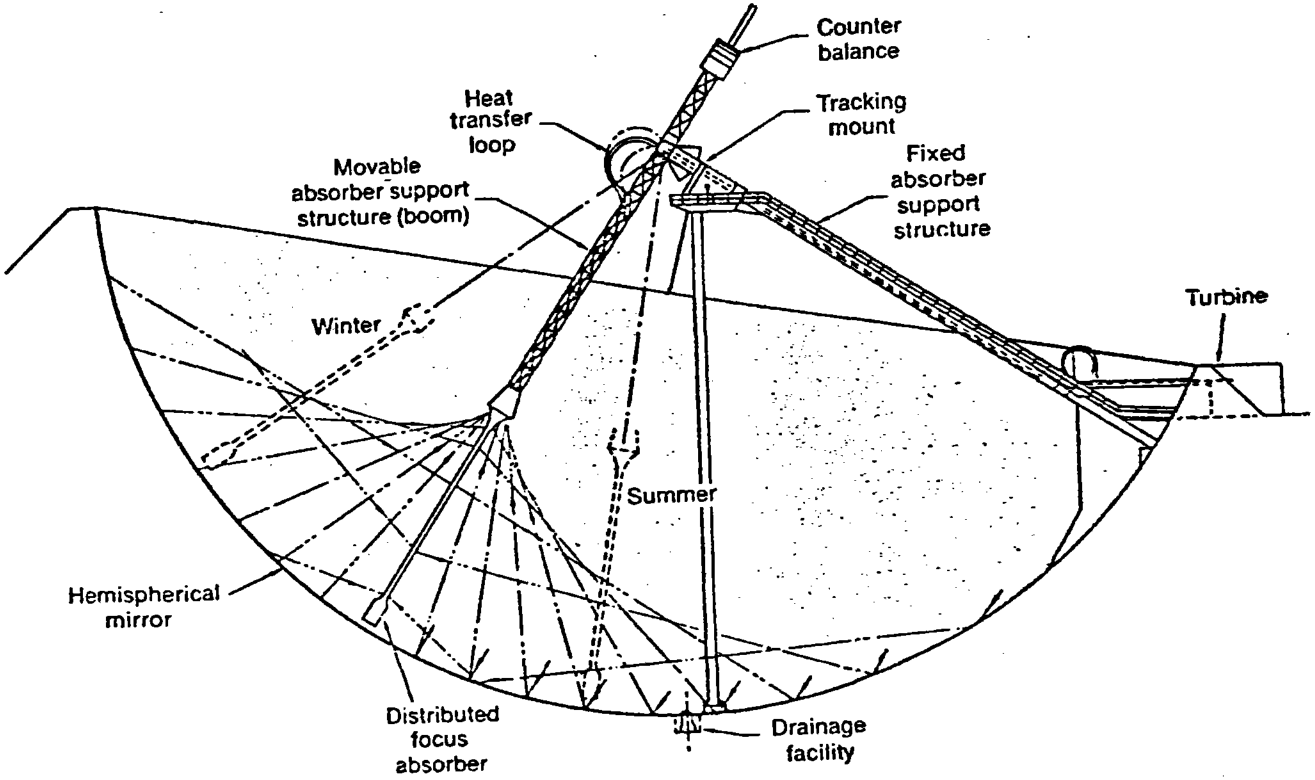


Figure 2-7 Cross-Section of Stationary Hemisphere Concentrator (Reference: Truscello, 1978)

### 2.1.4 System Comparison

Table 2-2 summarizes several of the important design features of the four generic types of STES. These figures are presented as rough preliminary comparisons because of several problems including:

- testing by different companies, under a wide range of assumptions and test methodologies.

- the size of a system can effect other parameters (i.e., efficiency, operating temperatures).

- data on some systems is lacking or incomplete.

- definitions (including overall efficiency) have not been standardized.

Each generic type of STES has an optimum output capability based on cost, and system efficiencies. The most common tradeoff is between economies of scale and system efficiencies and electrical and thermal energy transport costs. Central receiver systems appear to have optimum output capabilities at 100 MWe. Parabolic/central generating systems, because of thermal losses from field piping, have fairly large optimal output capacities (f10 MWe). Parabolic dish/distributed generating systems are quite versatile with a wide operational output range of between 15 KWe and 15 MWe (Ullman, *et al.*, 1979). Line-focusing parabolic trough systems are limited in size due to structural and solar concentration limitations. No optimum size has yet been determined for these or hemispherical bowl systems.

The mechanical failure rates (Table 2-2) and subsequent worker health and safety problems (Section 4) are also important in comparatively evaluating the four systems. For an equivalent power rating of 10 MWe, distributed systems appear to be more vulnerable to failure than central systems. Ullman, *et al.*, (1979) conclude that this is due primarily to the complexity, redundancy and large number of components in distributed systems.

Table 2-3 presents a summary of the relative advantages and disadvantages of the four generic types of STES. Distributed parabolic trough and dish systems offer the capability to incrementally add generating capacity when needed. This could allow substantial savings in investments in additional generating capacity.

### 2.1.5 Technical Planning Issues

The novelty and unconventional workings of STES present many difficulties in system siting and planning. These include:

- the diurnal nature of energy production

- the sensitivity of the systems to climatic and geographical conditions (a 400 MWe coal plant will generate 400 MWe anywhere)

Table 2-2

Summary of STES Design Features (Crosbyton Solar Power Project, 1979; General Electric Space Division, 1978; JPL, 1978; Kreith and Kreider, 1978, Thornton, et al., 1979; Ullman, et al., 1979; Wachtler, et al., 1977

| System | Module Size (ft) | Temperature Range (°F) | Solar Concentration Rates | Total Annual Failures/ 10 MWe | Scale (MWe) | Tracking | Distribution |
|---|---|---|---|---|---|---|---|
| Central Receiver | -- | ∿800 - 2000 | 1000 - 3000:1 | 1.1 - 18 | 10 - 100 | 2 axis | Centralized |
| Parabolic Dish/ Distributed Receiver | ∿22 dia. | ∿200 - 2400 | <1000:1 | 300 - 2400 | .015 - 500 | 2 axis | Distributed |
| Parabolic Trough | (2x10) to (9x20) | ∿300 - 650 | <100:1 | 180 - 1100 | -- | 1 axis | Distributed |
| Hemispherical Bowl | 11 to 200 dia | ∿500 - 1300 | 30 - 600:1<br>$\bar{x}$ = 115:1 | -- |  | fixed, with 2 axis tracking receiver | Distributed |

## Table 2-3

### Relative Advantages and Disadvantages of the Four STES Configurations (Curto, 1977; Harrigan, 1979; Kreith and Kreider, 1978; Truscello, 1978; Ullman, *et al*., 1979)

| System | Advantages | Disadvantages |
|---|---|---|
| Central Receiver | - no long distance transport of working fluids<br>- fewer leaks, failures and thermal loses<br>- high concentration ratios ($\sim$1000)<br>- high temperatures possible (up to 2190°F) | - longer transmission lines<br>- intricate, costly heliostat tracking<br>- heliostat design, operation and maintenance requirements may be high<br>- large, flat tracts of land required<br>- highest efficiences and operational temperatures in larger facilities<br>- receiver malfunction shuts down the entire system<br>- requirements for cooling water |
| Parabolic Dish/ Distributed Receiver | - ease and cost of incremental capacity additions<br>- mass production of modular units<br>- wide range of efficient output capabilities<br>- high concentration ratios, conversion efficiencies and temperature output<br>- adaptable to topography, structures<br>- short transmission lines<br>- low range power capabilities (15 MWe)<br>- reduced heat losses in energy transmission<br>- reduced cooling water requirement<br>- malfunction in one component will not effect the entire system | - less efficient<br>- cost of large number of heat engines<br>- complex 2-axis tracking<br>- difficult in mass producing and transporting large dishes (may limit to 20-30 m diameter or 150 KWe output) |

Table 2-3, (Continued)

| System | Advantages | Disadvantages |
|---|---|---|
| Parabolic Trough | - dispersed nature gives many of the advantages of parabolic dishes<br>- reduced costs of centralized heat engines<br>- most easily integrated into urban form | - fluid hazards and losses by piping network<br>- heat losses in transmission<br>- lower concentration ratios, conversion efficiencies, temperatures<br>- tracking expensive and difficult<br>- malfunction may disrupt the entire system<br>- cooling water requirements |
| Hemishperical Bowl | - low cost of fixed concentrator element | - lower collection efficiencies<br>- intricate receiver tracking |

- energy storage or backup system requirements
- variable, multiple energy output modes (thermal, electrical or mechanical energy)
- potential for waste heat utilization
- overcoming large front end land, labor and resource requirements for these systems
- technical and institutional utility grid interfaces
- maintenance and control of new types of heat engines
- proper containment and management of hot toxic fluids
- limited operating experience to determine durability and reliability

It can be concluded that aside from variations in temperatures, efficiency, reliability and centralization, major technical distinctions do not exist among the four generic typs of STES. Thus the key planning factors are to overcome the high front end costs and to properly site the systems. These are discussed in Sections 2.2 and 2.3 respectively.

## 2.2 Resource Availability

STES resource requirements and patterns of use must be compatible with the capabilities of target communities. Without proper planning, the high front end resource requirements of STES could limit system utilization.

### 2.2.1 Capital

The manufacturing and construction costs of STES are currently prohibitively expensive and difficult to assess because of rapid technological advancement, changing market conditions, variation in system size and design, and continued progress in cost reductions. Significant reduction in STES costs will be necessary to make them economically viable. Table 2-4 presents the U.S. Department of Energy's Solar Thermal Program's near and far term cost goals. If these estimates are accurate, distributed trough and central receiver industrial process heat systems may become competative in the near term, remote small community systems in the far term (DOE, 1980). System costs are currently approaching the 1983 goals (DOE, 1978). Government financial incentive programs and accelerated research could provide near term economic feasibility for low temperature applications (Kreith, 1979).

### 2.2.2 Insolation

Efficient STES energy production can only be achieved when sufficient direct insolation (solar radiation) is available. Evaluation of the quantity and availability of direct solar radiation is important in assessing the applicability of STES. Data on direct insolation in a given area (measured in watts/$m^2$/season or day) may be obtained from the U.S. Weather Service, U.S. Climatological Atlases or may be measured using a tracking heliometer (Holbeck and Ireland, 1979). Daily and seasonal insolation rates and STES efficiencies should be compared with energy demands load patterns to ascertain compatible load matches.

Table 2-4

Major Solar Thermal Program Cost Goals (DOE, 1980)

| Technology/Application | Cost Goals | | |
|---|---|---|---|
| | 1982 | 1985 | 1990 |
| Central receiver systems | | | |
| Repowering (\$/KWe) | 4,000 | 1,500 | 1,200 |
| Stand alone (\$/KWe) | -- | 1,900 | 1,400 |
| Cogeneration (\$/KWe) | 8,000 | 3,000 | 2,400 |
| Industrial, process heat (\$/KWth) | 1,100 | 400 | 300 |
| Distributed receiver technology | | | |
| Remote small community (\$/KWe) | 6,000 | 1,900 | 1,400 |
| Total energy systems (\$/KWe) | 12,000 | 3,600 | 2,400 |
| Industrial process heat (\$/KWth) | 1,700 | 500 | 300 |
| Component costs | | | |
| Troughs (\$/$ft^2$) | 19 | 12 | 10 |
| Dishes (\$/$ft^2$) | 25 | 15.5 | 12 |
| Heliostats (\$/$ft^2$) | 24 | 16.6 | 9 |

### 2.2.3 Land

Land requirements of STES vary with the availability of direct insolation, system design and physical site characteristics. The General Electric Space Division (1978) estimates that a 10 MWe parabolic dish/central generation system would require approximately 100 acres of land (10 acres/MWe). The 60 MWe central tower system proposed by Black and Veatch would require approximately 145 acres of land (2.4 acres/MWe) (Ullman, et al., 1979). Additional land may be necessary to buffer the systems from adjacent land uses (i.e., reduce glare and fluid release hazards), guarantee water or solar access rights, or to provide service roads and transmission corridors. Care must be taken to site STES in areas of compatible adjacent land uses. Coating or corrosion of collector surfaces from adjacent agricultural, mining or industrial activities could seriously reduce system efficiencies (Holbeck and Ireland, 1979).

The cost, availability, and competition for land in urban areas could limit STES utilization. To achieve sufficient collector areas, STES may have to be integrated into structures or multiple land use patterns (see Section 7). Thus the physical use and cost of urban lands may be important in siting STES.

### 2.2.4 Water

Water availability, cost, or quality could limit STES utilization, especially in arid areas in the U.S. Southwest (DOE, 1979). Water requirements of STES vary widely with system size and design. Depending on the system, water may be required for cooling, maintenance, and energy transport. The reduced water requirements of small scale and parabolic dish systems favor them in arid areas. Some systems may require high water quality and potentially toxic additives to prevent impurity accumulation and deposition.

Water use should be carefully planned to be compatible with the demands and water quality concerns and requirements of target communities. Problems associated with the intentional and accidental release and disposal of toxic materials should be anticipated and planned. Withdrawals from natural hydrological cycles should not adversely effect natural ecosystems. In most areas of the U.S., water resource and water quality control agencies are well established and can assist in evaluating site compatibility (Holbeck and Ireland, 1979; DOE, 1979).

### 2.2.5 Materials and Labor

The labor and material requirements of STES construction and operation would not differ significantly from those of other power generating facilities. Differences in the materials required and the level and requisite skills of the labor force would be minor (JPL, Jan. 1979). The widespread use of STES, however, would expand job opportunities with moderate skill requirements. Training programs to facilitate the design, installation and operation of STES may be necessary in a rapidly growing market.

Communities with an adequate labor force and sufficient resources and equipment will be least impacted by STES utilization. Economic activities will be stimulated without the expansion of public services. Communities without sufficient labor and material resources will need to import them and expand public services. The indirect impacts of these activities may be significant (Holbeck and Ireland, 1979).

## 2.3 Physical Siting Limitations

### 2.3.1 Geological

Physical limitations are important in siting STES. Topography should be considered from the standpoint of shading, spacing, orientation, and site preparation. STES should have an uninterrupted solar access to an angle of 10 degrees above the horizon, extending from Southeast to Southwest. Shading from adjacent vegetation, structures, or land contours should be prevented by proper siting and legal restrictions on ownership of adjacent lands (ERDA, 1976; Thomas et al., 1978). Contoured areas would require more land for siting, greater grading and filling requirements, and would increase environmental hazards from flooding, erosion, stream siltation, landslides and habitat destruction.

Because of their precise focusing, STES are particularly sensitive to ground movements from earthquakes (>7.0 on Richter scale), mining, adjacent transportation facilities, etc. Such sites should be avoided in areas of vibration because of their tendency to magnify vibration.

Unstable soils such as sand, dry lake sediments, expansive soils, or soils prone to liquifaction should be avoided to minimize airborne particulate matter and soil movements (JPL, Jan. 1979).

### 2.3.2 Meteorological

Meteorologic conditions can be limiting for STES because of the vulnerability of lightweight, thin-walled reflector surfaces. High wind velocities may directly damage reflector surfaces if the systems are not designed to obtain a more wind resistant orientation in adverse conditions. Data on wind speed and direction is important for siting and design analysis (JPL 1979). Winds may also damage reflective surfaces by abrasion from dust particles, dirt and sand. Therefore, data on frequency of dust or sandstorms is important.

Rain, snow, ice and hail may damage collector surfaces. Hailstones greater than 2 in. in diameter would dent collector surfaces. The weight of snow and ice could cause structural damage or failure of tracking mechanisms. Therefore, STES should not be sited in areas of extreme conditions. The systems should be properly designed to incorporate the range of meteorologies conditions encounterd (Holbeck and Ireland, 1979).

Meteorologic conditions vary considerably from site to site. Detailed microclimatic maps are therefore beyond the scope of this report. Much of the data necessary for analysis (Table 2-5) may be obtained from Baldwin (1974), Boes, et al. (1976), Environmental Science Service Administration (1968), or from local weather stations.

## Table 2-5

## Climatic Information for STES Evaluation and Siting

1) Annual, monthly and daily insolation: to indicate the amount of solar energy available for use in all regions of the United States throughout the year.

2) Percent cloud cover: to indicate the timing and duration of interruptions of the solar supply.

3) Hail, icing and wind data: to indicate areas where these climatic conditions could damage STES components.

4) Snow cover: to indicate areas where snowfall and snow cover could damage or weigh down collector surfaces.

5) Degree heating and cooling days: to indicate heating and cooling needs that could potentially be met by STES.

6) Annual precipitation: to indicate arid regions where water availability could limit STES use.

7) Maximum and minimum temperature data: to indicate areas of excessively hot or cold temperatures that may effect the design and functioning of a STES.

## 2.4 References

Anonymous. "Major Demonstration Project Dedicated - The Coolidge Project." Solar Thermal Report. Vol. 1:3-4 (1980).

Baldwin, J.L. Climate of the United States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (1974).

Boes, E.C., I.R. Hall, R.R. Prairie, R.P. Stromberg, and H.E. Anderson. "Distibution of Direct and Total Solar Radiation Availabilities for the U.S.A." In Sharing the Sun: Solar Technologies in the Seventies. AS/ISES and the Solar Energy Society of Canada, Inc. Joint Conference, K.W. Baer (ed.), pp. 238-263 (1976).

Caputo, R.S. and V.C. Truscello. "Solar Thermal Electric Power Plants: Their Performance Characteristics and Total Social Costs." In Intersociety Energy Conversion Engineering Conference Proceedings. Jet Propulsion Lab (1976).

Crosbyton Solar Power Project. A 5 MW Electric Powerplant for Crosbyton. Texas Tech. University (November 1979).

Curto, P. Systems Description and Engineering Costs for Solar-Related Technologies. Volume V, Solar Thermal Electric Systems. MITRE Technical Report, MTR-7485, McLean, VA (June 1977).

Duffie, J.A. and W.A. Beckman. Solar Energy Thermal Processes. Chapter 8: Focusing Collectors. John Wiley and Sons, New York (1974).

Energy Research and Development Administration (ERDA). Central Receiver Solar Power 10 Megawatt Electric Pilot Plant Project Site Selection. Program Opportunity Notice (PON), Washington, D.C. (1976).

Environmental Science Service Administration. Climate Atlas of the United States. U.S. Department of Commerce, Washington, D.C. (1968).

General Electric Space Division. Solar Thermal Energy-Large Scale Experiment at Shenandoah, Georgia. Phase III, Preliminary Design (September 1978).

Harrigan, R.W. "Midtemperature Solar Thermal Systems Design Handbook: Parabolic Troughs." In Sun II - Proceedings of the International Solar Energy Society. Boer, K.W. and B.H. Glenn (eds). Atlanta, Georgia, Volume II (1979).

Holbeck, H.J. and S.J. Ireland. Siting Issues for Solar Thermal Power Plants with Small Community Applications. DOE/JPL-1060-78/2, Rev. 1 (1979).

Jet Propulsion Laboratory (JPL). Assessment of the Potential of Solar Thermal Small Power Systems in Small Utilities. Final Report. JPL Contract 95471 78-008-4-000 (1978).

__________. Annual Technical Report. JPL Publication 79-43, Volume 2 (1979).

__________. Annual Technical Report. Thermal Power Systems, Small Power Systems Application Project. Volume 1. Executive Summary. DOE/JPL-1060-9 (Jan. 1979).

Kreith, F. A Technical and Economic Assessment of Three Solar Conversion Technologies. SERI/TP-34-262 (1979).

Kreith, F. and J.F. Kreider. Principles of Solar Engineering. Hemisphere Publishing, McGraw-Hill, London, pp. 252-302 (1978).

Marriott, A.T. and K. Kiceniuk. "The Small Community Solar Thermal Power Experiment." Proceedings of the 1980 Annual Meeting - AS/ISES. Volume 3:1 (June 1980).

Office of Technology Assessment. Application of Solar Technology to Today's Energy Needs. Volume 1, Washington, D.C., pp. 264-290 (1978).

Thomas, W.A., A.S. Miller and R.L. Robbins. *Overcoming Legal Uncertainties About the Use of Solar Energy Systems*. American Bar Association, Chicago, Illinois (1978).

Thornton, J.P., *et al*. *Comparative Ranking of 1-10 MWe Solar Thermal Electric Power Systems: An Executive Overview*. SERI, Golden Colorado, SERI/TRE-35-238 (1979).

Truscello, V.A. "The Parabolic Concentrating Collector." In *Proceedings of the Solar Thermal Concentrating Collector Technology Symposium*. B.P. Gulpa and F. Kreith (eds.) (1978).

Truscello, V.A., *et al*. *Siting Issues for Solar Thermal Power Plants with Small Community Application*. DOE/JPL-1060-78/2 Rev. 1 (1978).

Ullman, A.Z., *et al*. *Worker Health and Safety in Solar Thermal Power Systems*. Volumes 1-5 UCLA 12-/1210-1215 (1979).

U.S. Department of Energy (DOE). *Solar Thermal Power Systems Program Summary*. DOE/ET-0078 (December 1978).

____________. *Environmenal Readiness Document: Solar Thermal Power Systems*. DOE/ERD 0019 (August 1979).

__________. *A Guide to the Solar Thermal Program: FY 1980*. Division of Central Solar Technology, Solar Thermal Branch, Washington, D.C. (1980).

Wachtler, W.J., J.H. Price, R.L. Henry and B.L. Hale. "Survey of Generic Types of Focusing Collectors for Large Scale Applications." In *Solar Concentating Collectors*. Proceedings of the ERDA Conference on Concentrating Solar Collectors, Georgia Insitute of Technology, pp. 8-35 to 8-45 (1977).

# 3.0 END USE APPLICATIONS OF STES

## 3.1 Introduction

Estimates of the optimal STES market are difficult to make with a high degree of confidence because of technological developments, shifts in the national economy, uncertainties about the availability and cost of competing energy sources, and financial and institutional uncertainties. Thus, projections of the potential demand for solar thermal energy (regardless of scale) for the year 2000 range from 1 to 7 Quadrillion BTU's (Q) (National Research Council, 1979; Bush and Manjal, 1978).

Demand for the forms of energy STES can provide is growing. In 1973, the U.S. consumed approximately 23 percent of its energy in the form of higher-temperature thermal energy, 8 percent of its energy in the form of electricity (Lovins, 1978). By the year 2000, higher-temperature thermal energy is predicted to represent 25-30 percent and electricity 30-40 percent of demand (Kendall and Nadis, 1980).

## 3.2 End-Use Applications

### 3.2.1 Industrial

Industrial consumption of energy represents the largest share among all sectors of the U.S. economy. Of the 72 Q of energy consumed in 1978, 37 percent was used in the industrial sector (SERI, 1979; World Oil, 1980). This energy was consumed in the forms of process heat (68.4 percent), electricity (21.8 percent), and feedstocks (8.8 percent) (Brown, 1980). Projected increases in the industrial demand for electricity and thermal energy make this sector a prime target for STES applications.

Research is currently underway on industrial process heat (IPH) and total energy systems (TES) applications of STES. The IPH market is currently fairly well defined. IPH computer end-use matching methodologies and supporting data bases can be found in Brown, et al. (1979), Brown et al. (1980), Stadjuhar (1979) and Kreith and Kearney (1979). Table 3-1 lists thirteen industries (3-digit SIC) considered to be prime candidates for solar IPH applications (Ketels and Reeve, 1979). A list of current solar IPH demonstration projects is given in Table 3-2 (For a list of manufacturers, see Solar Engineering, June 1979).

Central receivers are capable of supplying hot air and steam for industrial high temperature (>500°F) applications (which account for 50-60 percent of the U.S. total IPH demand). Parabolic dish systems with central or dispersed receiver system may efficiently generate energy over a very wide range of temperatures (200°F to 2400°F). Parabolic trough collectors may be efficiently applied to lower temperature demands (below 500°F) (Brown, 1980; SERI, 1979).

Table 3-1

Ranked Order of Preferred Candidates for STES Industrial Process Heat Applications (Ketels and Reeve, 1979)

| Standard Industrial Classification Code (SIC) | Industry |
|---|---|
| 291 | Petroleum refining |
| 286 | Industrial organic chemicals |
| 261 | Pulp mills |
| 262 | Paper mills |
| 263 | Paperboard mills |
| 281 | Industrial inorganic chemicals |
| 282 | Plastic materials - synthetic |
| 287 | Agricultural chemicals |
| 332 | Iron and steel foundries |
| 206 | Confectionary products |
| 295 | Paving and roofing materials |
| 226 | Textile finishing |
| 242 | Sawmills and planing mills |

According to SERI (1979) the advantages gained from solar IPH projects include:

- pollution control and abatement.
- public relations benefits resulting from air pollution reduction and conservation of nonrenewable resources.
- reduction of the vulnerability to fuel supply interruptions.
- avoidance of rising construction costs (due in part to pollution control devices).
- avoidance of escalating fuel costs.

The second major area of STES industrial research is on total energy systems (TES). A total energy system provides heat, electrical power, and space heating and cooling, all at maximum possible efficiency (McDonnell-Douglas, 1977). Optimum candidates for STES total energy system applications (4-digit SIC) are given in Table 3-3. These applications were chosen based upon load profile, peak demand, unit displacement, number and location of industries, ratio of thermal to electrical loads, current

Table 3-2

Solar IPH Demonstration Projects (SERI, 1979)

| Location | Process | Collectors | Owner | Status |
|---|---|---|---|---|
| | | Hot Water (140° - 212°F) | | |
| Sacramento, California | can washing | flat-plat & parabolic | Campbell Soup Company | operational (April 1978) |
| Harrisburg, Pennsylvania | concrete block curing | multiple reflector | York Building Products | operational (Sept. 1978) |
| France, South Carolina | textile dyeing | evacuated tube | Reigel Textile Corporation | operational (June 1978) |
| | | Hot Air (140° - 212°F) | | |
| Fresno, California | fruit drying | flat-plate | Lamanuzzi & Pantaleo Foods | operational (May 1978) |
| Canton, Miss. | kiln drying of lumber | flat-plate | LaCour Kiln Services, Inc. | operational (Nov. 1977) |
| Decatur, Alabama | soybean drying | flat-plate | Gold Kist, Inc. | operational (May 1978) |
| Gilroy, California | onion drying | evacuated tube | Gilroy Foods, Inc. | operational (Sept. 1978) |
| | | Low Temperature Steam (212° - 350°F) | | |
| Fairfax, Alabama | fabric drying | parabolic trough | West Point Pepperell | operational (Sept. 1978) |
| Sherman, Texas | gauze bleaching | parabolic trough | Johnson & Johnson | operational (Nov. 1979) |
| Pasadena, California | laundry | parabolic trough | Home Cleaning & Laundry | construction |
| Bradenton, Florida | orange juice pasteurization | evacuated tube | Tropicana Products, Inc. | construction |

Table 3-2, (Continued)

| Location | Process | Collectors | Owner | Status |
|---|---|---|---|---|
| | | Intermediate Temperature Steam (350° - 550°F) | | |
| Mobile, Alabama | oil heating | parabolic trough | Ergon, Inc. | design only |
| Dalton, Georgia | latex production | multiple reflector | Dow Chemical | construction |
| Newberry Springs, California | hectorite processing | parabolic trough | National Lead Industries | design only |
| Hobbs, New Mexico | oil refinery | parabolic trough | Southern Union Company | construction |
| San Antonio, Texas | brewery | parabolic trough | Lone Star Brewing Co. | design only |
| Ontario, Oregon | potato processing | parabolic trough | Ore-Ida Company | construction |
| | | Privately Funded | | |
| Youngstown, Ohio | aluminum anodizing | fixed half parabolic | General Extrusions, Inc. | operational (Sept. 1977) |
| Jacksonville, Florida | beer pasteurization | evacuated tube | Anheuser-Busch, Inc. | operational (Feb. 1978) |

utility contracts, total industry energy usage, potential market penetration and return on investment. According to McDonnell-Douglas (1977), all exhibited a positive return on investment for small central receiver system applications.

Table 3-3

Ranked Order of Optimum Industrial Candidates for STES
Total Energy System Applications (McDonnel-Douglas, 1977)

| SIC | Industry |
|---|---|
| 2011 | Meatpacking |
| 2026 | Fluid milk |
| 2063 | Sugar beets |
| 2951 | Asphalt materials |
| 3272 | Concrete block |

STES appear to be very well suited for industrial park applications for several reasons. First, STES can provide the mixture of energy demanded. Second, industrial parks are generally sited in areas of low population density (low land values) and are usually comprised of newer, scattered low to medium-rise structures. Finally, the load demand pattern of a mixture of smaller facilities is likely to be more uniform than the demand pattern of larger individual facilities (Brown, 1980).

### 3.2.2 Agriculture

In 1974, the agricultural sector consumed 16 percent of the U.S. supply of energy (U.S. Department of Commerce, 1974). Within the agricultural sector there are three basic categories of energy demand. The first includes farm machinery and transportation systems powered by portable fossil fuels. STES are not expected to play a significant role in meeting these needs. The second category is process heat for crop-drying, brooding, greenhouses, and space and water heating. These end-uses are primarily supplied by liquified petroleun (LP) and natural gas. Flat plate solar systems appear to be the most cost-effective method of meeting these demands with renewable systems, unless large amounts of electricity are also required. Electricity for irrigation pumping, food processing and milking facilities constitutes the third major category of agricultural end-uses. STES could supply the needed electricity for these end-uses. On-site utilization of waste heat could improve overall system economics. Table 3-4 summarizes fuel consumption and end-use applications for five candidate agricultural subsectors that could potentially use STES. Note that the thermal energy requirements for the five candidate subsectors are quite low. Thus, the primary intent of agricultural STES applications will be to provide mechanical and electrical power, with the waste heat used for secondary, low-temperature applications.

### Irrigation

Irrigation consumes most of the electricity in agriculture and accounts for nearly one-half of the fossil fuel consumption of the five candidate end-use subsectors (Table 3-4). Much of this energy can be supplied by STES. Approximately 0.3 percent of U.S. energy consumption is used to irrigate 7 percent of the country's cropland. While at first glance these figures seem small, they are significant when considered from a local and regional perspective. For example, 9.5 percent of all electricity and 8.5 percent of all natural gas consumed in Arizona are used for irrigation. Additionally, the Southwest states of California, Arizona, New Mexico and Texas consume 60 percent of all energy used for irrigation (Federal Energy Administration, 1974; U.S. Department of Commerce, 1974). High irrigation demands in these states coincide with peak annual insolation, a condition that would favor solar systems. The market for STES irrigation systems also appears to be quite promising because of increasing demands for irrigation, rising costs of conventional systems and an absence of significant land use barriers.

### Dairy Farms and Milk Procesing

Dairy farming consumes the second highest percentage of electricity in the agricultural sector. Electricity is used for milking, processing, ventilation and lighting. A lesser amount of thermal energy, predominantly derived from LP gas, is used for space and water heating and milk cooling (U.S. Department of Agriculture, June 1977).

The combined electrical and thermal (40-70°C) requirements of dairy operations favor STES applications. Further, dairy energy demand is diurnal and characterized by fairly even annual load distribution. Dairy farms are generally located in rural areas of lower land value, with uneven topography or poor soils, minimizing problems of land cost and availability.

STES are also being considered for the milk processing industry. Milk processing facilities (e.g., pasteurizing, homogenizing and bottling) require temperatures up to 77°C and consume large amounts of fossil fuels and electricity in production. Processing generally occurs during daylight hours, six days a week, with fairly even annual load requirements (Brown, et al., 1979).

### Crop Drying

In 1974, the U.S. consumed 1.05 x $10^{14}$ BTU's (85 percent LP or natural gas and 7.3 percent electricity) for crop drying. Of the potential agricultural end-uses, crop drying is second to irrigation in total energy consumption. Crop drying processes reduce the moisture content in grains (e.g., rice sorgum, soybeans, etc.), so that they can be stored without

Table 3-4

Energy Demand and Mode of Energy Application for Selected Agricultural Operations in 1974
(Federal Energy Administration, 1974: U.S. Department of Commerce, 1974)

| Operation | Energy Demand | | | Mode of Application ($10^{12}$ BTU) | | | |
|---|---|---|---|---|---|---|---|
| | Electricity | | Organic Fuels | Mechanical Drive | Lighting, Appliances Refrigeration | Thermal Energy | |
| | ($10^9$ kwh) | ($10^{12}$ BTU) | ($10^{12}$ BTU) | | | Amount | Temp. Range °C |
| Irrigation | 19.3 | 65.8 | 195.0 | 260.8 | 0 | 0 | 0 |
| Crop drying | 0.86 | 2.9 | 102.7 | 0 | 0 | 105.6 | 40-135 |
| Dairy farms | 4.5 | 15.4 | 8.2 | 0 | 15.6 | 8.2 | 40-75 |
| Poultry brooding | 0 | 0 | 24.3 | 0 | 0 | 24.3 | 20-35 |
| Greenhouses | 0.47 | 1.6 | 55.7 | 0 | 1.6 | 55.7 | 10-27 |
| TOTAL* | 25.3 | 85.7 | 385.9 | 260.8 | 17.2 | 193.8 | -- |

* Numbers rounded to the nearest tenth

spoiling. Crop drying sytems are of two types: 1) high-temperature, high-speed systems, and 2) low-temperature, in-storage systems. Most grain is now dried using the former systems which require temperatures up to 135°C (for sorgum). STES could provide the combined electrical and thermal needs of such facilities. One serious problem, however, is the seasonal nature of the harvest. Energy for the majority of these purposes is needed only from August to mid-November.

### Poultry Brooding and Egg Handling

STES ay also be considered for use in the poultry brooding and egg handling industries. Nearly 80 percent of the poultry and egg industry is concentrated in high insolation states in the South Atlantic and South Central regions of the U.S. Energy for the poultry industry comes mostly from LP gas with a small contribution from electricity. Conversely, the egg industry consumes almost exclusively electricity. Both industries have proven especially vulnerable to energy shortages because fuel costs comprise a significant portion of industry costs. The annual electrical load and low temperature heat demands are relatively even (U.S. Department of Agriculture, October 1976).

### Greenhouses

Commercial greenhouses require substantial amounts of energy in the form of electricity and low-temperature heat. The industry is largely fossil fuel dependent and, therefore, fuel shortages can significantly disrupt production schedules. Most of the energy consumed in the greenhouse industry is used for space heating and cooling. Thus, STES could be used, but solar flat plate collectors are a more cost effective means of providing the needed energy, given the temperatures required.

## 3.2.3 Commercial

The commercial sector includes utilities, communications, wholesale and retail trade, financial institutions, public services, schools, hospitals, nursing homes and government facilities (Federal Energy Administration, 1977). The primary energy demands in this sector in 1974 were for space conditioning (65 percent), lighting (15 percent) and water heating (6 percent) (see Table 3-5). Natural gas, fuel oil and electricity supplied 42 percent, 18 percent, and 34 percent of the energy consumed, respectively.

In the commercial sector, the most immediate application of STES is for utility power production. In areas of adequate direct insolation, STES can be used to provide a portion of daily peak-load electrical requirements. STES energy delivery capabilities coincide closely with daily cooling demand cycles, making them very well suited for supplying the share of daily electrical demand used for air conditioning (National Research Council, 1979).

The U.S. Department of Energy (DOE) is concentrating on utility owned and managed systems in its Small Community Solar Thermal Power Experiment

Table 3-5

Energy Consumption in the Commercial Sector in 1974
(Federal Energy Administration, 1974)

($10^{12}$ BTU's)

| | Coal | Fuel | Liquid Propane Gas | Natural Gas | Electricity | Steam | Total |
|---|---|---|---|---|---|---|---|
| Space Conditioning | 130 | 833 | 47 | 1,708 | 698 | 115 | 3,531 |
| Water Heating | 10 | 85 | 17 | 210 | 0 | 7 | 329 |
| Cooking | 0 | 0 | 39 | 123 | 45 | 0 | 207 |
| Lighting | 0 | 0 | 0 | 0 | 796 | 0 | 796 |
| Refrigeration | 0 | 0 | 0 | 0 | 122 | 0 | 122 |
| Other | 1 | 51 | 0 | 210 | 147 | 8 | 417 |
| TOTAL | 141 | 969 | 103 | 2,251 | 1,808 | 130 | 5,402 |

(Marriott and Kiceniuk, 1980). They are currently selecting a community for 1 MWe parabolic dish solar thermal electric system. Utility applications such as this are prime candidates for STES because utilities have the resources, personnel and experience necessary to plan and manage these systems. However, as mentioned previously, this report focuses on non-utility applications because of the negligible community impacts and requirements of utility systems.

The energy demands of non-utility commercial firms are generally a function of the physical characteristics (including size, location, and uses) of individual structures. High operating and maintenance costs and potential health and safety problems of STES tend to favor larger commercial applications. The reduced energy requirements of smaller commercial facilities (less than 200 KWe or under 20,000 $ft^2$ of floor space) may be insufficient to warrant the use of STES. Commercial facilities generally have centralized heating and cooling systems into which STES can most easily be integrated. Conversely, large residential complexes have unitized heating and cooling systems, making STES integration much more difficult (Boobar *et al*., 1978).

Over two-thirds of the 18,500 retail shopping centers in the U.S. exceed 50,000 $ft^2$ of floor space and are considered to be prime candidates for STES use. The majority of these are located in California, Florida, and Texas (all with high insolation rates), and in New York, Ohio, Pennsylvania and Illinois (with high energy costs) (Boobar *et al*., 1978).

The cost and availability of land near commercial facilities are significant constraints on STES use. Structures over three stories high may have problems with shading or insufficient collector space. Further, photovoltaic total energy systems appear to offer operation, costs and safety advantages in smaller systems (<800 KWe) while STES economies of scale and efficiencies seem to favor larger systems (Boobar *et al*., 1978).

Commercial uses of STES are likely to be initiated in large shopping centers in the Northeast (because of high energy costs) between the years 1990 and 2000. Such systems could provide between 0.8 and 1.8 Q per year in the commercial sector by the year 2010. Although shopping centers are only 2 percent of the commercial market, they may eventually account for 70 to 80 percent of the commercial uses of STES (Boobar *et al*., 1978). Table 3-6 provides a market profile of all commercial applications of STES including a summary of the advantages and disadvantages of various commercial uses.

### 3.2.4 Residential

In 1977, the residential sector consumed approximately 15.9 pecent of total U.S. energy consumption. Table 3-7 summarizes the residential energy consumed by single-family attached dwellings (duplexes and triplexes), single-family detached dwellings (single family houses), multi-family low-rise dwellings and multi-family high-rise (apartments), and mobile homes.

Table 3-6

Market Profile on Commercial STES Applications (Boobar *et al*., 1978) (Hock, 1978)

| Market Rating | Commercial Application | Advantages | Disadvantages |
|---|---|---|---|
| A. High | Utilities | - may integrate STES into grid | - possible citizen opposition |
| B. Intermediate | Retail Trade | - consumes ∿22 percent of total commercial energy<br>- over 1/2 of consumption is electrical (largest electrical consumer in commercial sector)<br>- compatible loads and energy end use<br>- most centers are in suburban sunbelt industrial areas with rapid growth | - high cost and low availability<br>- tall buildings have insufficient space<br>- smaller facilities do not have sufficient energy demand (<200 KWe)<br>- photovoltaics may outcompete for smaller systems |
| C. Intermediate-Low | Finance, Insurance, Real Estate (FIRE) and Services | - consumes ∿19 percent of total commercial energy<br>- 40 percent of consumption is electricity<br>- much of the energy in service sector used for air conditioning in the South Atlantic and Pacific Regions | - generally very small facilities<br>- majority of energy end uses incompatible (portable liquids and low temperature heat)<br>- photovoltaics may outcompete for smaller systems |
| | Public Administration | - consumes ∿20 percent of total commercial energy<br>- greater tendencies for innovation and demonstration | - only 18 percent is electricity<br>- majority of energy is low temperature heat |

Table 3-6, (Continued)

| Market Rating | Commercial Application | Advantages | Disadvantages |
|---|---|---|---|
| C. Intermediate-Low | Wholesale Trade | - heavy reliance (>50 percent) on electricity to supply air conditioning, lighting and refrigeration | - consumes only 5 percent of total commercial consumption<br>- larger facilities in East North Central and Middle Atlantic Regions in urban areas<br>- smaller distribution centers may require insufficient energy |
| D. Low | Communications | - 2/3 of consumption is electricity primarily in South Atlantic and Pacific regions<br>- may be used in large transmission stations remotely sited | - consumes only 1 percent of total commercial consumption<br>- photovoltaics more appropriate for small remote relay stations |
| | School | - uses 16 percent of total commercial consumption<br>- larger facilities may have sufficient needs | - electricity only 19 percent of consumption<br>- majority of demand for low temperature heat |
| | Hospitals and Nursing Homes | - consumes 11 percent of total commercial consumption | - only 15 percent of consumption is electrical<br>- majority of consumption is low temperature heat |

## Table 3-7

## Residential Energy Consumption by End Use and Type of Structure in 1977 (U.S. Department of Commerce, 1979; U.S. Department of Energy, 1977)

| | Single Family Attached | Single Family Detached | Multi-Family Low Rise | Multi-Family High Rise | Mobile Homes | Totals |
|---|---|---|---|---|---|---|
| 1. Total Energy Consumption ($10^{12}$ BTU/year) | 1330.8 | 7452.3 | 1334.5 | 482.4 | 587.5 | $\Sigma$=11,077 |
| 2. Average BTU's/ft$^2$/yr | 47 | 69 | 43 | 46 | 75 | - |
| 3. Percentage of Households | 3.9 | 63.5 | 23 | 5 | 4.6 | 100 |
| 4. End Use (Percentage) | | | | | | |
| - Space Heating | 63.8 | 66.7 | 51.3 | 54.4 | 58.7 | $\bar{x}$ = 58.9 |
| - Space Cooling | 1.5 | 3.1 | 1.9 | 0.9 | 2.6 | 2.0 |
| - Water Heating | 20.6 | 15.4 | 29.4 | 30.4 | 18.9 | 22.9 |
| - Cooking | 5.9 | 5.1 | 7.2 | 5.7 | 13.1 | 7.4 |
| - Lighting | 1.7 | 2.5 | 2.2 | 1.8 | 1.2 | 1.9 |
| - Clothes Drying | 1.5 | 1.5 | 2.0 | 1.6 | 1.1 | 1.5 |
| - Refrigeration | 3.1 | 3.4 | 3.2 | 2.7 | 2.2 | 2.9 |
| - Appliances | 2.0 | 2.4 | 2.9 | 2.4 | 2.2 | 2.2 |

It is significant that over 80 percent of the energy consumed in the residential sector is used for space and water heating (with temperatures well within the range of solar flat plate collector capabilities). Thus, the majority of energy needs of the residential sector could be provided by proper building design and solar flat plate thermal collectors. Only about 7.2 percent of residential energy consumption requires the use of electricity (lighting, refrigeration and appliances). Therefore, the relatively low-temperature thermal and electrical requirements of the residential sector appear unsuited to STES, although these systems may be applicable to district heating in uses in some areas of the U.S. (see Section 5 and 3.3).

Table 3-8 summarizes the energy consumption of the residential sector. Over 80 percent of the energy used in the residential sector is provided by fossil fuels. Between 1972 and 1977 the residential price of oil increased 65 percent, while natural gas prices increased 35 percent (in constant 1975 dollars). These higher fuel costs have contributed to a reduction in the growth of residential energy consumption (Hirst and Hannon, 1979). At first glance, higher prices and potential shortages would appear to favor domestic solar systems. However, the residential sector has the highest fuel allocation priority of all the economic sectors. Furthermore, it is estimted that 50 percent of the energy currently consumed in the residential sector could be conserved (Ross and Williams, 1978). Therefore, the residential sector may be the last sector to experience problems from fossil fuel shortfalls. Moreover, conservation measures could contribute significantly should shortages occur.

High capital, operation and maintenance requirements of STES should favor use in multi-family high density structures. Yet these high density applications occur in areas where land is scarce and expensive and solar access is a potential barrier. As noted earlier, the unitary configuration of aggregate residential heating/cooling systems makes centralized STES applications difficult for a retrofit market.

Energy consumption patterns vary considerably according to region, primarily because of economic differences, regional energy resource availability, and climate. The East-South-Central residential market meets 34 percent (compared to a national average of 18 percent) of its energy needs with electricity. High electrical consumption is also found in the South Atlantic, West-South-Central, and Southwestern regions, due to a large extent to air conditioning requirements (Dole, 1975). These geographical regions have favorable insolation rates and would appear to favor STES use. However, high electrical costs (which tend to reduce demand for electricity), saturation of the air conditioning market, increasing availability and use of energy efficient air conditioners, and growing interest in passive cooling retrofits may reduce the demand for electrically supplied air conditioning in the near future.

Table 3-8

Fuel Consumption for the Residential Sector in 1977
(U.S. Department of Energy, 1977)

| Fuel Source | Of Total Residential Consumption | | |
|---|---|---|---|
| Natural gas | 47 | Refrigeration | 3.2 |
| Petroleum | 24.5 | Space cooling | 2.7 |
| Electricity | 18 | Applicances | 2.4 |
| LP gas | 6.5 | Lighting | 2.2 |
| Kerosene | 3.3 | Clothes drying | 1.5 |
| Miscellaneous | 0.7 | Cooking, space and water heating | 6.0 |

## 3.3 Community Applications

Several attempts have been made to estimate the maximum theoretical contribution of various solar technologies to community energy needs (Milne et al., 1978; Craig et al., 1978; and Armstrong and Armstrong, 1979). Using an analysis of a hypothetical city with median demographic, social, land use and climatic characteristics (see Milne, et al., 1978), Blaunstein (1979) concluded that in the year 2000, solar thermal systems could provide approximately 23 percent of residential, 11 percent of commercial and 12 percent of industrial on-site thermal energy requirements. Armstrong and Armstrong (1979) estimate that parabolic dishes and troughs could provide 5 percent of residential, 8 percent of commercial and 36 percent of industrial electrical demand in a similar time frame.

Blaunstein (1979) estimates that between 44 and 62 percent of multiple family thermal energy requirements can be supplied through the combined use of district and on-site solar flat plate and solar thermal energy systems. A study comparing the costs of a community district (grid) solar heating system with an independent (non-grid) solar heating system, in California, concluded that grid systems were 20 to 30 percent cheaper (Craig et al., 1978). The study further concluded that proper authority already exists in California for municipalities to create district systems. For instance, one of the conditions for new subdivision approval could be a requirement for the installation of district or neighborhood solar systems.

It must be emphasized that these studies are theoretical in nature and generally address the potential market for new energy production systems. A community-wide retrofit program to accommodate small scale centralized solar systems would be very difficult to plan and prohibitively expensive. Since the majority of new construction is in the form of aggregate housing, commercial and industrial centers (because of reduced costs of planning, construction and public services), these would appear to be the most promising near-term STES market.

### 3.4 Summary

Table 3-9 summarizes the market potential for STES by sector. As indicated, industrial processes and agricultural irrigation systems would appear to have the greatest potential for STES applications. The initial market, therefore, will be almost exclusively in the industrial sector. Assuming a continuously developing market, food processing facilities and suburban shopping centers may subsequently be targeted for STES applications. Agricultural operations such as greenhouse and brooding facilities, commercial services, public administration, wholesale trade, and multiple family low-rise residences could potentially use STES. However, these demands may be achieved with greater cost-effectiveness through the use of solar flat plate collectors.

In all sectors, STES may be applicable to larger facilities with combined thermal and electricity needs and no serious constraints on land availability or cost. However, unpredictable changes in energy consumption profiles and urban patterns could considerably alter this picture.

## Table 3-9

## Summary of Applications of STES by Sector

| Subsector Categories | Market Rating | | | |
|---|---|---|---|---|
| | H | I | IL | L |
| Industrial | | | | |
| Petroleum Refining | X | | | |
| Industrial Organic Chemicals | X | | | |
| Pulp, Paper and Paperboard Mills | X | | | |
| Industrial Inorganic Chemicals | X | | | |
| Synthetic Plastics | X | | | |
| Agricultural Chemicals | X | | | |
| Iron and Steel Foundries | X | | | |
| Confectionary Products | X | | | |
| Paving and Roofing | X | | | |
| Agricultural | | | | |
| Irrigation | X | | | |
| Dairy Processing | | X | | |
| Brooding | | | X | |
| Greenhouses | | | X | |
| Crop Drying | | | | X |
| Commercial | | | | |
| Retail Trade | | X | | |
| Services | | | X | |
| Public Administration | | | X | |
| Wholesale Trade | | | X | |
| Communications | | | | X |
| Utilities | X | | | |
| Schools | | | | X |
| Hospitals and Nursing Homes | | | | X |
| Residential | | | | |
| Single Family Attached Residences | | | | X |
| Single Family Detached Residences | | | | X |
| Multiple Family Low Rise Residences | | X | | |
| Multiple Family High Rise Residences | | | | X |
| Mobile Homes | | | | X |

Key to Market Ratings

| | |
|---|---|
| H - High Potential Use | IL - Intermediate to Low Potential Use |
| I - Intermediate Potential Use | L - Low Potential Use |

## 3.5 References

Armstrong, M. and J.E. Armstrong. *Community Impediments of Solar Energy*. Stanford Research Institute, Palo Alto, California (1979).

Blaunstein, R.Y. *Assessment of Solar Energy within a Community: Summary of Three Community Level Studies*. U.S. Dept. of Energy, Washington, D.C. (October 1979).

Boobar, M.G., *et al*. *Commercial Applications of Solar Total Energy Systems*. Rockwell International, Atomics International Division, Canoga Park, California (July 1978).

Brown, K.C., P.A. Katels and S.A. Stadjuhar. *Industrial Applications Analysis: Market Characterization and System Definition for Several Industries*. SERI/TP-353-467 (1979).

Brown, K.C. *Applications and System Studies for Solar Industries Process Heat*. SERI/TR-351-481 (1980).

Brown, K.C., *et al*. *End-Use Matching for Solar Industrial Process Heat: Final Report*. SERI/TR-34-091 (1980).

Bush, L.R. and P.K. Manjal. "Future Solar Thermal Energy Markets for the U.S. Industrial Sector." AIAA/ASERC Conference on Solar Energy: Technical Status, Phoenix, Arizona (1978).

Craig, P., *et al*. *Distributed Energy Systems in California's Future*. Lawrence Berkeley Laboratory, Vol. II, Berkeley, California (1978).

Dole, S.H. *Energy Use and Conservation in the Residential Sector: A Regional Analysis*. RAND (June 1975).

Federal Energy Administration. *Energy and U.S. Agriculture: 1974 Data Base*. Office of Conservation, Vol. 2 (1974).

______________. *Energy Consumption in Commercial Industries by Census Division - 1974*. Report No. FEA/B-77/167 (March 1977).

Hirst, E. and B. Hannon. "Effects of Energy Conservation in Residential and Commercial Buildings." *Science*. Vol. 205:656-661 (August 17, 1978).

Hoch, *Energy Use in the United States by State and Region: A Statistical Compendium of 1972 Consumption, Prices and Expenditures*. Resources for the Future (1978).

Institute of Gas Technology. *Application Analysis of Solar Total Energy Systems to the Residential Sector*. Chicago, Illinois, Vol. 4, Market Penetration (1978).

Kendall, H. and S. Nadis. *Energy Strategies: Toward a Solar Future*. Ballanger Pub. Co., Cambridge, Massachusetts (1980).

Ketels, P.A. and H.R. Reeve. Market Characterization of Solar Industrial Process Heat Applications: Progress Report. Second Quarter 1978-1979, SERI/PR-353-212 (1979).

Kreith, F. and D. Kearney. End-Use Matching of Solar Energy Systems. SERI/TP-34-325 (1979).

Lovins, A. "Energy Strategy: The Industry, Small Business and Public Stakes." In Perspectives on Energy. L. Ruedisili and M.W. Firebaugh (eds.). Oxford U. Press, New York, Second Edition (1978).

Marriott, A.T. and T. Kiceniuk. "The Small Community Solar Thermal Power Experiment." In AS/ISES Proceedings of the 1980 Annual Meeting. G. Granta and B. Glenn (eds.). Vol. 3:1:519-523 (1977).

McDonnell Douglas Aeronautics Company. Industrial Applications of Solar Total Energy. Final Report, SAN/1132-2/1 (1977).

Milne, M., M. Adelson, and R. Corwin. Urban Innovations Group. Three Solar Urban Futures. Los Angeles, California (1979).

National Research Council. "Domestic Potential for Solar and Other Renewable Energy Sources." Study of Nuclear and Alternative Energy Systems. Supporting Paper No. 6 (1979).

Ross, M.H. and R.H. Williams. "The Potential for Fuel Conservation." In Perspectives on Energy. L.C. Rudisili and M.W. Firebaugh (eds.). Oxford U. Press, New York (1978).

Solar Energy Research Institute. Putting the Sun to Work in Industry. Second Edition, SERI/SP-34-175 R (1979).

Solar Engineering. Vol. 4, No. 6 (June 1979).

Stadjuhar, S. An Application Analysis for the Solar Industry Process Heat Market. SERI/TP-34-236 (1979).

United States Department of Agriculture. Energy Use and Conservation in the Poultry and Egg Industry. Economic Research Service (October 1976).

__________. A Guide to Energy Savings to the Dairy Farmer. For the Federal Energy Administration (June 1977).

United States Department of Commerce. 1974 Census of Agriculture: Special Reports Graphic Summary. Bureau of the Census, Vol. 4, Part 1 (1974).

__________. Annual Housing Survey: 1977. Part E, United States and Regions. Department of Housing and Urban Development (September 1979).

United States Department of Energy. End-Use Energy Consumption Data Base. Energy Information Administration, Series 1 (1977).

________. *Monthly Energy Review.* Energy Information Administration, Washington, D.C., DOE/EIA 0035/02(80) (February 1979).

# 4.0 HEALTH, SAFETY AND ENVIRONMENTAL IMPACTS

## 4.1 Introduction

There are several health, safety and environmental problems created by the construction and operation of STES. However, it is important to emphasize that these problems are considerably less severe than those associated with conventional energy technologies; and may be further reduced or eliminated through proper STES design, siting, management and operation.

The risks and impacts of STES construction and operation are difficult to assess because of limited operational experience with STES technologies and variation in impacts with system design, scale and location. Much of the information contained in this discussion was derived from assessments of large scale (100 MWe) solar thermal energy system designs. Because of their decentralized, dispersed nature, the risks and impacts of smaller systems would likely be less significant than those of larger systems.

## 4.2 On-Site Impacts

### 4.2.1 Health and Safety

Recent analyses of the nature and degree of health and safety impacts of solar thermal energy systems have indicated that the occupational hazards would be comparable to those in the safest 10 percent of American industry (Ullman, et al., 1979 I-V; ERDA, 1977). Safety hazards of STES generally fall into two categories: (1) routine hazards from normal plant operation and maintenance, and (2) "off-normal" events with infrequent random occurrence.

Hazards resulting from routine failures of various components of solar thermal energy systems are a function of the system design and number of components used (Ullman and Sokolow, 1979). For example, the overall failure rate for a 10 MWe parabolic dish system is greater than that of a 10 MWe central receiver system because of its modular design and greater number of parts. Failure rates of components, however, do not indicate the severity of hazard resulting from each failure. A failure in one system which uses a potentially toxic substance such as toluene as a working fluid may present a greater hazard than a similar failure in a system using water. The hazards represented by system failures are design dependent and, at present, are difficult to assess properly without definitive system design and operating experience.

The greatest occupational hazards of STES result from occupational exposure to hazardous working fluids. Fluid exposures may result from routine valve, pump, pipe or mechanical failures; from disassembly of components for maintenance; and from disposal of fluid wastes. The most serious occupational hazards would result from an "interruption of fluid flow" (IFF) off-normal receiver accident. In such an accident, the flow of thermal fluid in the receiver is inhibited causing overheating (from constant thermal imput to the same fluid), ruptured and fluid release. Candidate thermal transport and storage fluids include liquid sodium,

sodium hydroxide, organic oils and eutetic salts (composed of sodium or potassium nitrates or nitrites). Uncontrolled releases of these fluids could cause explosions, fires, and burns (DOE, 1979; ERDA, 1977; Holbeck and Ireland, 1979). A listing of potential STES system working fluids and fluid additives is presented in Table 4-1.

Solar radiation reflected from collector surfaces may create on-site glare hazards. The glare intensity is a function of the intensity of insolation, the angle of the sun, and the angle and reflectivity of collector surface (Brumleve, 1977). Proper STES design and management can minimize potential problems.

### 4.2.2 Environmental Impacts

The primary on-site environmental impact of STES is the ecological destruction of the site. To control dust and vegetation, sites are often denuded, paved, or chemically or physically treated. Herbicides and cleaning solvents, used routinely for vegetation control and mirror washing, can disrupt native communities. The nature and degree of the disruption is highly dependent upon the site and STES design and management. The microclimate of the area under collectors will likely be cooler and wetter from shading and periodic washing. Changes in the physical and climatological conditions of the site would discourage the growth of native flora and fauna.

Prior to site selection, a biological assessment of the flora and fauna on-site and on adjacent lands should be performed. If rare or endangered species are found in the area, protection measures required by the Endangered Species Act of 1973, as amended, would be prohibitively expensive and time consuming.

## 4.3 Off-Site Impacts

The off-site health, safety and environmental consequences of STES are much less than those of conventional fossil fuel energy sources. A well managed STES will not generate large amounts of air or water pollution and will not require mining, transportation and disposal of fuels and wastes. However, STES operation could cause some off-site problems.

### 4.3.1 Microclimate and Air Quality

Vapor plumes from STES evaporative cooling systems could influence microclimatic conditions. The magnitudes of these impacts will vary significantly with system, site and size, but are expected to be insignificant for systems below 1 MWe (Holbeck and Ireland, 1979). STES will have their most serious, although temporary, air quality impacts during construction. STES operation in areas of poor air quality may produce a variety of secondary pollutants. These impacts are under study by the Department of Energy, but are not expected to be significant (DOE, 1979). Finally, degradation of air quality through leaks and evaporation of working, storage, cooling and cleaning fluids may occur. Compared to a conventional fossil fueled 1 MWe generating plant, however, a 1 MWe solar

## Table 4-1

## Potential Working Fluids and Fluids Additives for STES Operation (modified from Ullman, *et al*., 1979 V)

1. Thermal Working Fluids

### Thermal Transport and Power Generation

- Steam/water
- Helium
- Argon
- Mercury
- Sodium
- Potassium
- Sulfur dioxide

- Ammonia
- Organics
  - Freon II
  - Isobatane
  - Chlorobenzene
  - Fluorinol
  - Toluene
  - Hexafluorobenzene

### Thermal Storage

- Sensible heat storage
  - Organic oils
- Latent heat storage
  - Eutectic salts
  - Sodium hydroxide
  - Sodium nitrate
- Thermochemical storage
  - Sulfates

2. Cooling Tower Water Additives (may not be required for STES).

### Scale and/or Corrosion Control

- Sulfuric acid
- Chromate salts
- Dicromate salts
- Zinc salts
- Polyphosphate
- Hexametaphosphate
- Pyrophosphate
- Polyol-esters
- Phosphonates
- Silicates
- Polymeric silicates
- Nitrites

- Amines
- Amides
- Pyridines
- Sulfamic Acid
- Polyelectrolytes
- Organic esters
- Carboxylic acids
- Molybdate
- Fluoride
- Ferrocyanide
- Copper

- Mercaptobenzothiazole
- Polyacrylamide
- Carboxy methyl cellulose
- Aminomethylene Phosphoric acid
- Borax
- Potassium hydroxide
- Sodium Hydroxide
- Manganese
- Nickel
- Trivalent chromium
- Benzotriazole

- Aromatic nitrogen compounds

### General Fouling Control

- Lignins
- Tannins
- Lignosulfonates
- EDTA

- Starch
- Sodium silicofluoride
- Polyethyleneimine

- Citric acid
- Gluconic acid
- Polyacrylate

### Biocides

- Chlorine
- Hypochlorite
- Chlorocyanurate
- Polychlorophenols
- Dichloro-naphthoquinone
- Mercury compounds
- Acrolein
- Copper sulfate
- Arsenic acid
- Tri-butyltin oxide

- Thiocyanates
- Bromides
- Creosote
- Cupric chromate
- Zinc chromate
- Bolinden
- Erdalith
- Quaternary ammonium compounds
- Chloromethylsulfones
- Tertiary butyl hydrogen peroxide

thermal power system should represent a net improvement in air quality (Holbeck and Ireland, 1979).

### 4.3.2 Water Quality and Ecological Effects

Fluid release and subsequent water quality contamination are the primary safety and environmental concerns of STES designers. Thermal transport, storage, cooling and cleaning fluids for STES can be released through routine operation or accidental spills into waterways. Uncontrolled releases could contaminate drinking water, increase soil salinity and damage aquatic and terrestrial ecosystems. These consequences are highly dependent upon the size and design of the system and the ecosystem impacted (DOE, 1979; ERDA, 1977; Holbeck and Ireland, 1979).

Several water quality problems could result from STES fluid spills. Potential problems associated with nitrate, phosphate and chromate compounds are representative. Nitrogen and phosphorous compounds may cause eutrophication and/or be toxic to aquatic life. Since only large volumes of nitrogen, sulfur, and phosporous compounds cause serious impacts, however, leaks and accidental releases from smaller STES are not likely to have significant effects (ERDA, 1977).

Chromates are highly toxic compounds used as working fluid additives in STES. Chromium is one of several toxic chemicals that should be monitored closely (ERDA, 1977). Several candidate working fluid chemicals are so toxic that disposal in a class I waste disposal site would be required (DOE, 1979).

Many of these toxic working fluids will degrade over time, requiring periodic system evacuation and replacement. If these fluids were released into sewage systems, they could inhibit or destroy the aerobic and anaerobic digestive systems of sewage treatment facilities. The release of these working fluids into local water bodies could violate water quality standards (ERDA, 1977).

The routine disposal of toxic fluids from STES operations could pose a threat to the general public. Recent federal legislation (the Resource Conservation and Recovery Act of 1976) place strict controls upon the use, handling and disposal of toxic materials. Proper STES design and siting and adherence to these regulations would significantly reduce potential problems.

Various methods for preventing water contamination, pertaining particularly to residential solar system working fluids, have been described in HUD (1976). These regulations apply to all federally funded heating and cooling projects and require:

- inventories of system chemicals.
- limits on the BOD of organic fluids.

- limits on the lethal dose concentration of chemical constituents in fluids.

- mandatory use of leak indicators.

- double wall heat exchangers and separate working fluid/water systems.

- use of dyes in working fluids to facilitate detection of leaks.

These requirements, if adopted for STES technologies could minimize the environmental impacts of STES system working fluids (ERDA, 1977).

The off-site ecological effects of STES should not be significant, unless they are sited in sensitive ecosystems, such as deserts. The delicate water balances, fragile vegetation and wildlife of arid ecosystems could all be adversely affected by STES construction and operation (DOE, 1979). Wherever sited, access roads, transmission corridors, secondary development, and recreational access could disrupt or destroy areas around STES facilities (DOE, 1979).

### 4.3.3 Aesthetics

The visual impacts of STES will depend on the type, size and location of the facilities. Currently, relatively large arrays of solar thermal power systems are being considered for rural or remote areas. Small STES may be integrated into urban settings in an aestheically pleasing manner through proper design, building orientation, landscaping, and structural clustering (see Section 7).

## 4.4 Summary of Potential Environmental Impacts

The following is a brief summary of the environmental problems of STES:

- Water contamination from accidents or improper handling and disposal of working fluids.

- Large land requirements and consequent loss of native cover.

- Threat to rare and endangered species.

- Temporary noise, air quality, erosion and wildlife impacts from construction activities.

- Potential disturbance of local water patterns through withdrawal or addition of water and through the alteration of runoff patterns.

- "Off-normal" ruptures of fluid systems, with possible toxic emissions.

- Aesthetic impacts

## 4.5 Required Environmental Information

A complete environmental inventory of each potential STES site should be performed to properly site the systems and to calculate and mitigate the impacts of plant construction and operation. Evaluation criteria are summarized in the following inventory:

- Geology and soils--describe topography, seismic risk, wind and water erosion potential during construction and operation; detail adjacent land uses; describe soil types and foundation stability.
- Climate--describe the average, distribution, range and direction of wind, precipitation, temperature, and insolation.
- Hydrology--describe surface waters, runoff, flooding potential, accumulation potential, quality and availability of groundwater, area water quality and water uses.
- Biology--describe the flora and fauna; detail rare or endangered species.

## 4.6 References

Brumleve, T.D. Eye Hazard Glint Evaluation for the MWt Solar Thermal Test. Sandia Labs Test Report, SAND 76-8022/UC-62 (May 1977).

Energy Research and Development Administration (ERDA). Solar Thermal Electric, Solar Program Assessment; Environmental Factors. ERDA-77-47-4 (March 1977).

Holbeck, H.J. and S.J. Ireland. Siting Issues for Solar Thermal Power Plants with Small Community Applications. Jet Propulsion Lab, Pasadena, California. DOE/JPL-1960-78/2 Rev. 1 (February 1979).

Ullman, A.Z. and B.B. Sokolow. "On the Safety of Electric Power Generation." Solar Energy Fundamentals and Applications Symposium, 72nd Annual AIChE Meeting, San Francisco (1979).

Ullman, A.Z., B.B. Sokolow and J.I. Daniels. Worker Health and Safety Solar Thermal Power Systems. I. Overview of Safety Assessments. U.C. 12/1211 (October 1979).

______________. Worker Health and Safety in Solar Thermal Power Systems. II. Data Base and Methodology for the Estimation of Worker Injury Rates. UC 12/1212 (September 1979).

______________. Worker Health and Safety in Solar Thermal Power Systems. III. Thermal Energy Storage Subsystems. UC 11/1213 (September 1979).

______________. Worker Health and Safety in Solar Thermal Power Systems. IV. Routine Failure Hazards. UC 11/1214 (October 1979).

________. Worker Health and Safety in Solar Thermal Power Systems. V. Off-Normal Events. UC 12/1215 (November 1979).

United States Department of Energy (DOE). Solar Thermal Power Systems Environmental Readiness Document. DOE/ERD-0019 (August 1979).

United States Department of Housing and Urban Development (HUD), Bureau of Standards. Intermediate Minimum Property Standards for Solar Heating and Domestic Hot Water Systems. Washington, D.C. (1976).

# 5.0 UTILITY ISSUES

## 5.1 Introduction

This section reviews the impact of federal, state, constitutional and statutory provisions concerning utilities on the solar energy market. The potential effects of recent federal legislation, particularly the Public Utility Regulatory Policies Act of 1978, on STES users are then discussed and summarized.

These regulatory variables play an important role in defining the degree of commercialization of solar systems. STES energy outputs must be marketed in sufficient quantities, sold at a reasonable cost, and integrated into a local energy infrastructure. The regulatory environment determines the success of these efforts and, therefore, the success of STES as a whole.

However, it is impossible in this short space to adequately describe each region's or locale's utility and energy industry regulations. The laws are vastly different and often very complex. Instead, the following generally describes the regulatory agencies and issues a solar system developer will most likely deal with.

## 5.2 Regulatory Overview

Because utilities may purchase, sell, and transmit solar-generated electricity, as well as provide back-up power for solar systems, public utility regulation is an important issue to the prospective developer. This regulation incorporates four principal components: 1) setting and regulation of utility and energy rates, 2) control of entry into, and competition within, the energy arena, 3) establishment of service and quality standards for energy producers and distributors, and 4) imposition of a general obligation to serve utility customers under all reasonable conditions. The first issue, that of rate-making regulation, is widely perceived to be the most significant facing solar developers (Laitos et al., 1979).

Federal and state jurisdiction over utilities and energy producers may overlap. For instance, many states include power plant and utility facility siting as actions requiring environmental review. Those states which do mandate environmental review typically ask: 1) whether a planned power plant is needed from the perspective of current power production, 2) what the likely implications are of a proposed project on a utility's financial standing, and 3) what the proposed project's implications for energy and electricity rates will be. Therefore, solar developers should stay well informed of the requirements of their state.

One key feature of public utility regulation is the control of the means by which prospective utility businesses may enter the energy market. State utility regulatory statutes universally require that every public utility must obtain a certificate of "public convenience and necessity" before beginning operation or even construction of its equipment. This requirement affects new utilities, including utilities seeking to sell solar-produced energy, in two important ways. First, state public utility commissions (PUC's) can, and do use the certification process to protect the monopolies of existing utilities (even when these utilities provide inadequate and inefficient service). Consequently, new utilities are rarely permitted in areas already served by existing utilities. Second, certification proceedings before regulatory agencies are usually time-consuming and expensive. This adds to the solar developer's struggle to sell their electricity and energy efficiently and at a reasonable price.

Laitos, et al. (1979) state that the certification process promises to be the major obstacle to solar utility participation in the power generation market. There are several means, however, by which this barrier to electric service competition may be removed. State PUC's could decide simply not to exercise jurisdiction over solar electric generating facilities. Alternatively, legislation might allow general PUC regulation, but also expressly permit solar facilities to compete with existing utilities. Solar utilities could attempt to gain entry into the electric service market by purchasing an existing utility's certificate, subject to the discretion of the PUC. Finally, the PUC could consider the economic feasibility of constructing a solar plant and system, together with possible social costs and benefits, in deciding whether to award a certificate.

Once a utility is granted a certificate to operate, it must satisfy certain other statutory requirements. Most states require that utilities furnish all of its customers with "adequate and safe service." This requirement is interpreted on a case-by-case basis with "reasonableness" and the "public interest" as major touchstones (Miller et al., 1977).

A related issue is the effect of state anti-discrimination statutes. Again, most states have statutes which prohibit utilities from favoring one class of customers over another. These statutes prohibit policies which are unreasonable, unjust, undue, or unlawful. But in reality, policies or rate schedules which have some "reasonable" basis are usually upheld. Thus, if solar customers cost more or less to serve than other customers, they may receive different service and be charged different rates. Moreover, solar users who challenge discriminatory rate practices must engage in lengthy administrative hearings and bear the burden of showing that the disputed rates are unlawfully discriminatory.

These statutes may also act in favor of solar users and customers. Preferential rate schedules are more likely to be found reasonable if they produce indirect benefits for all customers. One could therefore argue that discrimination in favor of solar users is not unreasonable or unlawful, where solar systems integrated into utility networks could potentially reduce the utility's needs for capital equipment and fuel. The furthering of national policy goals such as energy conservation and environmental protection could also support this form of benign discrimination.

Constitutional and antitrust restraints may affect a utility's discriminating in favor of, or against solar systems. Discriminatory practices may run afoul of the constitutional guarantee of equal protection under the law. However, the 14th Amendment applies only to states and state action, and simple PUC approval of rate structures may not be covered. A more hopeful approach rests with the antitrust laws, specifically when interpreting the Sherman Antitrust Act's applicability to electric utilities. An existing utility's application of high rates to solar users, or use of high backup rates in general, might be considered anti-competitive within the intent of the Sherman Act.

Again, the most important aspect of public utility regulation is rate regulation. Utilities must follow a two-step rate-making process during which: 1) its revenue is adjusted to the demands of a fair return, and 2) the rate schedule is adjusted to recover the necessary revenue. Because the specifics of rate-making are relatively complex, and because there are numerous types of rate schedules which can affect solar utilities and users, this area is more thoroughly discussed in Section 6.

## 5.3 Recent Federal Legislation

The Public Utility Regulatory Policies Act of 1978 (PURPA) (part of the National Energy Act of 1978) addresses many of the utility and regulatory problems of small scale energy producers. The provisions and regulations of PURPA that will likely affect STES are discussed in the following.

### 5.3.1 Rate Standards

Federal standards established by the Act provide that rates shall be established, to the extent possible, to reflect the cost of service to each customer class. Additionally, rates must identify and incorporate time-of-day and seasonal energy demand patterns, unless resulting metering costs to the utility are likely to exceed cost savings.

The national standards prescribed by PURPA for electric utility rates apply to electric utilities with retail sales of more than 500 million KWH annually. While these standards are not strictly mandatory, PUC's and non-regulated utilities must consider whether to implement PURPA's rate-making standards. This assures that standards potentially beneficial to the commercialization of STES will be addressed.

Consumers, including potential solar customers, are guaranteed the right to intervene in regulatory proceedings to advocate rate reform, standards, and other policies consistent with PURPA. This may remove the cost barrier to challenging rate-making practices. Solar customers could even be reimbursed for legal and other expenses associated with the successful advocacy of a particular standard.

### 5.3.2 Other Provisions

PURPA establishes the right of qualifying small scale power producers to sell excess power to utilities (see Subsection 5.3.3 for definitions of "qualifying small power producers"). Utilities must purchase power which is made available by qualifying facilities and must pay reasonable and non-discriminatory rates for the power. These provisions help create an alternative to utility owned power generating facilities (propsective power producers should verify their entitled rates through PURPA and its implementing regulations).

Utilities must also make arrangements to "wheel" or sell excess power to non-local public utilities through their own energy grid networks, if the excess power can be made available for resale purposes. This requirement of PURPA increases the feasibility of STES by enlarging the market for solar generated power. It also reinforces the interdependence of these systems with energy transmission and distribution networks.

Finally, PURPA grants qualifying facilities an additional statutory right to backup power service. Electric utilities must sell any energy and capacity requested by the qualifying facility, again at reasonable and non-discriminatory rates. Utilities are obligated under the implementing regulations to furnish supplementary power, backup power, maintenance power, and interruptable power. These obligations are in force unless the utility can demonstrate that compliance will impose an undue burden on the utility or impair its ability to provide adequate service to its customers.

### 5.3.3 Implementing Regulations

Certain implementing regulations authorized under PURPA (effective March 20, 1978), established in the Federal Register and printed in the Code of Federal Regulations (CFR), expand upon and reinforce the provisions of PURPA.

"Qualifying small power production facilities" must meet several criteria. Under the definition, no more than 50 percent of the equity interest in the facility can be held by an electric utility or utilities. At least 50 percent of the energy input to the facility must be produced by renewable energy sources. The total power production of a single facility may not exceed 80 MWe and may be as small as 1 MWe. Finally, the operations located at a single "site" and which are intended to comprise one qualifying facility, must not extend more than one mile from the central electrical generating equipment.

The implementing regulations reiterate the buyback power provisions previously mentioned. Additionally, electric utilities are obligated to make such interconnections with qualifying facilities as are necessary to accomplish these purchases and sales. Qualifying facilities, however, are obligated to pay any interconnection costs if the regulatory authorities or PUC's do not provide for cost reimbursements.

PURPA and its implementing regulations allow small power producers (less than 30 MWe) to be exempted from certain provisions of the Federal Power Act, the Public Utility Holding Company Act, and state laws pertaining to rate regulation of electric utilities. In particular, qualifying facilities are exempted from state laws and regulations pertaining to finances, organization, and rate standards of electric utilities. These provisions remove the potential disincentive of utility-type regulation and may allow STES to compete more freely in the energy network.

### 5.3.4 Voluntary Guidelines

The Department of Energy's Economic Regulatory Administration has published voluntary guidelines pertaining to the PURPA rate standards insofar as these standards will affect "solar energy and renewable resources." The definition of the latter term is restricted to dispersed or on-site technologies for which solar energy provides only a portion of end-use requirements. As stated earlier, PURPA's standards support time-of-day, seasonal, and interruptable rate formulas and basically reject declining block rate standards. The guidelines explain how solar systems will benefit from these rate standards and elaborate on each standard's criteria. These guidelines are strictly voluntary but must be considered by state regulatory authorities.

### 5.3.5 Conclusion

The above provisions and regulations under PURPA benefit solar electric technologies by prohibiting rate discrimination in the purchase of auxiliary energy and in the sale of excess energy. A solar small power producer may secure exemptions from Federal and state rate regulations when the producer considers certain regulations detrimental to parallel operation with a utility. For the qualifying producer and facility, the Act resolves several issues that could have hindered the commercialization of solar-electric technologies. A particular producer or developer is urged to consult the Act and implementing regulations to ascertain how they will be affected.

## 5.4 References

Asbury, *et al*. *Solar Energy and Electric Utilities: Can They Be Interfaced?* Argonne National Laboratories (August 1976).

Davitian, H., *et al*. *Utility Load Management and Solar Energy: Study Background Outline*. Brookhaven National Laboratory, Upton, N.Y. (March 1978).

Doralek, P.J. *Utility Interface Requirements for a Solar Power System*. Office of Energy Research, U.S. Department of Energy, Washington, D.C. (September 1978).

Feldman, S.L., *et al*. *Public Utility and Solar Energy Interface: Assessment of Policy Options*. Clark University, Worcester, Mass. (December 1976).

Feuerstein, R.J. *Utility Rules an Service Policies as Potential Barriers to the Market Penetration of Decentralized Solar Technologies*. Solar Energy Research Institute, Golden, Colorado (August 1979).

Koger, R.K. "Regulatory Constraints on Solar Energy and Thermal Installation." Public Utilities Fortnightly (January 19, 1978).

Laitos, J., et al. Regulated Utilities and Solar Energy: A Legal-Economic Analysis of the Major Issues Affecting the Solar Commercialization Effort. Solar Energy Research Institute, Golden, Colorado (June 1979).

Messing, M. Electric Generation: Issus of Scale and Political Authority. Environmental Policy Institute, Washington, D.C. (1978).

Miller, A.S., et al. Legal Barriers to Solar Heating and Cooling in Buildings. Environmental Law Institute, Washington, D.C. (1977).

Office of Technology Assessment (OTA). Application of Solar Technology to Todays Energy Needs. U.S. Congress, Washington, D.C. (June 1978).

# 6.0 LEGAL AND REGULATORY ISSUES

## 6.1 Introduction

Because STES are commercially unproven technologies, no local, state, or federal regulations have been written specifically for these systems. Instead, certain issues common to energy systems (i.e., utility siting, land use procedures, and environmental control) are the major subjects of regulation. These regulations affect STES on a specific site/technology basis. Many of these issues have already been identified for related technologies and responsible agencies assigned (Holbeck and Ireland, 1979).

This section discusses regulations and regulatory issues which would apply to the implementation of STES. It does not give a compendium of legislation, since regulations will differ from site to site. Rather, the regulatory steps that a typical developer will have to address are discussed.

## 6.2 Project Assessment

Many government agencies will be invoved in the process of obtaining permits and licenses to site, build and operate STES facilities. STES developers should be aware of the overlap and hierarchy of regulatory authority pertaining to STES. A project may be subject to regulatory authority at local, state, and federal levels. The hierarchy of regulatory authority is given in Figure 6-1.

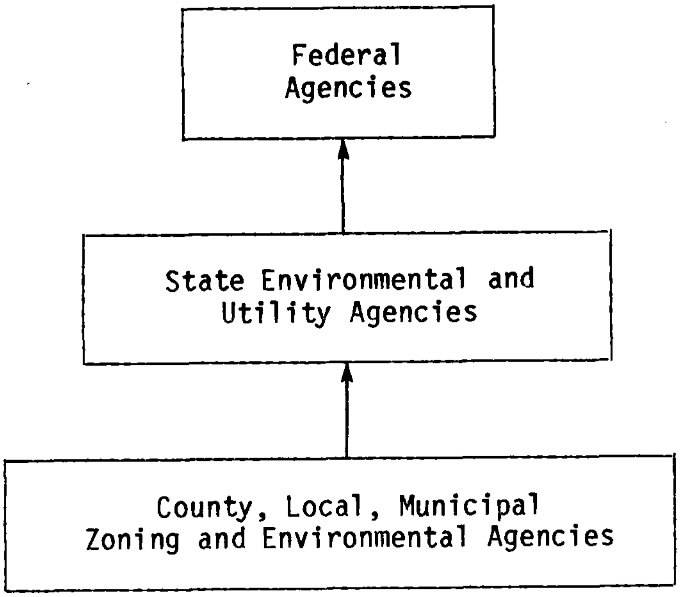


Figure 6-1

Hierarchy of Regulatory Authorities (Senew *et al.*, 1977)

## 6.3 Building Codes and Standards

The next important step is the actual development and construction of the STES facility. Building code regulations allow local governments to define terms and set standards for materials and equipment. Government agencies, scientific laboratories, and private firms are working to develop standards specific to STES (Riley, *et al.*, 1979). The Department of Energy plans to adopt performance criteria for the federal standards. The Argonne National Laboratory, Sandia Laboratories, and Foster Wheeler (a private consulting firm) are developing test conditions and design standards for solar central receivers and components. Design specifications have already been adoped which apply to heliostats, dispersed concentrating collectors, and other components. Finally, although building codes do not explicitly prohibit or prescribe STES, future government legislation may establish potential building code modifications and implementing guidelines that would favor advanced solar system applications. Riley *et al.* (1977) concludes that major revisions in local building codes will not be necessary for most central and dispersed residential and commercial solar applications.

## 6.4 Environmental Influences

STES operation will have several adverse environmental effects (see Section 4.0). The nature and extent of each should be analyzed in the initial stages of project assessment so that the facility complies with the provisions of The National Environmental Protection Act of 1969 (NEPA) and applicable state legislation.

### A. Water Quality

STES developers will need to coordinate water management activities with local water quality regulatory agencies. Permits for the discharge of waste water will need to be obtained under the requirements of the Federal Water Pollution Discharge Elimination System (NPDES) (DOE, 1979; Ireland, 1979). A developer is required to evaluate all proposed discharges to determine their environmental impact and appropriate mitigation procedures. The NPDES permit procedure is administered primarily by state and local water agencies (e.g., California's State Water Resources Control Board through Regional Water Quality Control Boards). Requirements usually include descriptions of discharge composition, the manner of discharge, and the characteristics of the receiving water.

### B. Air Quality

Air pollution impacts are subject to the regulation of the Environmental Protection Agency (EPA) as mandated by the Clean Air Act and its amendments. Site-specific pollutant emissions are subject to strict review. If sources exceed emissions or ambient air quality standards established by the Clean Air Act or those adopted by a state regulatory agency, these sources must use the "best available control technology" (BACT) in system design. If, with BACT, a system would still exceed standards, it must submit to a detailed air quality analysis or "new source review." STES facilities, because of their low air quality impacts, would not likely require extensive air quality management and analysis.

### C. Additional Environmental Regulations

STES will also need to comply with provisions of other environmental legislation, such as the Resource Conservation and Recovery Act, the Toxic Substances Control Act and the Federal Pesticides Act (DOE, 1979). Table 6-1 summarizes regulations pertinent to STES health and safety issues. A review of many of these regulations may be found in Ireland (1979).

## 6.5 General Zoning

A. In contract zoning, a landowner enters into a contract with another party, usually a municipality, promising to exercise certain land use restrictions in return for a promise that is of benefit to the landowner (Eisenstadt, and Utton, 1976). For example, a developer could place a STES on a building at the north end of a north/south oriented lot and then deed the southern end of the lot to the public authority for a solar park where more collectros could be situated. This can be done in return for a tax write-off to the developer in excess of the actual market value of the land.

B. A prototype has been suggested for a solar zoning concept. This process could establish two types of zoned districts defined by a local government that would favor solar energy utilization. A mandatory solar energy use district could be established requiring the application of cost-effective solar energy systems (e.g., STES) as primary sources of energy in all new structures. Or, an affirmative solar energy use district could be established where conditions are suitable for the use of cost-effective solar systems but where prevailing conditions prevent mandating solar energy use (Miller, 1977).

## 6.6 Solar Access and Land Use Issues

Solar access regulations and agreements, public and private, prescribe the legal rights of property owners to receive and utilize solar energy. Buildings, developments, and general landscape alterations may shade an adjacent landowner's property and thus impede access to sunlight. Access measures are designed to protect the landowner/solar developer's interests when constructing and operating a solar system.

Whether these guarantees are, or will be necessary is presently unclear. For example, many low-density residential neighborhoods appear free of shadows during high-insolation periods (Miller et al., 1977). Districts zoned for high-density residential and commercial, or into which integrated industrial energy systems will be placed, are not likely to face access problems.

## Table 6-1

## Codes, Ordinances, and Standards Related to Solar Thermal Power Plant Health and Safety

| | |
|---|---|
| Laws and Ordinances Federal | |
| • Clean Air Act | |
| • Noice Control Act | |
| • National Environmental Policy Act | • Clean Up or Containment of Toxic Spills |
| • Federal Water Pollution Control Act | |
| • Solid Waste Disposal and Resource Recovery Act | |
| • Toxic Substance Control Act | |
| Laws and Ordinances State and Local | |
| • S&L Water Quality Control Act | • Green Area |
| • Erosion and Sedimentation Control Act | • Building Setbacks<br>• Access Road Right of Way |
| • Dept. of Natural Resources Environmental Protection | • Site Grading Plan |
|     • Air Quality Control | • All Site Construction |
|     • Solid Waste Management | |
| Codes and Standards | |
| • OSHA | • Standard Practices |
|     • Occupational Safety & Health Standards | |
|     • Safety & Health Regulations | |
|     • NFPA | • Fire Protection in STES Building |
| • National Electric Code | |
| • Life Safety Code | • Fossil Heater |
| • Other National Fire Costs as Applicable | |
| • ANSI | • Power Piping<br>- Materials<br>- Wall Thickness<br>- Allowable Stresses |
|     • National Electrical Safety Code | |
|     • Other ANSI Standards as Applicable | |
| • ASME Boiler & Pressure Vessel Code | • PCS Vessel Design |
| • NEMA Standards | • Standard Practice |
| • AISO Steel Construction | • Field Fabricated |

### 6.6.1 Legislative Grants and Solar Rights

The following section discusses various tools available to the planner to ensure solar access at the STES site.

#### A. Prescriptive Rights

England recognized a right to light in its early "Doctrine of Ancient Lights" rule. A product of English common law, the rule gave property owners a right to solar access if they openly received and enjoyed that sunlight over a protracted period of time.

No state has adopted the rule's prescriptive principles. (See, e.g., Fontainbleu Hotel Corporation vs. Forty-Five Twenty-Five, Inc., 114 So. 2nd 357 (Fla. App. 1959), in which a landowner's right to construct a building was affirmed even when the building cut off another's light and air. The establishment today of such a solar access system is complicated by several serious problems: the length of time for which a prescriptive right is to be established; the necessity for notice when a property owner attempts to acquire such a right; and the need to define a legitimate interruption to solar access (Ashworth, *et al.*, 1979). Some researchers believe that the drawbacks accompanying a prescriptive system more than outweigh its potential usefulness (Miller, *et al.*, 1977).

#### B. Appropriative Rights

This approach grants a right to solar access based on concepts described in western water rights law. Appropriative principles establish a priority in time. Once a solar system demonstrates some beneficial use or minimum efficiency, no development can subsequently interfere with the system's right to sunlight.

The appropriative rights method has been strongly supported and recently incorporated into the statutes of New Mexico (New Mexico's Solar Rights Act of 1978). However, some problems are inhibiting the widespread feasibility of this approach. The allocative principles stress priority in time. Therefore, solar systems may be implemented prematurely in order to establish an access right. Moreover, the rigid appropriative framework may alter the balance between solar and property rights, resulting in a "taking" of property that requires just compensation (Pollock, 1979).

### 6.6.2 Nuisance Law

Public nuisance law discusses the potential interference of STES with the "public health, safety, or welfare." For example, structures which shade or adversely affect STES could be declared public nuisances. Conversely, solar systems which cause a substantial and recurring invasion of private property interests could be declared private nuisances. The difficulties surrounding the effective implementation of this approach are again considerable. Landowners bringing private nuisance suits may need to show irreparable damage to their property rights. Moreover, "nuisance" legislation, being inherently prohibitory, often requires lawsuits to effectuate its goals. Finally, courts seldom characterize certain property uses as nuisances if they are otherwise authorized through zoning laws (Ashworth, et al., 1979).

### 6.6.3 Restrictive Convenants

Covenants incorporate restrictions or promises into lot deeds either explicitly or by reference. These "private legal devices" control aesthetics through regulation of a development's homogeneity and by restricting the height, set-back and density of future developments (Ireland, 1979).

Restrictive covenants do not broadly define rights to solar access and therefore cannot be called comprehensive. However, many authors favor this approach in lieu of government controlled regulatory mechanisms. Covenants are conventional means of controlling private development activities and are often used by solar developers today (Jaffe, 1978; Jaffe, 1979). They are particularly applicable to new residential neighborhoods and large-scale subdivisions which often require convenant agreements (however, such agreements may not be applicable to commercial and industrial land) (Miller, et al., 1977).

### 6.6.4 Easements

Solar easements grant the recipient specific, limited access to sunlight through negotiations and written agreements with neighboring property owners. Express easements affirm the solar developer's right to solar energy by restricting adjacent structures and vegetation from blocking the passage of sunlight (Ireland, 1979). These mechanisms are recognized by the courts in most states.

The easement approach to solar access is the most popular. Express easements cost local governments nothing, they are adaptable to specific needs of different property owners, and they offer the permanence of access protection not often found in zoning laws. Easements may be especially well suited to developed areas where land uses are established and unlikely to change.

Express easements have certain disadvantages. Solar users who acquire easements to sunlight may be required to pay surrounding property owners for that right, which could be prohibitively expensive (Miller, et al., 1977). Moreover, express easements shift the entire expense of obtaining solar access to the solar developer, thus subjecting developers to the potential costs of lengthy enforcement proceedings (Office of Technology Assessment, 1978).

### 6.6.5 Land Use Planning

#### A. Flexible Zoning Techniques

The manipulation of zoning laws has been extensively analyzed as a means of guaranteeing solar access. Miller et al. (1977) detail how flexible zoning might play a role in industrial, commercial, and residential areas. Wallenstein (1978) suggests the additional designation of "solar radiation overlay zones" to assure access.

The application zoning laws has both advantages and disadvantages. Disadvantages include the inherently political and time-consuming nature of zoning and rezoning, the high costs of implementing zoning, and potential conflicts between blanket zoning for solar access and other energy-conserving techniques. Moreover, solar users may want to avoid continued reliance on governmental regulations in favor of market mechanisms to ensure access (Jaffe, 1978; Jaffe, 1979).

### B. Transferable Development Rights (TDR's)

Under the "transfer of development rights'" (TDR) concept, land development rights are transferable and can be sold independently of the land. This innovative approach allows owners of restricted property, including owners hampered by severe solar restrictions, to receive compensation for their losses. As yet largely untested, TDR's are quite complex and might better be used in a comprehensive land use plan rather than simple to promote solar access (Miller et al., 1977).

### C. Planned Unit Developments (PUD's)

Planned Unit Developments (PUD's) minimize zoning restrictions and allow developers to offer layouts, building designs, and suggested uses as a single package. The concept is specifically authorized in only a few states, although many communities have used it without serious legal problems (Office of Technology Assessment, 1978). PUD's can be used to minimize existing zoning and regulatory barriers to solar development.

### D. Solar Energy Elements

Many states use comprehensive plans to guide local zoning policy. Solar energy elements, if incorporated in these plans, would likely encourage the use of solar energy. Requirements for consideration or inclusion might authorize local governments to regulate solar access and otherwise provide for solar development. The use of a solar energy element in comprehensive plans may be one of the most important future tools in assuring solar access.

### E. Additional Approaches

#### Federal Involvement

The federal government could regulate solar access through its broad powers over interstate commerce, set national solar access policy, or incorporate solar access criteria into grant programs which finance land use planning. Federal activities may be required to induce local governments to adopt favorable solar access laws, because only 5,000 of 60,000 local jurisdictions with power over land use exercised general zoning powers in 1974 (Office of Technology Assessment, 1978).

### Energy Impact Statements

Some states require that environmental impact statements discuss the effects of projects on energy consumption. Because large land developments will come under the impact statement requirements in these states, the impact procedure might be used to increase consideration of, or even ensure, solar energy utilization.

### Solar Skyspace Easements

Suggested statutes would allow cities to negotiate or condemn skyspace easements. Such actions involve the taking of property and therefore require compensation. These easements would than be transferred to property owners who, in turn, could than be assessed for the cost of the airspace. The American Bar Association had developed a sample statute based on this approach (Miller *et al*., 1977).

## 6.7 References

Armstrong, J.E., *et al*. *Community Impediments to Implementation of Solar Energy*. Office of Technology Impacts, Department of Energy, Washington, D.C. (November 1979).

Ashworth, J., *et al*. *The Implementation of State Solar Incentives: A Preliminary Assessment*. Solar Energy Research Institute, Golden, Colorado (January 1979).

Eisenstadt, M. and A. Utton. "Solar Rights and Their Effect on Solar Heating and Cooling." *Natural Resources Journal*. Vol. 16:363 (1976).

*Environmental Comment*. "Solar Energy and Land Use." (May 1978).

Hillhouse, K., *et al*. *Legal and Institutional Perspectives on Solar Energy in Colorado*. Environmental Law Institute, Washington, D.C. (November 1977).

Holbeck, H.J. and S. Ireland. *Siting Issues for Solar Thermal Power Plants with Small Community Applications*. Jet Propulsion Laboratory, Pasadena, California (February 1979).

Ireland, S. *Regulations Applicable to Small Solar Thermal Power Plants: Interim Report*. Jet Propulsion Laboratory, Pasadena, California (March 1979).

Jaffe, M. *Protecting Solar Access for Residential Development: A Guidebook for Planning Officials*. The American Planning Association, Chicago, Ill. (1978).

Jaffe, M. *Protecting Solar Access: A Guidebook for California Communities*. The American Planning Association, Chicago, Ill. (June 1979).

Johnson, D.S. Legal Issues Affecting Solar Energy Development: A Right to Light? University of California, Los Angeles, California (Unpublished paper) (March 1980).

Johnson, S.B. Survey of State Approaches to Solar Energy Incentives. Solar Energy Research Institute, Golden, Colorado (July 1979).

Miller, A.S. "Solar Energy and Public Lands." In Journal of Contemporary Law. Vol. 4:1:78-94. (Winter 1977).

Miller, A.S., et al. Legal Barriers to Solar Heating and Cooling of Buildings. Environmental Law Institute, Washington, D.C. (March 1977).

Office of Technology Assessment. Application of Solar Energy to Today's Energy Needs. Washington, D.C. (June 1978).

Pollock, P. Implementation of State Solar Incentives: Land Use Planning to Ensure Solar Access. Solar Energy Research Institute, Golden, Colorado (March 1979).

Riley, J.O., et al. Standards, Building Codes, and Certification Programs for Solar Technology Applications. Solar Energy Research Institute, Golden, Colorado (July 1979).

Senew, et al. Impacts of Environmental and Utility Siting Laws on Community Energy Systems. Proceedings of the International Conference: Energy Use Management. Tucson, Arizona (October 24-28, 1977).

Thomas, W. A., et al. Overcoming Legal Uncertainties about the Use of Solar Energy Systems. American Bar Foundation, Chicago, Illinois (1978).

U.S. Department of Energy (DOE). Environmental Readiness Document: Small Thermal Power Systems. Washington, D.C. (August 1979).

Wallenstein, A.R. Barriers and Incentives to Solar Energy Development. Northeast Solar Energy Center, Cambridge, Mass. (December 1978).

Wallenstein, A.R. (ed.). Proceedings of a Workshop on Solar Access Legislation. Northeast Solar Energy Center, Cambridge, Mass. (July 1979).

Warren, M. Problems in the Administration of State Solar Legislation. Solar Energy Research Institute, Golden, Colorado (July 1979).

Yokell, M.O. Role of the Government in the Development of Solar Energy. Solar Energy Research Institute, Golden, Colorado (1979).

# 7.0 URBAN DESIGN IMPLICATIONS OF STES SYSTEMS

## 7.1 Introduction

To stimulate public awareness of the viability of the technologies, it may be desirable to operate initital STES in a highly visible manner. However, as public acceptance increases and systems begin to be integrated into new or existing urban patterns, visibility may become a liability (in some cases), rather than an asset. To prevent negative public reaction to potential aesthetic problems, STES will need to be carefully integrated into urban design patterns.

Assuming that STES are economically competitive with conventional energy systems, and that they are to be used in commerical structures and multifamily residential developments, the following sketches present several ways of integrating STES into urban design patterns. These sketches do not define potential end-uses of STES, rather, they illustrate ways of integrating designs into the urban setting. Several of these design suggestions may currently appear relatively unrealistic, but with technological evolution and community support, STES could evolve to fit these, and many other applications.

## 7.2 Integration of STES into the Urban Setting

The following are the general criteria upon which each of the sketches is based:

- Solar access must be maximized to promote collector efficiency. Shadows cast by adjacent buildings, trees or other obstructions on or off the site must be taken into account in order to establish the field of greatest exposure to annual solar cycles.
- The current stark appearance of STES collector arrays may present aesthetic problems. A more highly integrated design solution can reduce these problems without affecting collector performance.
- Health and safety problems may result from system operation in public areas. In areas where climatic conditions could place stress upon collector arrays, careful planning and design will be needed to prevent structural damage.

These sketches indicate potential STES integration within three segments of the urban landscape. These segments are: (1) structures, (2) user owned open space and easements, and (3) publicly owned easements and rights-of-way. Further areas of potential use should be investigated as they emerge in the future evaluation and selection of end uses.

Figures 7-1 and 7-2 indicate two methods of structural integration of STES. Figure 7-1 could represent office buildings, hospitals, nursing homes, municipal buildings, shopping malls, intermediate high rises, etc. STES are shown in a parking area, along the side of a building (vertical element), and on the roof of a building (horizontal element).

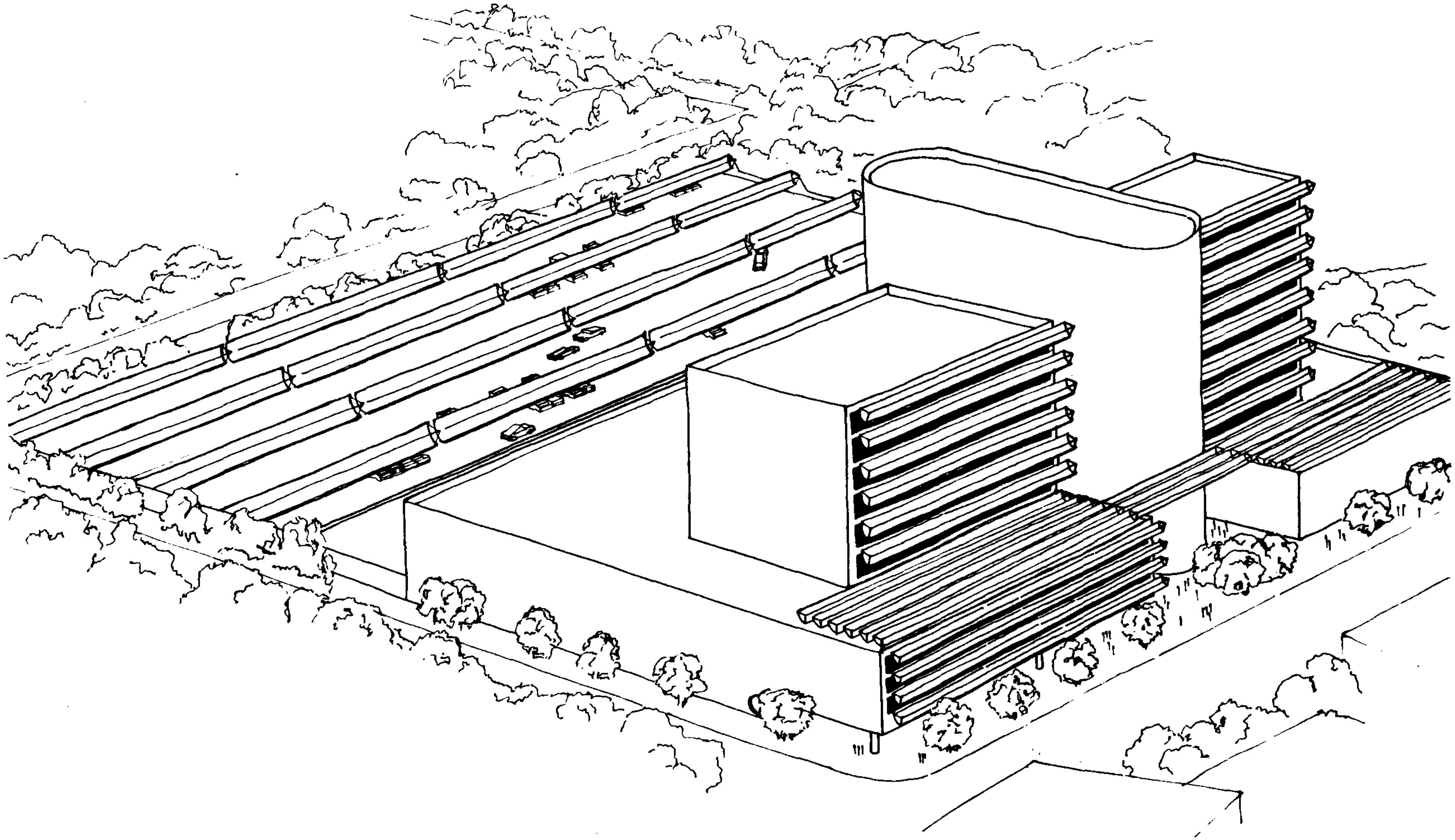


Figure 7-1

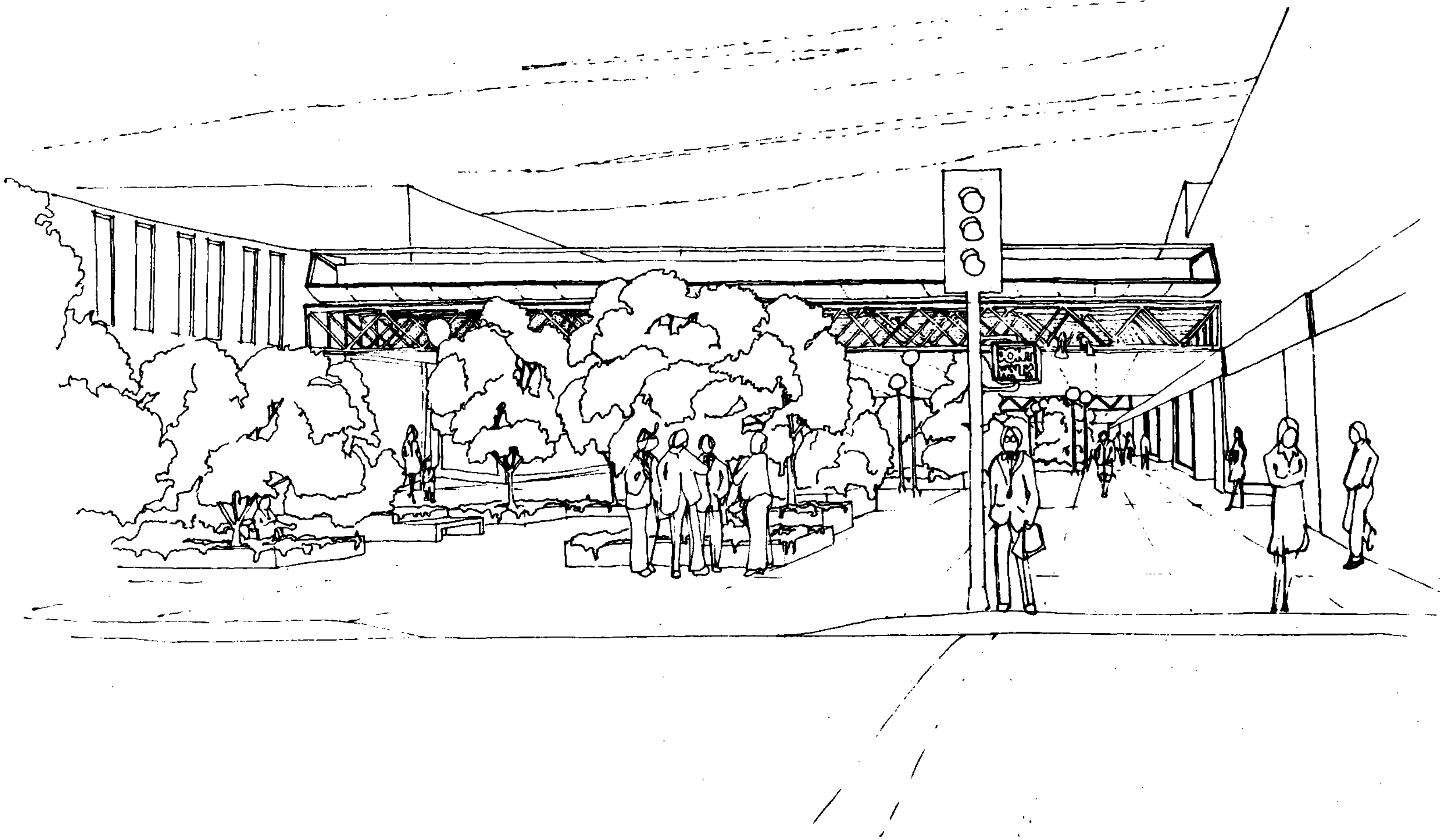


Figure 7-2

The advantages of each placement are:

(1) parking areas provide climatic protection (i.e., shade, etc.), and represent the largest unobstructed area in an urban setting.

(2) vertical building elements

- provide the opportunity for movable sun control.
- add poential day/lighting components, reducing building energy loads.
- reduce artificial lighting.
- eliminate need for heat absorbing or reflective overhangs.

(3) Horizontal building elements provide shade.

Figure 7-2 presents a sketch of the integration of STES into smaller commercial facilities. In this sketch, STES parabolic troughs are being used as a canopy shade structure over pedestrian malls or arcades connecting major building elements. Because of their linear form, trough collectors can easily be sized for particular uses and integrated into existing forms. The major disadvantages of trough applications are the potential health and safety hazards from chemical leakage.

Figures 7-3 and 7-4 present STES uses within user owned or leased open space. Figure 7-3 presents an integration of parabolic trough systems into residential or commercial facilities with considerable open space (such as steep hillsides that cannot be developed for other uses). Such a system could be used in planned single and multifamily developments, industrial and commercial complexes, college and universities, etc. Arrays can be located in areas poorly suited for development and can provide stability to otherwise unstable land forms. Figure 7-4 presents a similar end-use for STES central receiver systems.

Figure 7-5 represents the integration of STES into publically owned easements or rights-of-way, through the use of parabolic dish systems along transportation or utility corridors. A considerable amount of public land could be made available in transportation corridors, drainage easements, and power and pipeline rights-of-way. System ownership and maintenance must be integrated with the nature of easements or rights-of-way. Health, safety and security problems may inhibit certain applications. For instance, glare along highway rights-of-way could be a significant problem. These problems could be mitigated, if not entirely eliminated, by proper system design and management.

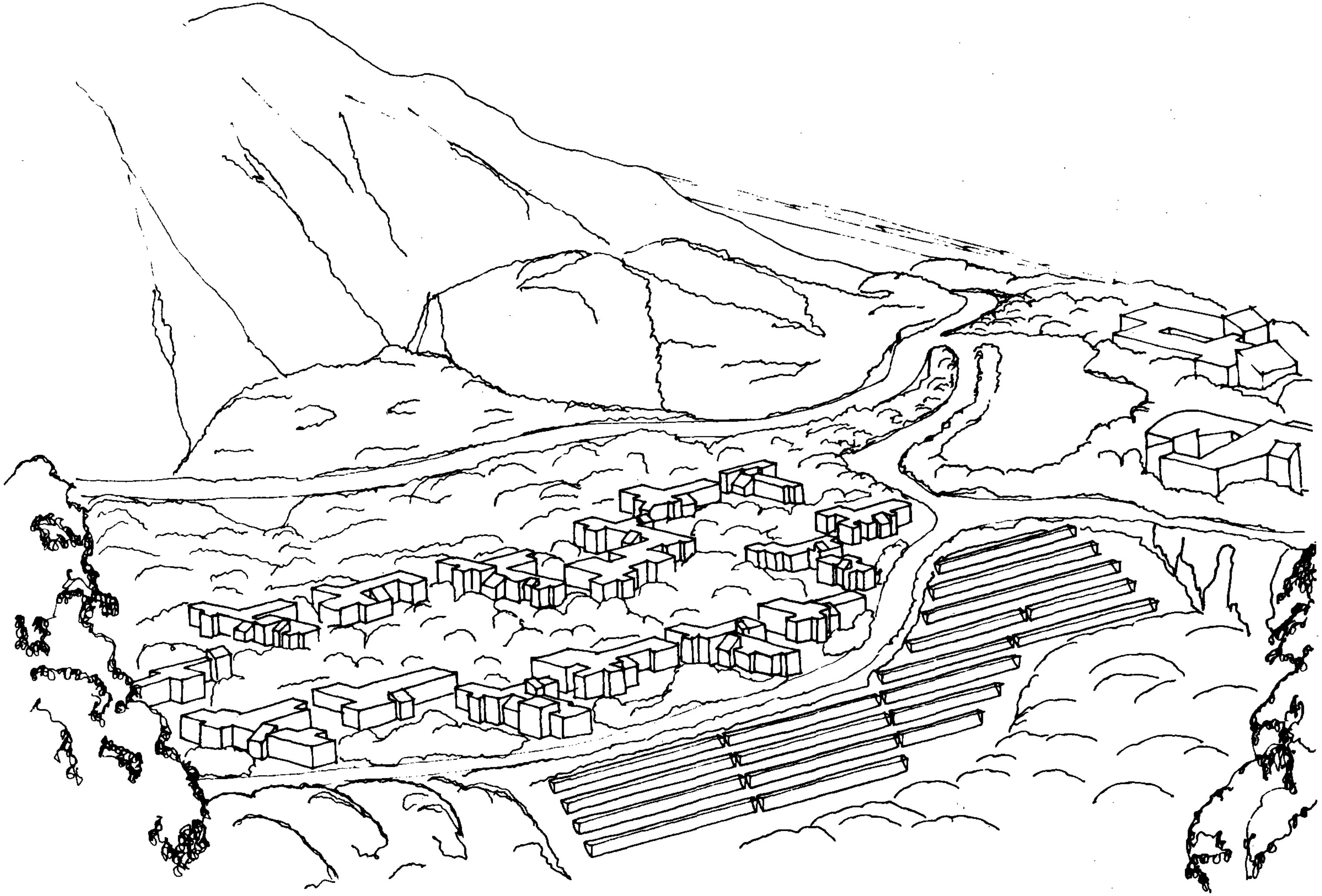


Figure 7-3

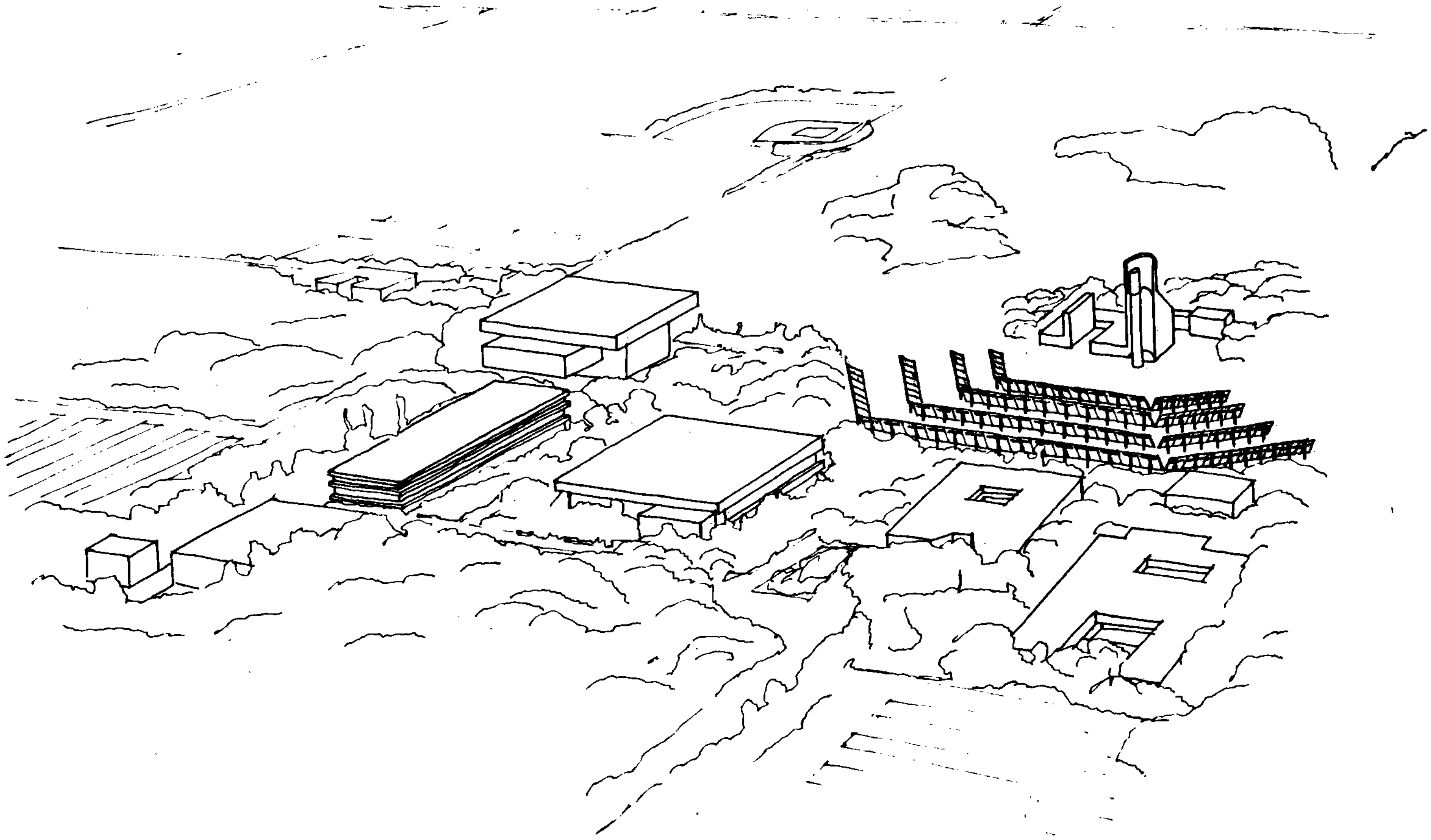


Figure 7-4

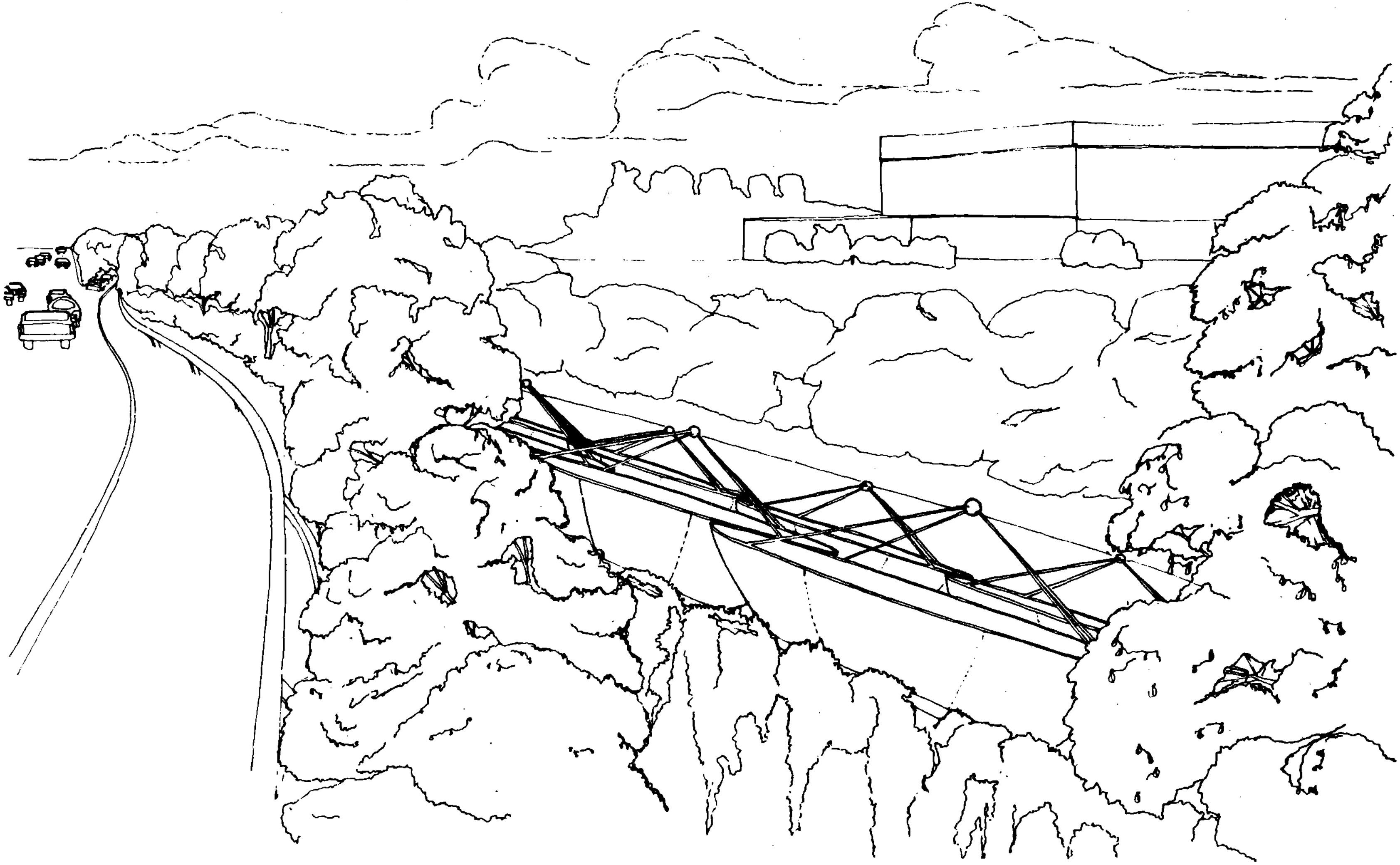


Figure 7-5

## 8.0 SOCIAL CONSIDERATIONS

### 8.1 Introduction

The social feasibility of a technology is a function of two primary considerations; technological competitiveness, and a willingness of consumers to adopt the technology. To date, government solar programs have concentrated on the former. Marcus and Tauber (1979) present and discuss factors which play important roles in the diffusion of a technology:

1) Relative advantage: superior products diffuse more quickly.
2) Compatibility: the degree to which a new idea is consistent with existing values and behaviors. Technologies that do not require accompanying lifestyle changes will diffuse more quickly (Hamrin, 1979).
3) Complexity: the degree to which a technology is comprehensive and manageable.
4) Divisibility: whether the product can be sampled at low risk.
5) Communicability: the difficulty in educating the public about a product depends in a large part on previous public exposure to a similar product.
6) Fulfillment of need: whether the product meets a real or perceived need more cheaply or easily than alternative products. The fulfillment of need depends on the compatibility of energy output with demands, dependability of energy supply, perceived risks of energy system operation, and ease of system maintenance.
7) Availability: of the product, service and information.
8) Immediacy of benefit: how quickly or easily the benefit from a product is realized.
9) Innovativeness of target customers: whether the target group has a history of adapting new ideas.

Therefore, several influential social factors, such as the attitudes and behavior of consumers, the quality and availability of STES information, community support for innovative programs, and the distribution of costs and benefits, play important roles in community acceptance of a new technology.

### 8.2 Consumer Attitudes and Behavior

Consumer attitudes and behavior are very important when adopting solar technologies (Holbeck and Ireland, 1979). However, research into attitudes on solar energy is complicated by the many types and combinations of solar applications and systems (Altseimer and Blaunstein, 1979). Second, evidence from psychological research indicates that attitudes are not always, or necessarily, manifested in behavior (Fishbein, 1967). Finally, from the standpoint of this report, there is little research into attitudes or equity factors affecting solar thermal energy systems of any size or configuration. To study potential attitudes and barriers to STES utilization, this section examines consumer attitudes toward related conventional solar technologies.

A recent nationwide poll of U.S. energy preferences for the year 2000 indicated that 53 percent of the polled favored solar energy, 21 percent coal, 16 percent nuclear and 4 percent oil. Nearly half the people surveyed stated they could be willing to pay more for a conversion to solar energy; less than 25 percent indicated they were not (NBC News and Associated Press National Poll, 1979). A second study found that 66 percent of the people surveyed felt that solar energy should be the primary method of meeting additional future energy demands (Conservation Research and Analysis, 1977). If there is so much support for solar energy, why is the market so small? Obviously, positive attitudes toward solar energy are not manifested in consumer purchasing behavior. There appear to be several reasons for these differences.

Concerns over system cost, reliability, and associated risk perceptions appear to be major barriers to solar system purchase and use. These considerations were the most important to purchasers of solar hot water heaters (Farhar, et al., 1979), industrial managers considering solar applications (Whitney, et al., 1980) and labor leaders (SERI, 1979).

The lack of willingness of industry to invest in power generating equipment could be another significant barrier to STES utilization. In testimony before the Energy and Power Subcommittee of the House Interstate and Foreign Commerce Committee, Henry Kelly (1979) of the Office of Technology Assessment, concluded that most non-utility investors have investment opportunities which offer less risk and higher returns than energy generating equipment. This may not be the case, however, for industries facing uncertain or exceedingly high priced energy supplies. Similar concerns are seen in the residential solar heating market where people are unaccustomed to making large capital investments which transfer liquid assets to fixed assets, reducing the flexibility of investments.

Benefits from conservation investments for homes, businesses or industries exceed those derived from investing in new energy generating systems (Consumer Reports, 1980). Cost-effective conservation programs and investments should be undertaken before more expensive production investments are made. Even though conservation measures are simpler, with faster payback times, approximately 70 percent of 200 firms interviewed had accomplished only 40 percent of known cost-effective conservation measures (Whitney, et al., 1980).

One of the greatest barriers to STES utilization is utility reluctance to support solar power or to endorse a technology that may not be suitable for their prime objective; production of base load electricity. Utilities contend that though their fuel bills would drop from the use of solar systems, so would their revenues. In addition, they would be required to provide backup power for solar system users. In combination, utilities often contend that these factors would increase utility rates (Business Week, October 9, 1978).

Energy industry attitudes are also relatively pessimistic toward solar energy. Exxon Chairman, Clifton C. Garvin, Jr., believes that solar energy will not be a major source of energy until the end of the century (New York Times, May 20, 1979). These negative utility and energy industry attitudes represent a significant market barrier to advanced solar system utilization.

## 8.3 Information

One of the problems confronting energy planners is the lack of accurate, objective information. Labor leaders interviewed in a recent survey (SERI, 1979) reported an alarming level of ignorance among workers concerning the current energy situation. The labor leaders concluded:

> Their membership did not have enough data about the various energy sources and problems, and this lack of information is particularly marked in the area of solar energy . . . union members are not aware of the feasibility, the costs, and benefits of solar energy.

Several of the industrial end-use studies reviewed in Section 3 stressed the need for better dissemination of information to industry about the benefits and availability of solar thermal technologies. The Whitney, et al (1980) survey concluded that this lack of information is a major barrier to solar thermal energy system utilization in industry. Thus, before any concerted effort is made to introduce STES into a community, a strong educational program should be instituted to overcome these informational barriers. The effectiveness of this educational effort could determine the success of community STES programs. McDonnell Douglas (1977) suggests that these informational problems could be overcome by the dissemination of information through trade organizations, industrial publications, seminars and improved communication between government and industry. In any event, large-scale experiments and demonstration projects should not be relied upon exclusively for the diffusion of information.

## 8.4 Community Support

An analysis of several existing community energy programs (e.g., Davis and San Bernardino, California; Franklin County, Massachusetts; and San Luis, Colorado) indicated that community support was essential to successful program implementation. Conversely, programs initiated or planned from outside the community, with little community participation, experience difficulty (e.g., Schuchuli Village, Arizona). The Davis experience (Noll and Palmiter, 1979) is representative:

> The most important contributing factor to the initiation and continuing success of the Davis program is that energy conservation advocates were elected to form a majority on the city council. With a supportive political climate, individuals within the community were able to initiate creative programs in order to raise the level of energy consciousness and undertake energy conserving measures.

Community applications of STES technologies will most likely encounter success if local needs, resources and citizen groups are involved in the planning process to the fullest extent possible. Resources and funding should be made available to communities so that they may choose and implement the energy program that best meets their needs.

## 8.5 Equity Considerations

Who decides, who benefits, and who pays? In the best of all possible worlds, those who decide, bear the burden of decision, and those who receive a service, bear the burden of its costs. But, because ours is a far-from-ideal society, questions of equity inevitably arise.

STES cannot be manufactured by cottage industries because of high capital, resource and labor requirements. Further, overview of the potential STES market stress larger industrial, commercial and agricultural applications (National Research Council, 1979). Thus, it appears that larger corporations will manufacture STES for the energy needs of larger firms. Numerous articles have been recently published (e.g., Barnes, 1975; Wasseerman, 1977; Munson, 1979; Reece, 1979) that discuss corporate control of the manufacture and distribution of solar energy technologies.

If STES are developed and marketed in this manner, several equity problems may arise. Industries and commercial firms will likely have access to government subsidies to facilitate the purchase and installation of STES. The cost of such subsidies are generally borne by consumers and taxpayers in the form of increased taxes and prices of goods and services. There is no guarantee, however, that the energy cost savings later experienced by commercial and industrial entities will be passed on to consumers. Thus, households that may receive no direct benefits may be required to bear the costs. This becomes an acute problem when examining the distribution of energy costs among income groups. The poor consume significantly less energy than higher income groups, yet pay a greater proportion of their annual income for energy (See Table 8-1).

Increases in energy costs are disproportionately borne by poor and lower middle income groups through increased energy and consumer prices and through higher taxes to support incentive programs. Thus, incentive programs to stimulate the STES market must be carefully planned to evenly distribute the costs and benefits. The poor could benefit from the protection against inflation in energy cost, provided by solar systems, if the high front-end costs can be overcome. To date, this group has had the greatest difficulty in overcoming the barriers of capital costs, financing, and access to land for solar systems (Unseld and Crews, 1979).

Table 8-1

Energy Consumption and Expenditures by Income Group
(The Ford Foundation, 1974)

| Income Group | Percentage of Total Households | Average Income | Annual Energy Consumption $10^6$ BTU/ Households | Annual Cost Per Household | Percentage of Total Annual Income Spent on Energy |
|---|---|---|---|---|---|
| Poor | 18% | $ 2,500 | 207 | $379 | 15.2% |
| Lower Middle | 42% | $ 8,000 | 294 | $572 | 7.2% |
| Upper Middle | 19% | $14,000 | 403 | $832 | 5.9% |
| Well-to-do | 20% | $24,500 | 478 | $994 | 4.1% |

As envisioned, STES appear to provide no solutions to the energy inequities in our society. STES may shift energy supply and consumption patterns, but all indications are that they will not close the ever-widening gap in energy expenditures between the poorer and more affluent members of our society. Solar programs in lower-income communities such as those in San Luis Valley in Colorado, the West Side Redevelopment Program in San Bernardino and building renovation programs in New York City (Senauke, *et al.*, 1980), however, have demonstrated that the benefits of conventional solar energy can be realized by less affluent members of society if programs are poorly planned and implemented.

## 8.6 References

Altseimer, J.H. and R.P. Blaunstein. "A Status Review of the Technology Assessment of Solar Energy Program." In *Sun II: Proceedings of the International Solar Energy Society*. Boer, K.W. and B.H. Glenn (eds.). Atlanta, Georgia (1979).

Barnes. "The Solar Derby: Who'll Control Solar Power?" *New Republic*. p. 17 (February 1, 1975).

*Business Week*. "The Coming Boom in Solar Energy." pp. 88-102 (October 9, 1978).

Conservation Research and Analysis. "Survey of Customer Attitudes Towards Home Solar Systems." Southern California Edison Company, Los Angeles, California (December 1977).

Consumer Reports. "Solar Water Heaters: What They Cost: What They Save." Vol. 45:5 (May 1980).

Farhar, B., et al. Public Opinion About Energy: A Literature Review. Solar Research Institute, Golden, Colorado, SERI/TR-53-155 (1979).

Fishbein, M. "Attitude and the Prediction of Behavior." In Fishbein, M. (ed.). Readings in Attitude Theory and Measurement. Wiley, New York (1967).

The Ford Foundation. A Time to Choose. Ballanger Publishing Company, Cambridge, Massachusetts (1974).

Hamrin, J. "Energy Saving Homes: Don't Bet on Technology Alone." Psychology Today. (April 1979).

Hirshberg, A. and R. Schoen. "Barriers to the Widespread Use of Residential Solar Energy: The Prospects for Solar Energy in the United States Housing Industry." Policy Sciences. Vol. 5:453-468 (1974).

Holbeck, H.J. and S.J. Ireland. Siting Issues for Solar Thermal Power Plants with Small Community Applications. Jet Propulsion Laboratory, Pasadena, California, DOE/JPL-1060-78/2 (1979).

Kelly, H. Testimony before the Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce of the 96th Congress, First Session on the Status of Federal Programs to Promote the Commercialization of Solar Energy, Serial No. 96-1. Representing the Congressional Office of Technology Assessment (January 1979).

Marcus, B. and E. Tauber. Marketing Analysis and Decision Making. Little, Brown and Co., Boston, Massachusetts and Toronto, Ontario, Canada (1979).

McDonnell Douglas Aeronautics Company. Industrial Applications of Solar Total Energy. Final Report, SAN/1132-2/1 (1977).

Munson, R. "Ripping off the Sun." Progressive. p. 12 (September 1979).

National Broadcasting Company (NBC) News and Associated Press National Poll. Exerpts in Perelman, L. "The ARK Plan: A Renewable Resources Trust Fund for the United States." Jet Propulsion Laboratory, Pasadena, California (May 1979).

National Research Council. "Domestic Potential for Solar and Other Renewable Energy Sources." Study of Nuclear and Alternative Energy Systems. Supporting Paper #6 (1979).

New York Times. Section IV, page 1 (May 20, 1979).

Noel, S.A., F. Roach and L. Palmiter. "Energy Planning with Solar and Conservation: Individual Values and Community Choice," in Boer, K.W. and B.H. Glenn (eds.). Sun II, Pergamon Press, Elmsford, New York (1979).

Solar Energy Research Institute (SERI). Organized Labor and Solar Energy. SERI/TR-62-148 (1979).

Reece, R. The Sun Betrayed. South End Press, Boston, Massachusetts (1979).

Senauke, S., et al. Survey of Successful Community Applications of Solar Technologies. Master's Thesis Project. School of Architecture and Urban Planning, University of California, Los Angeles, California (June 1980).

Unseld, C. and R. Crews. A Review of Empirical Studies of Residential Solar Energy Users. SERI/TR-53-245 (May 1979).

Wasserman, H. "Energy's Point of No Return: Industry Hides from the Sun." The Nation (March 5, 1977).

Whitney, S., et al. "Solar Augmented Applications in Industry." Final Report Phase I. Gas Research Institute (February 1980).

# 9.0 ECONOMIC INCENTIVE PROGRAMS

## 9.1 Introduction

Incentives can be used to disseminate information, overcome high capital costs, reduce the risks and assist in capturing the benefits of STES manufacture, sales and use. Incentive programs have traditionally been used to encourage the production and distribution of energy technologies. According to Bezdek, et al. (1977), $57 billion was spent between 1918 and 1976 for direct tax incentives to stimulate energy production. Renewable energy sources are currently at a competitive disadvantage in the energy market because of the large subsidies for conventional energy sources. Bezdek, et al. (1977) states:

> "there is no reason to expect a concensus that solar heating or cooling is, or will be, price competitive with other forms of energy, when the price of competitive energy forms is set in a market in which significant costs have been accepted by the public sector."

Many believe, however, that proper planning and application of economic incentives can overcome the competitive disadvantages and high front-end costs of solar systems. Wallenstein (1978) pointd out:

> "solar subsidies will be significantly less costly than those given to fossil or nuclear sources, because they consist primarily of tax credits, loans and other guarantees, and technical assistance: not the massive grants and R&D programs used to develop centralized energy technologies."

Incentive programs generally fall into two categories: those designed to accelerate technological development (e.g., education, research, development and demonstration projects), and those that facilitate commercialization (e.g., tax and loan incentives, government transfer incentives and a variety of federal, state and local initiatives). Emphasis in this report is on the latter because of our assumption that STES technologies will be ready for, and economically competitive in the market, in the near future.

In addition to improving the economic competitiveness of solar systems, incentives can also be used to reduce the user's perception of risk. Depending on the technology and end-use, many incentives are possible. Yokell (1979) states:

> "For the homeowner, Federal cost-sharing of warranties on solar systems is likely to be the best program. Industrial users of large amounts of energy would probably be more influenced by major Federal Demonstration projects. Commercial users probably stand somewhere in between."

In the latter part of the 1980's when STES systems become marketable, it is unlikely that existing incentive programs will be functionally viable because of the changing nature of the technology, energy market and government programs. Therefore, this report will not concentrate on existing solar incentive programs (although they are listed and discussed in tables) but will focus on evaluating programs best suited for potential problems and objectives.

## 9.2 Evaluation of Economic Incentives

### 9.2.1 Tax Incentives

A. Income Tax Credit (applies to individuals)/Investment Tax Credit (applies to corporations)

1. Advantages:
   - reduces taxpayer's net tax liability.
   - low marginal administrative costs (IRS is in place).
2. Disadvantages:
   - tends to favor, in practice, high income groups.
3. Comments:
   - can be applied to individuals or corporations.
   - income level does not affect amount of tax credit--in practice, however, only middle and upper income groups have sufficient tax liability to fully benefit from credit.
   - as tax incentives encourage STES purchases, solar investment serves as hedge against inflation and declining value of dollar.

B. Accelerated Depreciation Allowance

1. Advantages:
   - low marginal administrative costs.
2. Disadvantages:
   - does not offer direct tax benefits for all levels and types of income groups/corporate entities which might purchase STES.
3. Comments:
   - used primarily by corporations, utilities, manufacturers and high income groups.

C. Tax-Exempt Bonds

1. Advantages:
   - familiar to government at all levels.
   - low marginal administrative costs.
   - available to all investors equally.

2. Comments:
   - often serves as a federal subsidy to a local or municipal financing initiative.
   - most promising application probably at municipal level of government (Hyatt, 1979; White, 1979).

Tax Incentives Conclusion
- Tax incentives can be implemented by existing institutions. Since policy makers are familiar with taxing mechanisms, tax incentives are among the lowest cost techniques for encouraging solar development.

### 9.2.2 Loan Incentives

A. Low Interest Loans

1. Advantages:
   - reduce long-term costs of financing capital-intensive STES facilities.
   - can be administered by existing lending institutions or public agencies.
2. Disadvantages:
   - while usually equitable, low-income groups typically pay higher interest rates and do not have equal access to capital markets.
   - life cycle costs to the government are a primary drawback: the costs, however, may be modest in the short run compared to those of direct subsidies, large demonstration projects and tax credits.
3. Comments:
   - can be administered directly by any level of government or by public financing of loans to private lenders or borrowers.

B. Government Guaranteed/Insured Loans

1. Advantages:
   - by reducing risk to lenders, banks are able to make more and larger loans.
   - administrative costs can be kept low if existing institutions are utilized.
   - benefits all income groups equally.
   - by demonstrating confidence in the viability of solar technologies, government guarantees would stimulate industrial innovation and investment.

2. Disadvantages:

- all taxpayers are underwriting risks for projects they have not approved.

3. Comments:

- recommended that guaranteed/insured loans be used in conjunction with low-interest loan program (Hyatt, 1979).
- besides moderate administrative expenses, cost of program depends on default rate.

Loan Incentives Conclusion

- the cost of loan incentives depend largely on the particular program. The potential, however, for a significant impact on STES develoment is widely recognized. Loan programs are potentially the lowest cost incentives to stimulate the solar industry. No significant legal barriers exist which preclude enactment of solar loan incentives.

### 9.2.3 Government Transfer Incentives

A. Federal Grants-in-Aid

1. Advantages:

- encourage local initiative in STES development.
- offer wide range of incentive options: research, demonstration, accelerate commercialization.

2. Disadvantages:

- often favor middle and upper income groups.

B. State and Local Grants-in-Aid

1. Advantages:

- states usually administer federal grant programs and are well suited for this because of their familiarity with local issues, constituencies and problems.

Government Transfer Incentives Conclusions

- generally, government transfer incentives have been directed at technology demonstration projects and in this capacity transfer incentives can contribute to STES commercialization.

### 9.2.4 Government Procurement

1. Advantages:
    - is equitable and benefits entire nation through improvements to property and reduction in fuel costs and imports.
    - by creating demand for solar equipment, a viable solar manufacturing industry is created and sustained.
    - by demonstrating confidence in solar technologies, government procurement also increases consumer confidence.
    - low marginal administrative costs (GSA is in place).
    - in an inflationary economy with rapidly escalating fuel costs, returns on investment could reduce procurement costs.
    - reduces U.S. vulnerability to fuel supply interruptions and improves national security.
2. Disadvantages:
    - industry is often hesitant to commit large investments in plant/manufacturing facilities if government is the only major buyer. Changes in policy and/or the government administration could shift procurement priorities.
3. Comments
    - generally, procurement will facilitate the acceptance of innovation by industry. Subsequent growth in consumer confidence should permit diversification.

### 9.2.5 Government Demonstration Programs

1. Advantages:
    - do not offer "active" incentives but are necessary to reveal the appearance and effectiveness of the system.
    - may help counter traditional conservatism of building industry and its suppliers.
2. Disadvantages:
    - costs are high in relation to impact.
    - administratively inefficient.
    - measurement of impact is expensive and difficult at best.

3. Comments: ● indicate government's active concern for innovative approaches to energy supply problems.

### 9.2.6 Incentives Indirectly Affecting Solar Development

A. Reduction of Subsidies of Nonrenewable Energy Sources

1. Advantages: ● will make prices of non-solar energy resources reflect market value and encourage conservation and exploration for new energy supplies.

2. Disadvantages: ● deregulation of non-solar industries will raise energy prices and may indirectly increase the cost of solar.

3. Comments: ● solar development is presently at a considerable competitive disadvantage due to longstanding subsidies and incentives granted to non-solar energy industries. Reversal of this policy will help accelerate STES commercialization.

B. Government Action to Insure Operation of STES

1. Advantages: ● will improve solar industry public image and increase public confidence in solar technologies.

2. Comments: ● a tainted solar industry reputation and lack of consumer/lender confidence will greatly impede STES commercialization. Measures to counter these trends should be taken by government at all levels.

C. Government-Sponsored Education, Research and Development Programs

1. Advantages: ● will improve the quality of information available to consumers, lenders, builders and solar manufacturers.

2. Comments: ● probably the most important incentive to encourage disseminating information to potential users, lenders, etc. Without adequate information and sufficient confidence in the practibability of STES technologies, commercialization will not occur.

### D. Government Tax on Competing Energy Sources

1. Advantages:
   - provides effective stimulus to solar energy development.
   - direct cost method of increasing competitiveness of solar energy technologies.
   - government would gain revenue.
   - only incentive that offers government positive cash flow.
2. Disadvantages:
   - energy cost increases may be regressive.
   - may be inflationary.
   - may be politically unpopular.
   - resistance from energy industries could result.
   - removal of tax could negatively impact an emerging solar industry.

## 9.3 Incentive Selection

The incentive selection process involves the formulation of incentive programs that fulfill specific needs on policy objectives. Table 9-1 summarizes solar commercialization problems or objectives (vertical axis) and possible incentive solutions (horizontal axis). The table and subsequent discussion (modified from Yokell, 1979) provide a framework for selecting appropriate incentives for specific needs.

Selection of the proper incentives is complicated by the diversity of policies that can fulfill similar objectives. Yokell (1979) points out:

> ...direct grants to end-users, solar tax credits, and tax benefits for manufacturers all are directed toward the solution of largely the same problem (overcoming high capital costs). Selection among competing policies must therefore, be based on distributional effects, administrative costs and public attitudes.

Thus, for proper incentive selection, data on individual applications and sites will need to be combined with the information presented in Sections 9.2 and 9.3. The optimal mix of incentives for consideration should strive for equitable economic impact distribution among population groups, be user-oriented, account for the needs of the participants and be consistent with federal and state policies.

## 9.4 Summaries of Current Incentive Programs and Offices

### 9.4.1 Federal

The following Federal agencies and programs have been selected from a long list published by the U.S. Department of Housing and Urban Development (1980) as possible incentive programs and "brokers" for solar system

Table 9-1. Problems of Solar Energy Commercialization and Proposed Solutions (modified from Yokell, 1979)

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SOLUTIONS (Proposed)<br>PROBLEMS | Direct Grants to End Users | Income Tax Credit or Deductions to End Users | Low Interest Loans to End Users | Loan Guaranteed to End Users | Gov't Provided Warranties or Insurance to End Users | Government Procurement | Demonstration Programs | Gov't Equity Investment in Manufacturing Firms | Tax Benefits for Manufacturers | Research and Development | Federally Funded Training Programs |
| Private Innovators Cannot Capture Full Social Benefits of Innovation | | | | | | | | X | | X | |
| Individual Innovators Are More Risk Averse Than Society | | | | | | X | X | X | | X | |
| Individual End Users Are More Risk Averse Than Society | | | | X | X | | X | | | | X |
| Capital Market Imperfections | X | X | X | X | | | | X | X | | |
| Subsidies to Conventional Energy Sources | X | X | X | X | X | X | | | X | X | X |
| Average Cost Pricing | X | X | X | X | X | X | | | X | X | X |
| Environmental External Diseconomies | X | X | X | X | X | X | | | X | X | X |

X indicates that a proposed solution is capable of affecting a problem.

Table 9-1, (Continued)

Discussion of Proposed Solutions
(modified from Yokell, 1979)

A. Direct grants to end-uses can compensate for underpricing conventional energy sources and for the high first cost barrier, which lowers or eliminates the need for end-user financing.

B. Income tax credits for end-uses have the same function as Solution A except that the subsidies are limited to large entities with sufficient taxes to offset against credits, unless a rebate is provided for. The extent to which an income tax credit affects the cash flow of the end-use depends upon whether the credit is available before or after the tax return is filed.

C. Low interest loans serve the same function as solutions A and B. The extent to which low interest loans assist in overcoming capital market barriers depends on the size of the loans relative to the required investment.

D. Loan guarantees for end-users reduce the risk of lending money. If the reduction in risk is reflected in lower interest rates, a subsidy is received by solar end-users. Government loan guarantees may reduce the perceived risk by acting as a statement of faith.

E. Government provided warranties reduce the risk to end-users. The level of warranty must be carefully established so that it does not create a subsidy to end-users.

F. Government procurement subsidies should represent the cost differential between a cost effective conventional system and an "uneconomic" solar system. Government procurements can act as subsidies or reduce the risk of innovators if announced with sufficient lead times and if they provide multi-year funding.

G. Demonstration programs of the technical or economic viability of a technology may reduce the perceived risk of potential end-users and innovators of related products or processes.

H. Government equity investments in manufacturing firms reduce the private innovator's risk by limiting capital investments and may assist in an easier acquisition of benefit.

I. Tax breaks for solar manufacture can be a significant subsidy for solar development, similar to solutions A, B and C. Tax breaks directly subsidize manufactures; the other solutions only indirectly stimulate the market. Tax break subsidies are not necessarily passed on to consumers.

J. Federal research and development may assist the private sector in capturing the benefits of innovation, reducing the risks of private innovation, and ultimately providing a subsidy to end-users by lowering cost.

K. Federally funded training programs for architects, engineers and installers have the benefit of reducing the end-users perception of risk.

commercialization. This list is not exhaustive but should provide the planner/user with a base of information on potential Federal funding sources for STES. In some cases, a program is mandated directly for the development of solar technologies. However, Gunn (1979) states:

> ...when reviewing agency programs that do not at first glance seem applicable to renewable resource utilization, read between the lines. Some of the most noteworthy solar projects have been funded by agencies whose mission seem to have little to do with solar energy.

Additional details may be found in Gunn (1979), Hayes and Smollen (1976), Hyatt (1979), Wallenstein (1978) and Bezdek (1977). The Department of Energy publishes a helpful directory, Conservation and Renewable Resource Directory, which lists DOE's renewable resource and conservation divisions, staffs and services. This publication can be obtained from the National Technical Information Service of the U.S. Department of Commerce.

The following list summarizes many of the Federal agencies and programs that support solar energy development:

U.S. Department of Housing and Urban Development

Community Development Block Grant Program
Contact: Tony Carey
Dept. of Housing and
Urban Development
Room 7100
451 Seventh Street, S.W.
Washington, D.C. 20410

Telephone (202) 755-6170

Product Disseminaton and Transfer Program
Contact: Michael Lenzi
Dept. of Housing and
Urban Development
Room 8162
451 Seventh Street, S.W.
Washington, D.C. 20410

Telephone (202) 755-6900

Neighborhood Development Program
Contact: Cal J. Wilson, Director
of Consumer Affairs
Dept. of Housing and
Urban Development
Room 3248
451 Seventh Street, S.W.
Washington, D.C. 20410
Telephone (202) 755-6920

Policy Development and Research
Solar Heating and Cooling
Demonstration
Contact: David Moore
Dept. of Housing and
Urban Development
Room 8162
Washington, D.C. 20410
Telephone (202) 755-6900

"701" Comprehensive Planning
Assistance Program
Contact: Melvin Wachs
Dept. of Housing and
Urban Development
Room 7262
451 Seventh Street, S.W.
Washington, D.C. 20410
Telephone (202) 755-6201

U.S. Department of Energy
Technology Transfer Program
Contact: William Bethea,
Community Services Branch
Office of Conservation
and Solar Applications
Dept. of Energy
Forrestal Building
Washington, D.C. 20585
Telephone (202) 376-1964

U.S. Department of Commerce
Technical Assistance Program
Contact: I.M. Baill (Mort)
Office of Technical Assistance
Economic Development
Administration
Room 7844
Washingtion, D.C. 20230
Telephone (202) 377-5111

National Science Foundation
Innovation Groups Program
Contact: Bruce Reiss
Program Manager for
Local Government
National Science
Foundation, ISPT
Room 1150
1800 G Street, N.W.
Washington, D.C. 20550
Telephone: (202) 634-7996

U.S. Department of Agriculture
Cooperative Extension Service
Contact: Glenda Piffer
Department of
Agriculture
South Building
Room 5142
Washington, D.C. 20250
Telephone (202) 477-2179

Grant for Schools, Hospitals,
Local Goverments and Public
Care Institutions
Contact: Richard Minning
Office of Operations
and Regional Liaison
Program CS
Dept. of Energy
Forrestal Building
Washington, D.C. 20585
Telephone (202) 252-2330

Economic Development Districts
Contact: Pat Keyler
Office of Technical
Assistance
Economic Development
Administration
14th and E Streets, N.W.
Washington, D.C. 20230
Telephone (202) 377-3207

Science for Citizens
Contact: Bruce Reiss
Program Manager for
Local Government
National Science
Foundation, ISPT
Room 1150
1800 G Street, N.W.
Washington, D.C. 20550
Telephone: (202) 634-7996

Community Services Administration
National Center for Appropriate
Technology
Contact: Joseph Sedlak
National Center for Appropriate
Technology
P.O. Box 3838
Butte, Montana
Telephone (404) 494-4572

### 9.4.2 State

The Federal government has been authorized to provide financial and planning assistance to states through the 1978 State Energy Management and Planning Act. State assistance programs for solar technology development have taken many forms to meet a variety of objectives (OAT, 1980). Table 9-2 summarizes eight generic types of state solar management programs. Table 9-3 summarizes state tax incentive programs to promote renewable energy utilization. Table

9-4 summarizes state loan, grant, local use and regulatory programs. The majority of these programs are currently designed to promote conventional solar heating and cooling systems. However, these programs could easily be amended to include STES. The tables also indicate the depth of development of solar programs in various state governments.

## 9.5 Information Sources

An annotted bibliiography of major works on community applications of solar thermal energy systems in presented in Appendix B. Additional information may be obtained from:

a. Central receiver technology:

George Kaplan, Chief
Central Receiver Section
U.S. Department of Energy
6th and E Streets, N.W.
Washington, D.C. 20585
(202) 376-1935

b. Distributed receiver technology:

James Rannels, Chief
Distributed Receiver Section
U.S. Department of Energy
6th and E Streets, N.W.
Washington, D.C. 20585
(202) 376-1939

c. Small community solar thermal programs:

Al Marriot, Manager
Point Focusing Dish Projects
Point Focusing Thermal and
Electric Applications Project
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91103
(213) 354-4321

Joe Weisiger, Manager
Distributed Receiver Program
U.S. Department of Energy
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115
(505) 264-6917

d. SERI;

Margaret Cotton
Technology Information Dissemination
Solar Energy Research Institute
1536 Cole Boulevard
Golden, CO 80401
(303) 231-1000

## Table 9-2

## State Energy Management Programs

1. <u>Community Development Agencies</u>

   A. State Development Companies (SDC's)
   privately owned corporations authorized by the state to provide long-term loans or equity capital to assist small businesses to purchase equipment, finance construction and improve or expand facilities.

   B. State Industrial Development Authorities or Industrial Building Commissions (IBC's)
   provide long-term financing plans to stimulate local economic development. Levy (1974) presents a brief description of the financial assistance programs of all 50 states.

   C. Industrial Foundations
   nonprofit, private corporations that provide long-term loans or invest in companies that wish to expand or move into a community.

   D. Local Development Corporations (LDC's)
   privately owned corporations created in conjunction with the Small Business Administration to provide long-term loans or loan guarantees for small businesses.

2. <u>State Promotional Incentives</u>

   A. Research, Development, and Demonstration Programs (RD&D)
   state administered research and commercialization programs. (As of July 1979, existed in 23 states (Johnson, 1979)).

   B. Policy and Information Activities
   24 states have programs (as of July 1979) (Johnson, 1979) that encourage solar policy studies, legislative proposals, and educational activities undertaken by executive and legislative committees.

   C. Life Cycle Costing and State Construction
   10 states have programs to assess solar and conservation construction programs (Johnson, 1979).

   D. Model State Energy Programs
   many states have model state programs for the promotion of solar and energy conservation activities (Courier, <u>et al</u>., 1980).

Table 9-3. State Renewable Energy Tax Incentive Programs (Johnson, 1979)

| | Real Property Tax Incentives (1979) | | | | | | | | | Income Tax Incentives (1979) | | | | | | | | | Excise Taxes (1979) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | System | | | | | | | Sector | | System | | | | | | | Sector | | System | | | | | | | | Sector | | | |
| | Solar heating | Passive | Hot water | Wind | Biomass | Photovoltaic | Hydro | Residential | Commercial | Solar heating | Passive | Hot water | Wind | Biomass | Photovoltaic | Hydro | Residential | Commercial | Solar heating | Passive | Hot water | Wind | Photovoltaics | Hydro | Heat pump | Storage | Residential | Agricultural | Industrial | Commercial |
| Alaska | | | | | | | | | | X | | X | X | X | | X | | | | | | | | | | | | | | |
| Arizona | X | X | X | X | | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X |
| Arkansas | | | | | | | | | | X | | X | | | | | X | X | | | | | | | | | | | | |
| California | | | | | | | | | | X | X | X | X | | X | | X | X | | | | | | | | | | | | |
| Colorado | X | X | X | | | | | | | X | X | X | X | | | | X | X | | | | | | | | | | | | |
| Connecticut | X | | X | X | | | X | X | X | | | | | | | | | | X | | X | | | | | | X | X | X | X |
| Delaware | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Florida | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Georgia | X | X | X | | | | | X | X | | | | | | | | | | X | | X | | | | X | X | X | X | X | X |
| Hawaii | X | | X | X | X | X | X | | | X | X | X | X | X | | | X | X | | | | | | | | | | | | |
| Idaho | | | | | | | | | | X | | X | X | X | X | | X | | | | | | | | | | | | | |
| Illinois | X | X | X | X | | X | X | | | | | | | | | | | | | | | | | | | | | | | |
| Indiana | X | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | |
| Iowa | X | | | | | | | X | | | | | | | | | | | | | | | | | | | | | | |
| Kansas | X | | | X | | X | | X | X | X | | X | X | | X | | X | X | | | | | | | | | | | | |
| Louisiana | X | X | X | | | X | | X | X | | | | | | | | | | | | | | | | | | | | | |
| Maine | X | X | X | | | | | X | X | | | | | | | | | | X | X | X | | | | X | | X | X | X | X |
| Maryland | X | X | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | |
| Massachusetts | X | | X | X | | X | | X | X | X | | X | | | | | | X | X | X | X | X | | | X | X | X | | | |
| Michigan | X | X | X | X | | X | X | X | X | | | | | | | | | | X | X | X | X | X | X | | | X | | | X |
| Minnesota | X | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | |
| Mississippi | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Missouri | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Montana | | | | | | | | | | X | X | X | X | X | | X | X | X | | | | | | | | | | | | |
| Nebraska | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nevada | X | X | | X | X | | X | X | | | | | | | | | | | | | | | | | | | | | | |
| New Hampshire | X | | X | X | | | | X | X | | | | | | | | | | | | | | | | | | | | | |
| New Jersey | | X | X | X | X | X | X | X | X | | | | | | | | | | X | X | X | X | X | | | | X | X | X | X |
| New Mexico | | | | | | | | | | X | X | X | | | | | X | X | | | | | | | | | | | | |
| New York | X | X | | | X | | | | | | | | | | | | | | | | | | | | | | | | | |
| North Carolina | X | | | | | | | X | X | X | | X | | | | | X | X | | | | | | | | | | | | |
| North Dakota | X | | | | | | | X | X | X | X | X | X | X | X | | X | X | | | | | | | | | | | | |
| Ohio | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Oklahoma | | | | | | | | | | X | X | X | | | | | X | | | | | | | | | | | | | |
| Oregon | X | X | X | X | | X | | X | X | X | X | X | X | X | X | X | X | | | | | | | | | | | | | |
| Rhode Island | X | | | | | | | X | X | | | | | | | | | | | | | | | | | | | | | |
| South Carolina | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| South Dakota | X | X | X | X | X | X | | X | X | | | | | | | | | | | | | | | | | | | | | |
| Tennessee | X | | | X | | X | | | | | | | | | | | | | | | | | | | | | | | | |
| Texas | X | | | X | | | | | | | | | | | | | | | X | X | X | X | X | X | | X | X | X | X | X |
| Utah | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Vermont | X | X | X | X | X | X | | X | X | | | | | | | | | | | | | | | | | | | | | |
| Virginia | X | X | X | | | X | | | | | | | | | | | | | | | | | | | | | | | | |
| Washington | X | X | X | | | | | X | X | | | | | | | | | | | | | | | | | | | | | |
| Wisconsin | | | | | | | | | | X | X | X | | X | X | | X | X | | | | | | | | | | | | |

Table 9-4. State Loan, Grant, Land Use and Regulatory Programs to Facilitate Solar Energy Development (Hyatt, 1979; Johnson, 1979)

| | Loans | Grants | Land Use Provisions | Standards & Regulation of Construction |
|---|---|---|---|---|
| Alaska | X | X | | |
| Arizona | | | X | X |
| Arkansas | | | | |
| California | X | X | X | X |
| Colorado | | | X | X |
| Conneticut | | | X | X |
| Delaware | | | | |
| Florida | | | X | X |
| Georgia | | | X | |
| Hawaii | | | | |
| Idaho | | | X | |
| Illinois | | | | X |
| Indiana | | | | |
| Iowa | | X | | |
| Kansas | | | X | |
| Lousiana | | | | X |
| Maine | | | X | X |
| Maryland | | | X | |
| Massachusetts | X | X | | |
| Michigan | | | | X |
| Minnesota | X | X | X | X |
| Mississippi | | | | |
| Missouri | | | X | |
| Montana | | X | X | |
| Nebraska | | | X | |
| Nevada | | | X | X |
| New Hampshire | | | | X |
| New Jersey | | | X | X |
| New Mexico | | | X | X |
| New York | | | X | X |
| North Carolina | | | | |
| North Dakota | | | X | |
| Ohio | | | X | |
| Oklahoma | | | | X |
| Oregon | X | | X | X |
| Rhode Island | | | | |
| South Carolina | | | | X |
| South Dakota | | | | |
| Tennessee | X | | X | X |
| Texas | | | | |
| Utah | | | X | |
| Vermont | | | | |
| Virginia | | | X | |
| Washington | | | X | |
| Wisconsin | | | | |

e. Additional sources of information;

- U.S. Department of Energy

Technical Information Center
P.O. Box 62
Oak Ridge, TN 37830

Services available include: information acquisition and evaluation; bibliographic processing and information retrieval; computerized data bases; document management and control; publishing including microfiche; educational services; film library programs; computer support and services; abstracting subject indexing and conference literature coordination.

Energy Extension Service (EES)

DOE, Office of State and Local Programs
Forrestal Building, Room 2H027
Washington, D.C. 20585
(202) 252-2300

Typical programs include conservation hotlines, audits, conservation seminars and workshops. Energy information and technical assistance are the main benefits of the EES.

## 9.6 References

Bezdek, R., et al. Analysis of Policy Options for Accelerating Commercialization of Solar Heating and Cooling Systems. George Washington University, Washington, D.C. (1977).

Courier, K., et al. (eds.). Renewable Resources: A National Catalog of Model Projects. Center for Renewable Resources, Washington, D.C. (1980).

Gunn, A. Sources of Funds for Solar Activities. Center for Renewable Resources, Washington, D.C. (1980).

Hayes, J. and L. E. Smollen. Sources of Capital for Community Economic Development. Center for Community Economic Development, Cambridge, Massachusetts (1976).

Hyatt, R. J. Legal and Institutional Implications of Providing Financial Incentives to Encourage the Development of Solar Technologies. SERI/TR=62-269 (1979).

Johnson, S. B. A Survey of State Approaches to Solar Energy Incentives. SERI/TR-62-265 (1979).

Levy, R. S. *The Directory of State and Federal Funds for Business Development*. Pilot Books, New York (1974).

Office of Appropriate Technology (OAT). *Sources of State and Federal Funding for Solar/Appropriate Technology Activities*. Sacramento, California (1980).

U.S. Department of Commerce. National Technical Information Service (NTIS), Washington, D.C.

U.S. Department of Housing and Urban Development (HUD). *Comparisons of Federal Programs Related to Community Energy Conservation*. Washington, D.C. (1980).

U.S. Senate. *State Energy Management and Planning Act*. Hearings before the Committee on Energy and Natural Resources, United States Senate, 95th Congress. U.S. Government Printing Office, Publication No. 95-156, Washington, D.C. (1978).

Wallenstein, A. R. *Barriers and Incentives to Solar Energy Development: An Analysis of Legal and Institutional Issues in the Northeast*. Northeast Solar Energy Center, Cambridge, Massachusetts (1978).

White, S. S. *Municipal Bond Financing of Solar Energy Facilities*. SERI/TR-62-191d (1979).

Yokell, M. D. *The Role of the Government in the Development of Solar Energy*. SERI/TP 52-138 (January 1979).

# Appendix A

## Technical Evaluation of STES

### -Outline-

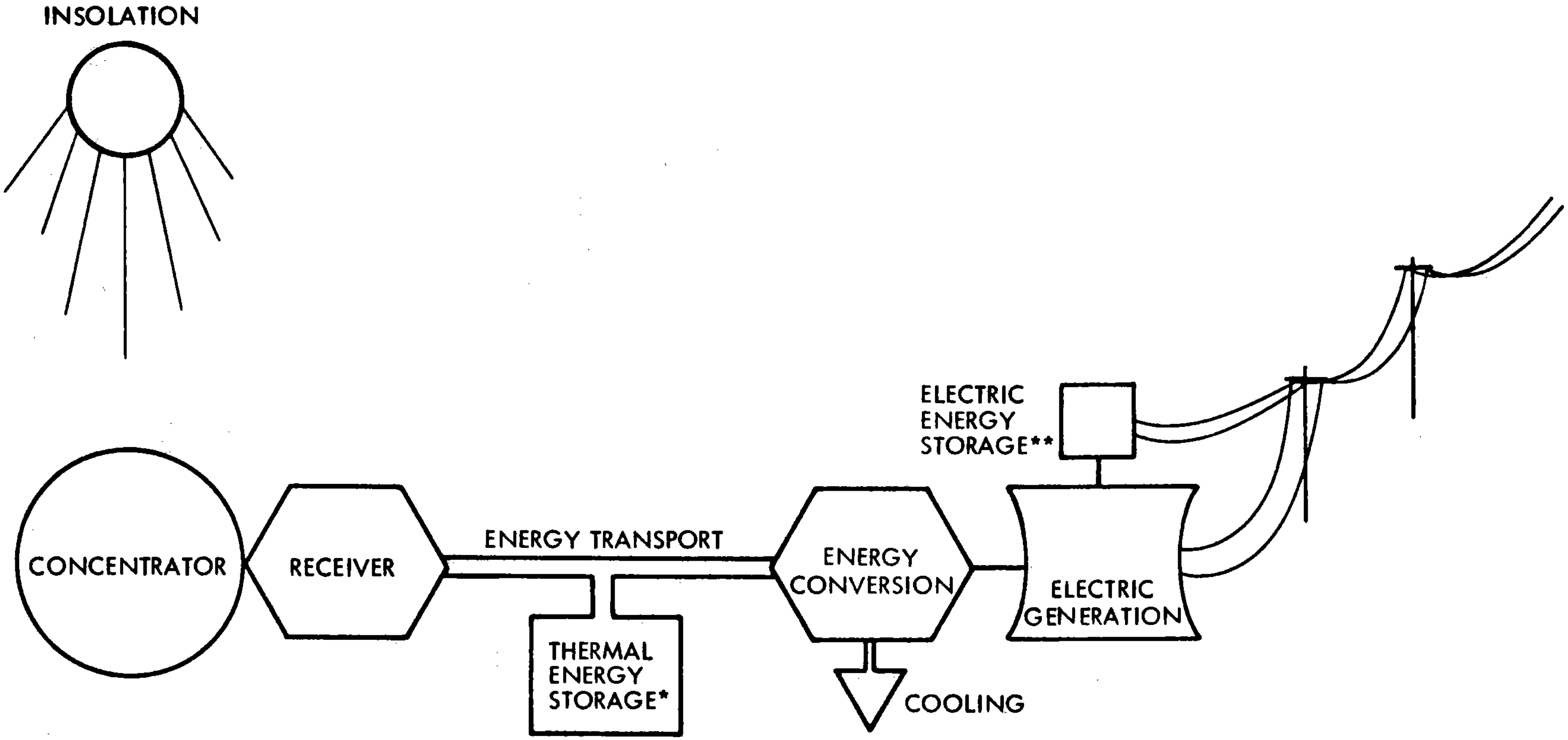
## A-1.0 INTRODUCTION

### A-1.1 Purpose and Objectives

The purpose of this appendix is to provide detailed technical information on the workings and applications of STES. An analysis of STES subsystems is presented, followed by a description of the four major types of STES; central receivers, parabolic troughs, parabolic dishes, and fixed mirror hemispherical bowls. An example of each system is given, with an analysis of its current state of development.

### A-1.2 STES Description

The key elements of a solar thermal power system are shown in Figure A-1. To generate electrical and thermal energy, solar radiation is collected by reflecting surfaces, then redirected and/or focused on a receiver. A fluid (called a "heat transfer fluid" or "working fluid") is heated as it circulates through the receiver and transported to a heat engine, where the heat absorbed by the fluid is converted into mechanial energy. Some energy may be diverted and stored in the thermal energy storage subsystem for use at a later time, to buffer the system from fluctuating rates of insolation (i.e., cloudy days), or to provide energy during the night. Such buffering also allows the system to gradually raise or lower its operating capacity to prevent thermal shock to the mechanical equipment.



*Storage prior to conversion may be either thermal or chemical
**Storage after conversion may be either electric or mechanical

Figure A-1 Solar Thermal Energy Subsystems
Reference: Holbeck & Ireland, 1979

The properties of heat transfer and storage fluids are important in the selection of subsystems. Many of the candidate fluids are toxic, flammable or explosive. The heat transfer fluids most frequently considered for use in STES are water/steam, molten salts, molten sodium, oils, toluene, helium and air. Many of these fluids are also currently being considered for thermal energy storage.

There are two basic approaches to solar thermal energy systems: central receiver systems and distributed receiver systems (see Figures A-2 and A-3). The central receiver system consists of a large field of one or two-axis tracking heliostats (i.e., mirrors) which concentrate incident solar insolation onto an elevated receiver. A heat transfer fluid circulates through the receiver to the energy conversion system (i.e., turbine generator), which produces electricity, then recycles back to the receiver to absorb heat and reinitiate the cycle.

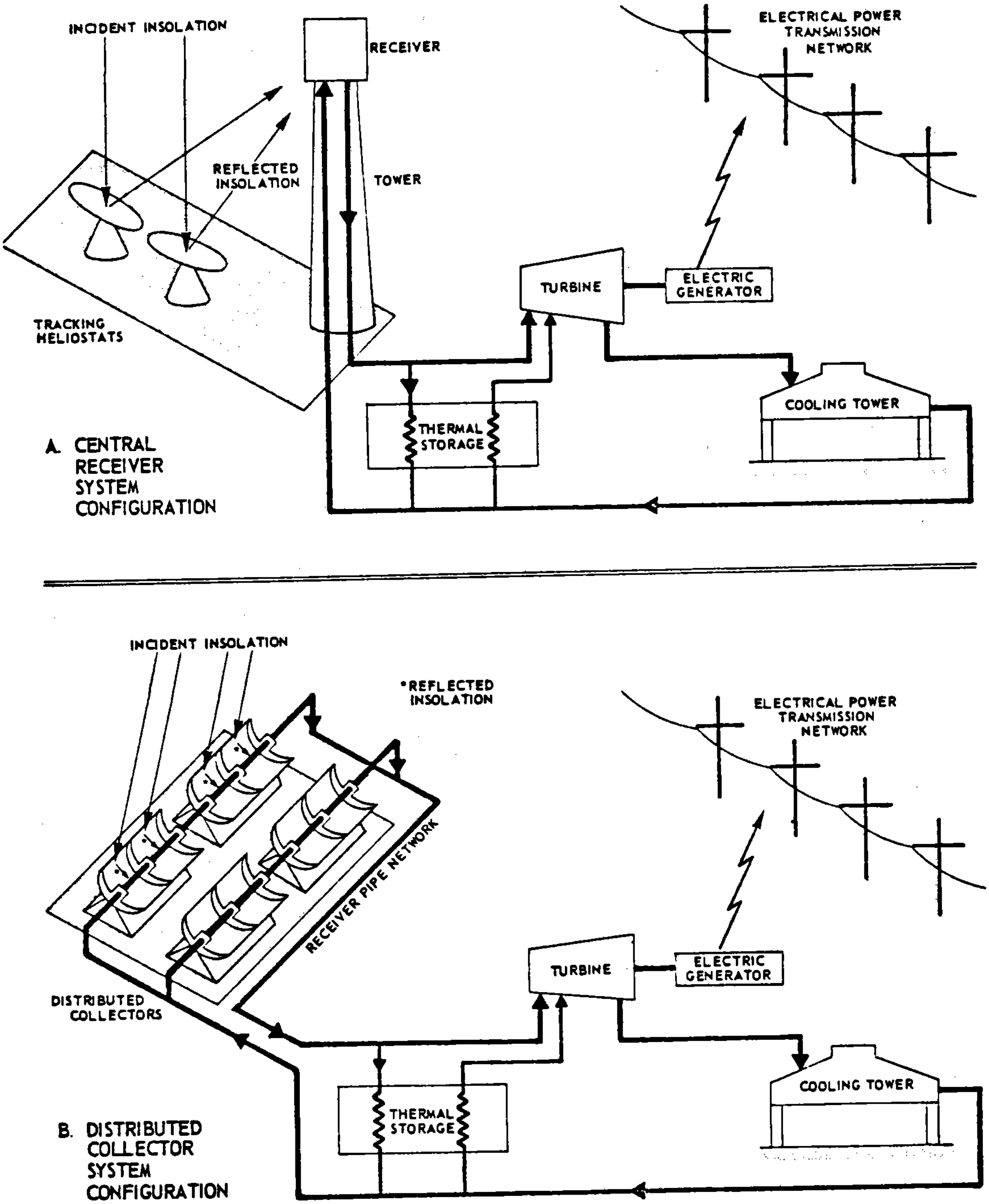
Distributed systems collect sunlight on separate modules, each containing a self-contained collector and receiver. Thermal energy collected at each collector-receiver module may be transported by working fluid to a central location to generate electricity. Thermal energy from each distributed receiver can also be converted directly to electricity if a turbine generator (or engine) is located on the module. The primary advantages of distributed generation are that it facilitates the use of thermal cycle waste heat and allows for incremented capacity additions (CONAES, 1979). Both central and distributed receiver STES may also have energy storage subsystems; either thermal (latent or sensible heat storage) or nonthermal (mechanical, electrical, or chemical storage).

Generally, STES have tracking subsystems which track the sun along either one or two axes. A more detailed description of tracking mechanisms can be found in Section A-2.3.

STES can also be classified by the method used for focus energy onto the receiver. Single curvature or cylindrical collectors, such as parabolic troughs, focus radiant energy along a line. Compound curvature collectors, such as parabolic dishes focus radiant energy to a point. The large heliostat fields associated with central receiver STES are considered "point focusing" systems because they have a geometry which simulates the compound curvature of a dish.

## A-2.0 Subsystem Overview

This section characterizes the subsystem options introduced in Section A-1. Criteria that can be used to differentiate systems are presented to provide the planner with quantitative tools for analysis. Examples of current applications of STES are presented in Section A-3.0.

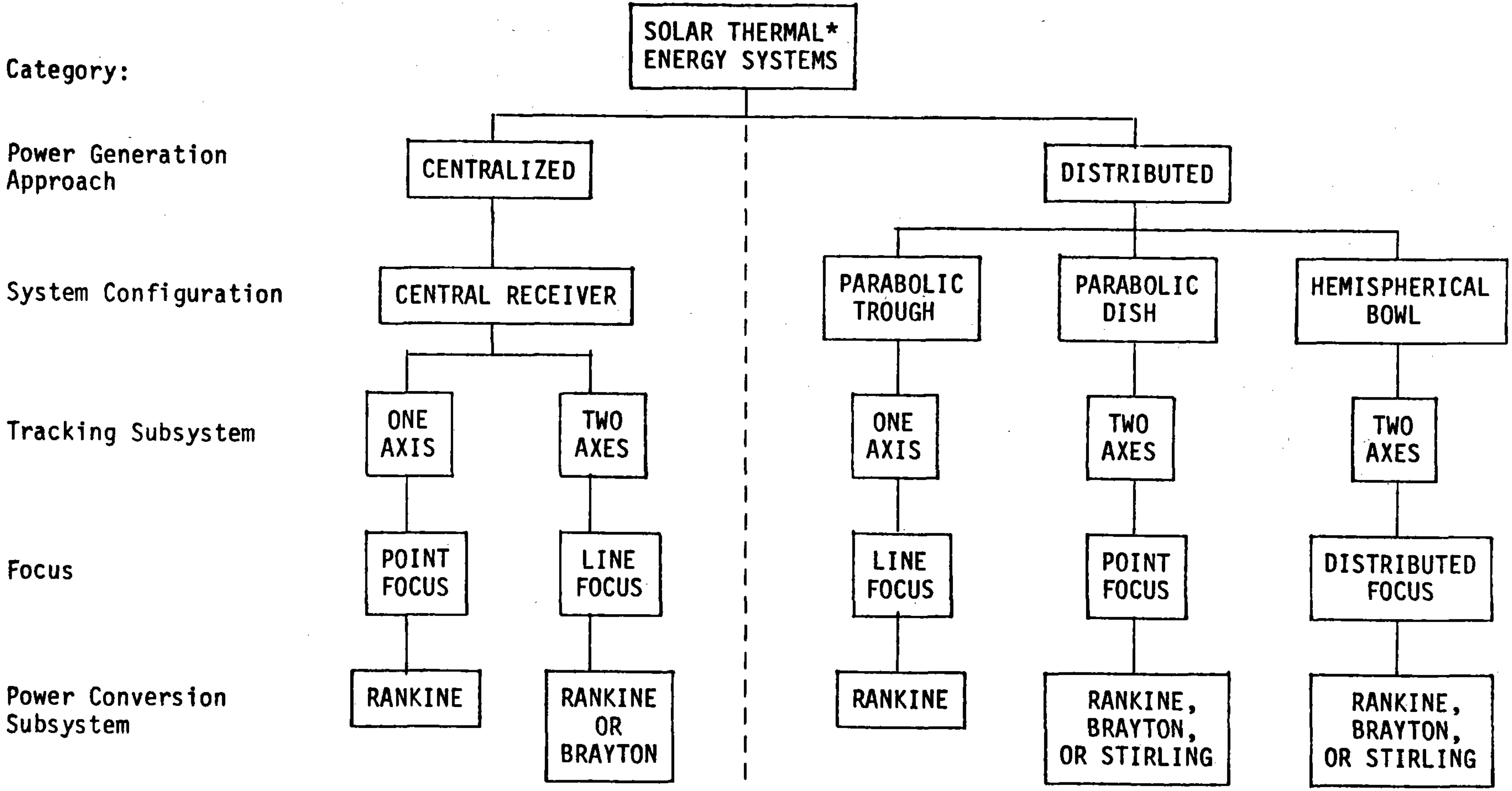


A. CENTRAL RECEIVER SYSTEM CONFIGURATION

B. DISTRIBUTED COLLECTOR SYSTEM CONFIGURATION

Source: DOE/EDP, 1978

Figure A-2 Centralized vs. Distributed Approach to Power Generation



* Subsystem option information from SERI, 1979 and JPL, 1979

Figure A-3 Subsystem Options Within the Central Receiver and Distributed Collector System Approaches

### A-2.1 Collector Subsystems

#### Optical Efficiency

"Optical efficiency" refers to the ratio of the transmitted (or reflected radiation) to the radiation incident on an optical system. Point focus collectors such as the parabolic dish STES have the highest efficiency. Reflective losses are small, due to both the circular symmetry of the collector and the two-axis tracking system which keeps the receiver aperature normal to the concentrated radiation beam. Line focus collectors have cylindrical symmetry which results in reduced efficiency (50-60 percent at peak) relative to point focus systems and only medium brightness and radiation balance concentrations. Wachtler, *et al*. (1977) compares the optical efficiency of parabolic troughs, fixed mirrors, and parabolic dishes. The results are illustrated in Table A-1.

Table A-1

Efficiencies of Selected STES
(adapted from Wachtler, *et al*, 1977)

| Generic Type | Optical Efficiency* | Receiver Efficiency** |
|---|---|---|
| Parabolic Trough | 0.64 - 0.74 | 0.70 |
| Fixed*** Mirrors | 0.64 | 0.75 |
| Linear-Segmented Array | 0.57 - 0.63 | 0.79 |
| Fresnel Lens | 0.71 | 0.72 |
| Parabolic Dish | 0.87 | 0.93 |

* Average Annual Performance
** Represents Thermal Losses
*** Includes the Cylinder Trough Only

### Collector Concentration Ratio

The "concentration ratio" refers to the ratio of radiant energy reflected at the absorber of a concentrating collector to the intensity of unconcentrated radiation at the collector site. The maximum theoretical concentration ratio of a single axis tracking solar concentrator (i.e., either parabolic trough, or line-focus concentrators) is 200, while for the point focus geometry (dishes), it is 40,000 (Rabl, 1978). However, attainable concentration ratios are reduced by a number of factors: 1) most conventional concentrators are based on designs which fall short of the thermodynamic limit by a factor of 2 to 4, 2) tracking errors, errors in mirror surface and contour, and problems of receiver alignment may cause acceptance angles (angular range over which 95 percent of the incident rays are accepted without moving any part of the collector) that are larger than the angular diameter of the sun, 3) no lens or mirror material is perfectly specular, so the acceptance angle must be enlarged further (this effect is aggravated by dirt and dust), and 4) due to atmospheric scattering, a significant portion of solar radiation may come from directions other than the sun itself (Rabl, 1978).

Point focus systems are useful when high concentration factors are required (as in central tower heliostat and parabolic dish power systems). Ratios of 1000:1 have been achieved in a point focus, two axis tracking, parabolic dish (Apley, 1978).

Line focus systems have been utilized when medium concentration is acceptable. Maximum concentration ratios are around 100:1 for the parabolic trough with 40:1 ratios for most systems. Central receiver systems have concentration ratios which range from 1000-3000 (Kreith and Kreider, 1978).

### Collector Control

"Collector control" refers to how well a collector can be manipulated to maintain a position normal to the incident solar radiation over the course of a day. Parabolic dish distributed systems contain two axis tracking mechanisms in each module. This set-up is more complex than the control systems of the point focus, distributed receiver/distributed generation (PFDR/DG) systems. Most line focus collectors have one axis focusing control (either polar or horizontal). This factor is limiting but is more efficient than a non-focusing, non-controlled collector, such as the solar pond.

## A-2.2 Receiver Subsystems

### Receiver Output Temperatures

Output temperatures are important in determining: (1) the overall efficiency of the system, (2) which power conversion strategy to pursue and (3) what kinds of material/structural stresses to expect.

One central receiver system built by McDonnell-Douglas has output temperatures of 482-500°C (900-930°F). The point focus, distributed receiver/central generation (PFDR/CG) system in Shenandoah has parabolic dish collectors which can withstand temperature changes of 76°C (139°F) (General Electric Space Division, 1978).

Parabolic dish - distributed systems with 2 axis tracking collectors can reach temperatures of 1500°C (2730°F). However, these temperatures are usually limited to 820°C (1508°F) due to materials constraints. Most single track linear concentrators range in operating temperatures from 300°C to 450°C (570-840°F). However, the achievable temperatures of a line focus parabolic trough are from 320-480°C (600-900°F). For comparison, solar ponds can achieve temperatures of 90°C (190°F) in the bottom layers of their salt gradients. A comparison of generic operating temperatures (directly related to collector output temperatures) is given in Table A-2. In addition, a similar comparison of temperature ranges, concentration ratio ranges and tracking systems is given in Table A-3 (Wachtler, et al., 1977).

### A-2.3 Tracking Subsystems

STES collectors may require a mechanical method for tracking the sun because the orientation of the collector/concentrator relative to the direction of incoming radiation is critical. A summary of orienting mechanisms that reflect incident solar radiation from the collector to the receiver is given in Table A-4 (Duffie and Beckman, 1974). In fixed mirror hemispherical bowls, the receiver moves rather than the reflective surfaces to maintain focus.

Parabolic trough and fixed-mirror hemispherical bowl collectors do not require accurate tracking of the sun, but as a consequence are limited in their ability to concentrate solar radiation. These collectors usually have large incident solar radiation acceptance angles, a moderate concentration ratio, and a simple single-curvature design. By comparison, fixed or intermittently adjusted collectors are oriented with their axis of rotation perpendicular to the north-south path of the sun (Kreith and Kreider, 1978). This east-west orientation can result in a 7 hour daily collection period with actual collector concentration ratios up to 10, although theoretical concentration ratios are much higher. Concentration ratios above 10 have been achieved only when the concentrator or receiver is mechanically adjusted over the course of the day, either manually, with servo mechanisms or computer controlled movements.

More complex collectors, such as parabolic dishes or central receiver heliostats, track the sun along two axes and can achieve concentration ratios above 20, for 6 hours or more per day throughout the year.

"Sun Tracking" can be accomplished with automated feedback control devices (utilizing sun sensors for precise tracking) or by using a simple clock device. However, a clock device can only be used for collectors where low concentration ratios are acceptable. For example, in point focus, distributed receiver/central generation systems (PFDR-CG), microprocessor control units operate the collector field. Coarse tracking is guided by a master computer which integrates the sun's position through optical sensors to track the path of each collector module as the sun passes overhead. This control system can also be used to protect the collector modules during wind storms or other adverse weather conditions.

## Table A-2

## Operating Temperature Comparisons
(adopted from Ullman, et al., 1979)

| | System | Receiver Mass kg | Working Area $m^2$ | Input Heat Flux MW/$m^2$ receiver | Operating Temperature °K |
|---|---|---|---|---|---|
| Central Tower | McDonnell-Douglas (steam) Pilot Plant (10 MWe) | 17,000<br>(63.7/$m^2$) | 267 | 0.163 av.<br>---------<br>0.33 max | 789 |
| | McDonnell-Douglas (steam) Commercial 100 MWe | 37,000<br>(28.3/$m^2$) | 1,310 | 0.423 av.<br>---------<br>0.85 max | 789 |
| | Willard Acurex Parabolic Trough (HT43) 19 KWe | 54.9 kg<br>(22.6/$m^2$) per 24.4m collector unit | 2.43 | 0.0095 expected peak<br>--------<br>0.0285 (3Xexpected) | 500<br>550 |
| | General Electric Shenandoah Parabolic Dish | 26.97<br>(32.4/$m^2$) | 0.832 | 0.026 | 672 |
| Central Tower | Boeing (Helium) 100 MWe | 90,200 kg<br>(44.28/$m^2$) | 2,037 | 0.123 | 1,089 |
| | UH/McDD/Al Sodium 100 MWe | 65,448<br>72,26/$m^2$ | 906 | 0.52 av.<br>1.70 peak | 866 |
| | Black and Veatch Air 60 MWe | | | 0.225 | 1,366 |

Table A-3

Summary of Design Features

| Generic Type | Module Sizes (ft) | Temperature Range $^{o}C$ | $(^{o}F)$ | Concentration Ratio Range | Tracking/Orientation Axes |
|---|---|---|---|---|---|
| Parabolic Trough | (2 x 10)<br>to<br>(9 x 20) | 150-340 | (300-650) | 13-60 | One/N-S or E-W |
| Fixed Mirror (Cylindrical Trough) | (7 x 10)<br>to<br>(3 x 32) | 150-315 | (300-600) | 8-32 | One/E-W |
| Fixed Mirror (Hemispherical Dish) | (11 to 200) Dia. | 260-540 | (500-1000) | 30-600<br>(115 Avg.) | Two/--- |
| Linear Segmented Array | (7 x 6)<br>t0<br>(10 x 40) | 315-340 | (600-650) | 24-38 | One/E-W |
| Fresnel Lens | (1 x 10)<br>to<br>(12 x 15) | 110-315 | (320-600) | 7-20 | One or Two/N-S |
| Parabolic Dish | 22 dia | 425 | (800) | 100 | Two/--- |

--- Not Applicable

Reference: Wachtler, et al., 1977

## Table A-4

### Possible Orientation Strategies for Solar Collectors
(Eibling, et al., 1953)

- Fixed so that its surface is normal (perpendicular) to the sun at noon on the equinoxes.
- Ability to rotate about a horizonal, east-west axis with a single, daily adjustment to align its surface normal to the solar beam at noon every day of the year.
- Rotation about a horizonal east-west axis with the ability to continually obtain maximum energy incidence.
- Rotation about a horizontal north-south axis with the ability to continually adjust to obtain maximum energy incidence.
- Rotation about two perpendicular axes with the ability to continually adjust to allow the surface to be normal to coincide with the solar beam at all times and to allow reflection to a fixed point (two-axis focusing).
- Rotation about an axis parallel to the earth's axis with the ability to continually adjust to obtain maximum energy incidence.

### A-2.4 Power Conversion Subsystems

Central and distributed power conversion systems generate electricity differently. Central receiver systems convert thermal energy into electricity in one large heat engine/generator unit. In distributed systems, smaller heat engine/generator units may be located near the collectors, with the electrical outputs combined on-site for off-site distribution. The principle power conversion options for STES are Rankine, Brayton, and Stirling engines. Cycle efficiencies (energy conversion efficiencies) depend upon the type of engine, working fluids used, relative scale of power production and the type of heat recovery systems employed.

### Rankine Cycle Engines

In a typical Rankine cycle engine, a pressurized liquid (working fluid) is pumped into a receiver of a solar collector where heat is added to vaporize the liquid (or generate superheated steam in some applications). The pressure is then reduced to allow the vapor to expand over turbine blades, or, in a piston engine, to produce electrical energy in a generator. The low-pressure vapor which emerges from this expansion process is then recondensed to a liquid and pumped under pressure to the solar receiver to reinitiate the cycle. In some advanced systems, the efficiency is increased 4 to 5 percent by preheating the water returning to the boiler with hot vapor extracted from the high temperature stages of the expansion process (regeneration) from the turbine. The turbine inlet conditions vary from nearly saturated steam at around 290°C (554°F) to superheated steam at 310°C (950°F). Water is the most commonly used working fluid this cycle, but other liquids can offer other advantages at low temperatures. Because of water's high specific heat, other fluids with lower thermal capacity may transmit heat more effectively at lower temperatures (OTA, 1978).

Steam Rankine cycles are the most attractive heat engines for the temperature ranges between 370-500°C (698-932°F). Low temperature engines are used in systems which utilize nontracking collector or tracking collectors with low concentration ratios. The steam Rankine cycle is probably most suitable if distributed collectors are used in a central power system (Curto, 1977).

Organic Rankine cycle systems use fluids such as toluene to produce mechanical work at relatively low temperatures from 65-370°C (150-700°F). However, organic Rankine cycles have low theoretical maximum efficiencies (OTA, 1978). The technology is reasonably well developed and Rankine cycle prototypes are available from kilowatt to megawatt size ranges.

Overall, organic Rankine systems are more attractive than steam Rankine systems in low temperature ranges because organic fluids can remain in the vapor state under conditions in which steam otherwise would begin to condense. This "phase stability" results in higher efficiencies for the organic Rankine systems at lower temperatures, with less mechanical stress on the turbine. However, many of the organic fluids under consideration are toxic and flammable and subject to regulation.

### Brayton Cycles

In Brayton cycle engines, solar radiation is concentrated in a high temperature heat exchanger through which air is compressed, heated, and expanded through a turbine to produce electricity. About two-thirds of the turbine's output energy is required to power the air compressor, with the remaining power converted to electricity by a generator (OTA, 1978).

Three approaches have been proposed for solar power use of Brayton cycle turbines:

1) small units (less than 1 MWe) positioned at the focal point of individual tracking collectors.

2) small units located at the counter weight position of individual collectors with heat transfer pipes connecting the collector to the unit's engine (Curto, 1977).

3) a central receiver concept with fluid piped to a heat exchanger/turbine on a central receiver tower (OTA, 1978).

Figure A-4 illustrates these three Brayton Cycle Systems.

The state-of-the-art operating temperature for the Brayton cycle is 815°C (1500°F) with a relatively high efficiency (30-36 percent). Engines are available in a wide range of sizes, with commercial devices ranging from a few

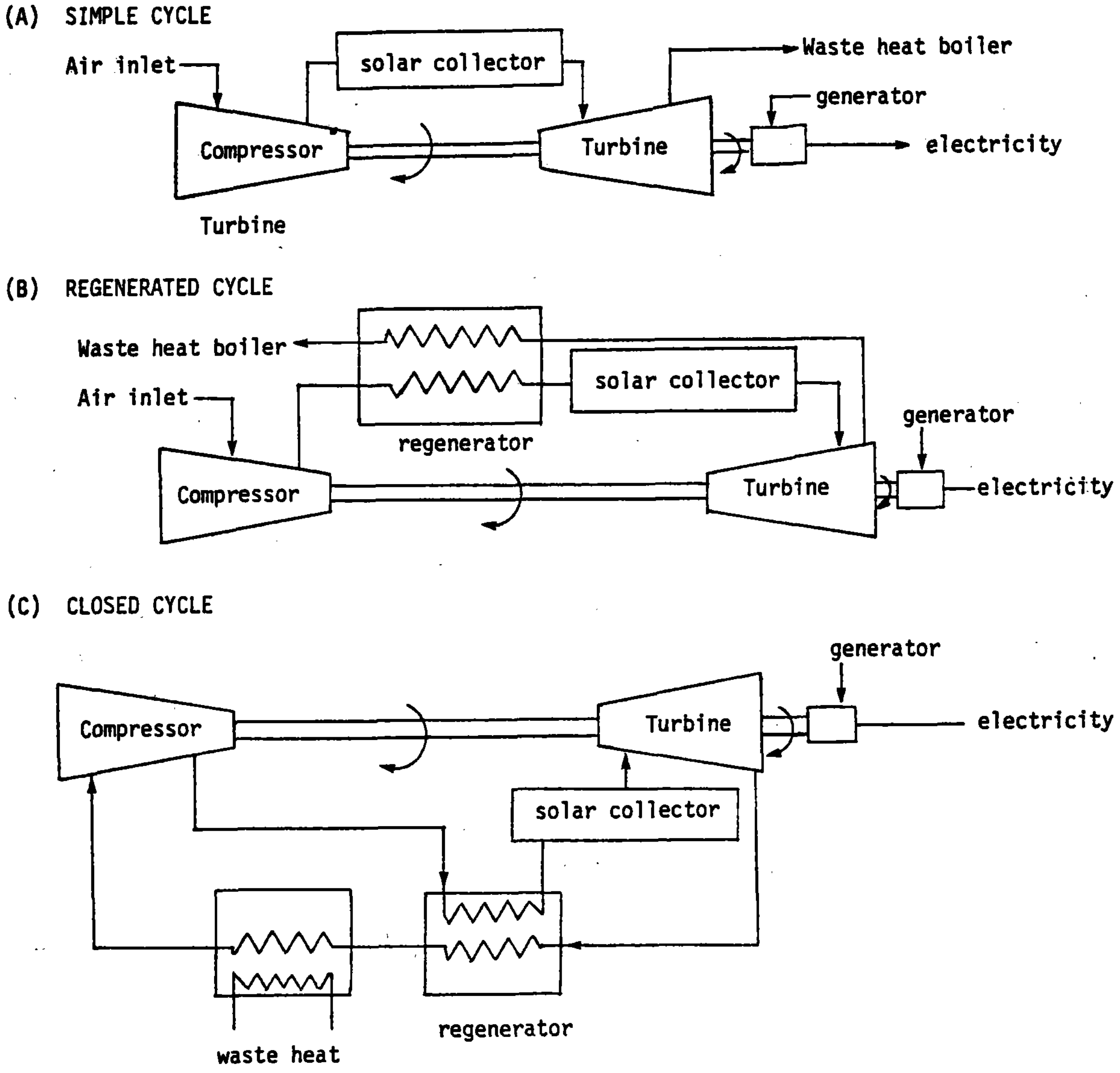


Figure A-4 Three Solar Brayton Cycle Systems Applications (From Office of Technology Assessments, Solar Technology to Today's Energy Needs, 1978)

KW to 50 MWe. Units with 1 MWe capacity and greater are the most efficient (OTA, 1978; Samuels and Meadows, 1974). Although large Brayton engines are feasible, most development to date has focused on engines of smaller sizes that are more suitable for the distributed collector and distributed power conversion concept.

Historically, electric utilities have used Brayton cycle gas-turbine power plants of up to a 125-150 MWe capacity to meet demands, with some base load applications. This choice emphasized the low capital investment per MWe output, and discounted the high operating cost. Yet, Electric Power Research Institute (EPRI) and U.S. Department of Energy (DOE) funded studies have shown that solar central receiver/fossil hybrid Brayton cycle plants can offer both good efficiency and acceptable operating costs for plants up to 100 MWe. These hybrid systems would use air as a receiver coolant and working fluid, if temperatures of 815°C (1500°F), or higher can be maintained.

Brayton cycle efficiencies are lower than steam Rankine efficiencies, even though the Brayton engines operate at higher temperatures. However, the high temperature exhaust from the Brayton cycle permits waste heat recovery without much loss in generating efficiency. The major barrier to Brayton cycle utilization is the need for heat exchangers capable of functioning at high temperatures with gaseous working fluids (OTA, 1978). Raw materials for the construction of these heat exchangers may be very expensive (Gintz, 1976). In addition, Brayton cycle turbines must be extensively baffled to minimize potential noise impacts.

### Stirling Cycle Engines

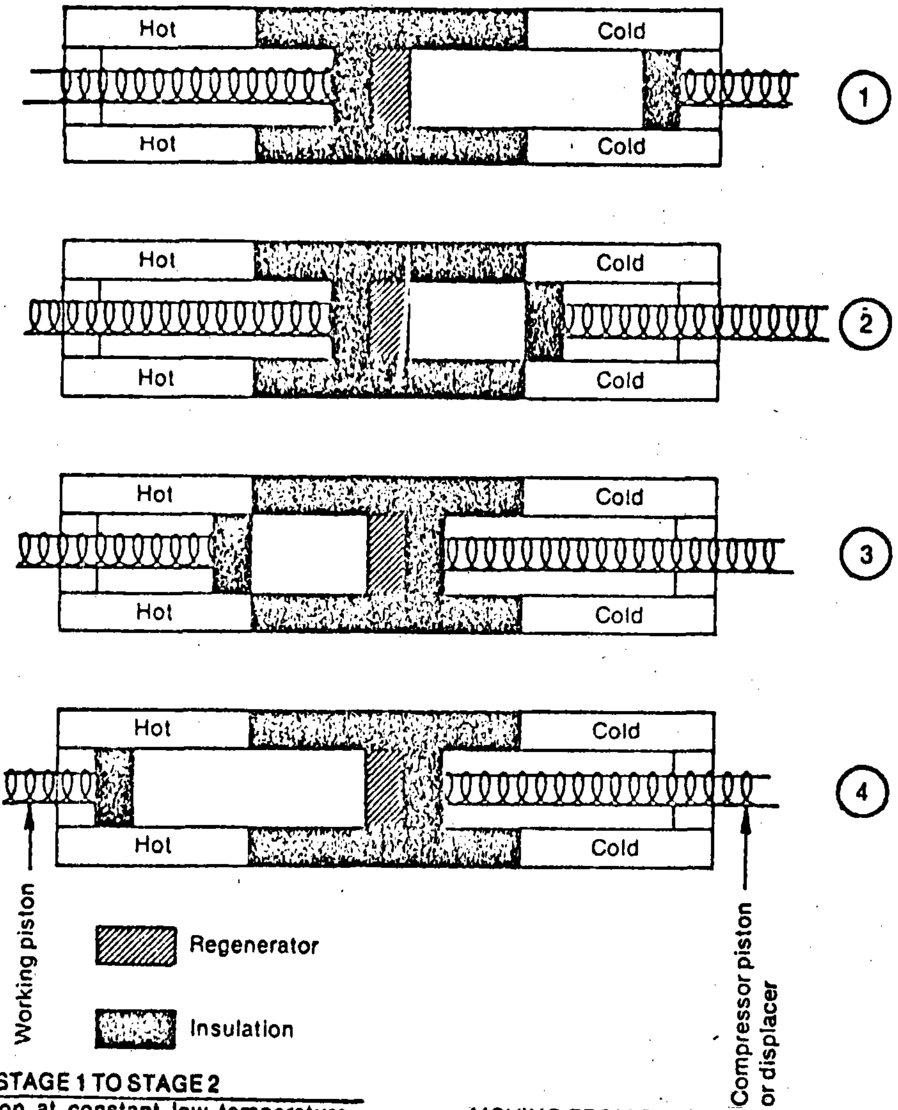
Of the three heat engines considered, the Stirling cycle, in theory, is the most capable of achieving the maximum theoretical efficiency because it maintains a constant temperature during the expansion and compression heat exchange processes.

Stirling cycle piston devices are available for electrical generation on a prototype basis with operating temperatures of 650-800°C (1200-1470°F). Initial indications are that Stirling Cycle engines will be best suited for small scale (300 kWe) power generation, with efficiencies of 40-50 percent. A summary of the Stirling cycle is given in Figure A-5.

Major development goals include the design of heat exchangers and regenerators needed to heat or cool the working fluid at a constant temperature without heat loss to other external engine systems (OTA, 1978). Ultimate design goals include reducing maintenance costs and increasing operating lifetimes.

### Summary: Power Conversion Subsystems

Most STES can utilize Rankine, Stirling or Brayton cycle systems interchangeably (for data on prototypes which compare these power conversion systems with respect to efficiencies, working experience and cost, see Section A-3.0.). The Shenandoah PFDR/CG system, for example, uses a steam Rankine power conversion system. An organic Rankine system that could have been substituted would have resulted in higher efficiencies. However, it was eliminated from



MOVING FROM STAGE 1 TO STAGE 2
- compression at constant low temperature raises the pressure
- energy is rejected into the cold heat exchange surfaces
- work is done on the system through the compressor piston

MOVING FROM STAGE 2 TO STAGE 3
- working fluid is forced through the regenerator and is heated as it absorbs heat from the regenerator
- no work is done on the system and no heat enters or leaves the working fluid except through the regenerator
- the process takes place at constant volume with increasing pressure in the Stirling cycle (as shown in the figure) and at constant pressure with increasing volume in the Ericsson cycle

Reference: OTA, 1978

MOVING FROM STAGE 3 TO STAGE 4
- the working fluid is allowed to expand at a constant temperature and the pressure decreases
- energy is absorbed from the hot heat exchange surfaces
- work is performed on the working piston

MOVING FROM STAGE 4 TO STAGE 1
- working fluid is forced back through the regenerator and is cooled as it gives up heat to the regenerator
- no work is done on the system and no heat enters or leaves the working fluid except through the regenerator
- the process takes place in constant volume with decreasing pressure in the Stirling cycle (as shown in the figure) and at constant pressure with decreasing volume in the Ericsson cycle

In actual engines, these stages will not be distinct.

Figure A-5 Ideal Stirling and Ericsson Cycles consideration because of limited operating experience and increased projected hardware costs (General Electric Space Division, 1978).

The Jet Propulsion Laboratory's parabolic dish--distributed system can use either the Stirling or the Brayton engine. The Stirling Engine is projected to be ten percent cheaper, have higher potential efficiency (45 percent) and the ability to function over a wider solar input range (Caputo and Trusello, 1976). The Brayton engine has a potential efficiency of 35 percent (Curto, 1977). Central tower systems have been proposed using either steam Rankine or Brayton cycles. Reliable, cost effective, Stirling and Brayton engines for STES applications are still under development. In the near term, Rankine engines will be the primary power conversion system.

### A-2.5 Heat Transfer Media

Several heat transfer media can be used as receiver coolant or for thermal storage. The Boeing 100 MWe high-temperature central receiver uses helium to transport energy from receivers to the turbine. It uses a latticework medium for storage. The central tower system proposed by the University of Houston (McDonnell-Douglas; Rockwell) uses sodium for both the receiver coolant and thermal storage medium.

Most central tower systems use water/steam in receivers. However, storage can vary (e.g., salts - Honeywell, HITEC/hydrocarbon heat transfer fluid - Martin-Marietta) (ERDA, 1977). The Black and Veatch Central Tower can use steam or sodium in an external configuration. Fossil fuel backup is the only storage. The central tower system of McDonnell-Douglas uses thermocline storage. In this system, hot and cold fluids are contained within the same tank. The medium is a mixture of Calorea, HT-43©, crushed rock and silica sand. Receiver coolant is HITEC fluid, a commercial heat transfer salt composed of 53 percent potassium nitrite, 40 percent sodium nitrite and 7 percent sodium nitrate (Ullman, et al., 1979).

A point-focus distributed receiver built by Sytherm 800 uses a trickle/oil dual medium in both receiver and storage subsystems. The use of the same medium in both subsystems results in increased thermal efficiency and cost reduction. A line focus receiver can use any high boiling point fluid, including automotive and organic oils and salts.

### A-2.6 Energy Storage

Small Scale STES produce power only during the daylight hours. Daily interruptions in insolation caused by inclement weather can reduce power output. To ensure a reliable source of energy, secondary fossil fuel generation systems or thermal storage subsystems can be used to maintain output during the day or extend the power output of STES after dark. A more conventional approach is to use an electric utility grid to obtain energy at times of insufficient insolation.

The rationale of thermal energy storage use is that:

- Thermal energy is available during cloudy periods and at night. Storage can also be used to facilitate operating large solar turbine systems in the morning by preheating the working fluid and to allow a graduate cooling of the system when it is closed at night or to maintain low rpm rotation of the turbine at night to reduce maintenance requirements. It can also mitigate rapid temperature changes during periods of partial cloudiness.

- Thermal energy storage can be used to make more effective use of generating equipment. Without storage the output of generating equipment must be continuously adjusted to meet fluctuating demands.

- It can improve the performance of heating, cooling, and other energy-consuming equipment. Without storage, the generating equipment must be operated at less than its maximum capacity much of the time, increasing the need for auxilliary generating equipment and decreasing system efficiency. Thermal storage can have the additional benefit of permitting heat-pump devices and air-conditioning devices to operate when ambient conditions are most favorable.

Storage systems for STES can be thermal and nonthermal. Thermal energy can be stored prior to the conversion to electricity, while nonthermal storage options occur once the thermal energy is converted to electricity. Several storage concepts that have been identified are listed in Table A-5 and presented in Figure A-6.

Most extant STES designs use thermal energy storage (TES). There are three principal types of TES subsystems:

1. Sensible Heat - heating a liquid or solid which does not melt or otherwise change state during heating. The amount of energy stored, increases directly with system temperature.

2. Latent Heat - heating a material which melts, vaporizes, or undergoes some other change of state at a constant temperature.

3. Thermochemical - using heat to produce a heat-absorbing chemical reaction which will then release this heat when the reaction is reversed.

Sensible heat energy storing systems are fairly simple in design and relatively inexpensive, if fluids are stored at temperatures below 205°C (400°F). Yet, constant output temperature maintenance may be difficult. If a constant generating temperature is desired, two separate storage tanks are needed; one to store the hot liquids prior to use, and one to store the low-temperature fluids emerging from the engine.

Latent heat storage can supply energy at constant temperature from a single vessel. More energy can usually be stored in latent heat systems than sensible heat systems for a given volume or weight of material. The materials used, however, are relatively expensive and mechanical problems may be encountered in moving thermal energy to and from the storage medium.

## Table A-5

## STES Energy Storage System Concepts (Ullman, *et al*., 1979)

| Thermal Storage | Non-Thermal Storage |
|---|---|
| 1. Sensible Heat<br>- oil rock<br>- oil<br>- oil/salt<br>- salt<br>- steel ingot | 1. Mechanical<br>- pumped hydro<br>- compressed air<br>- flywheel |
| 2. Latent Heat<br>- pressurized water<br>- eutectic salts | 2. Electric<br>- lead acid battery<br>- hydrogen fuel cell<br>- redox batteries<br>- superheating conducting magnet |
|  | 3. Chemical<br>- heat of dehydration<br>- chemical reactants with high enthalpy of reaction<br>Example:<br>$CH_4 + H_2O \underset{\text{catalyst}}{\overset{\text{heat}}{\rightleftarrows}} CO + 3H_2$ |

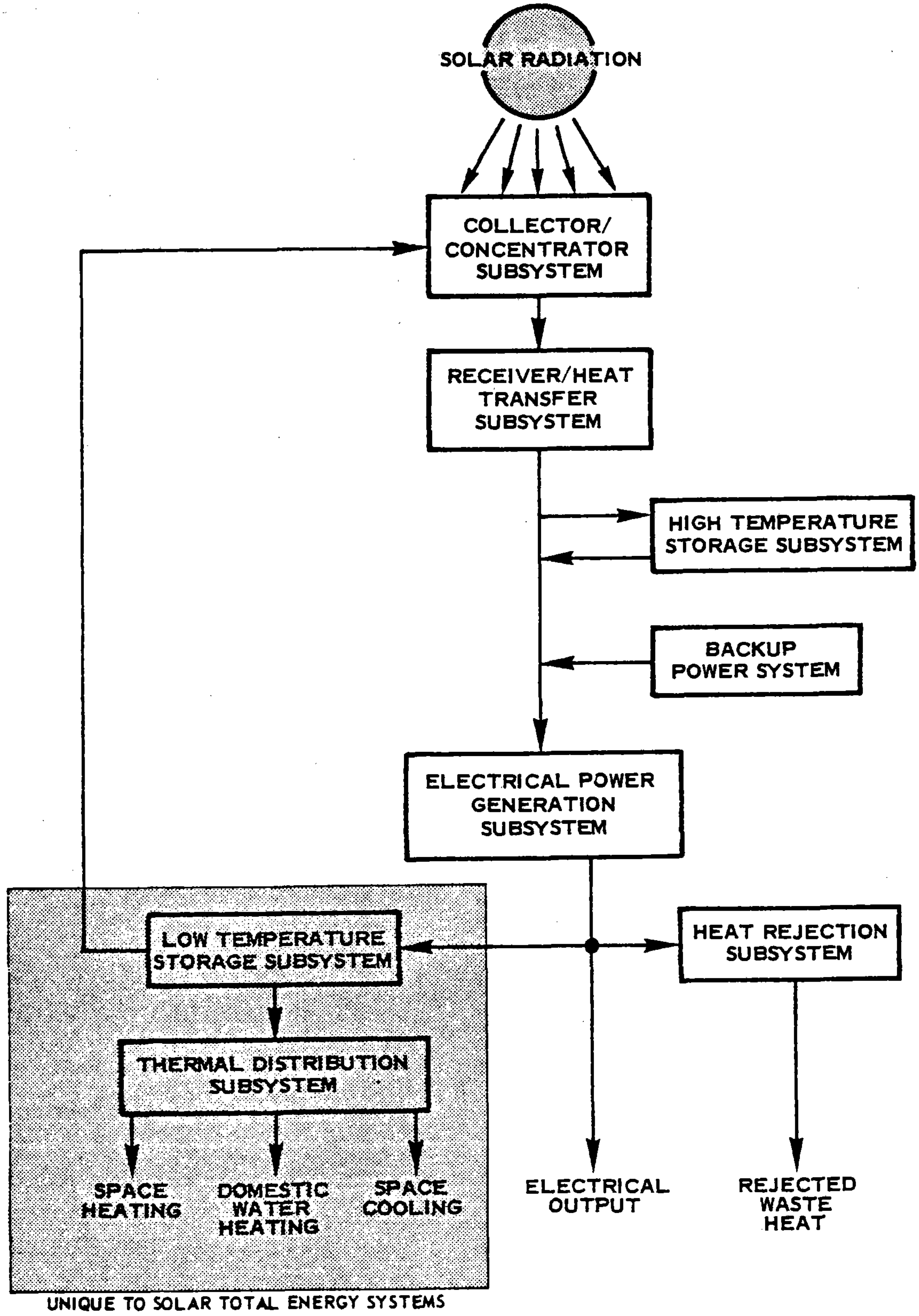


Figure A-6 Locations for Storage in STES Systems
Reference: DOE/EDP, 1978

Chemical storage techniques have the advantage of allowing storage of reaction products at (or near) ambient temperatures for long periods of time. This eliminates the need for expensive insulation. Chemical energy can also be transported conveniently. However, recovering energy from storage could be a difficult, exacting procedure, if expensive catalysts are required. For example, if some of the stored chemicals are in the form of pressurized gases, chemical storage can be expensive. A number of promising reactions are under study.

Several other forms of non-thermal energy storage (noted in Table A-5) are possible. Mechanical energy may be converted to potential energy. For example, water can be pumped into an elevated reservoir during periods when solar radiation is available. The energy is later recovered by releasing the water through a turbine at a lower elevation. This method, however, reduces the overall storage system efficiency.

Photochemical decompositions can be induced by solar radiation. An example is the photochemical decomposition of nitrosyl chloride:

$$2\ \mathrm{NOCl} + \text{photons} \rightleftarrows 2\ \mathrm{NO} + \mathrm{Cl}_2$$

The reverse reaction can be carried out to recover the energy of the photons entering the reaction. In this case, the system would store chemical products. The storage unit would consist of containers for each of the products (See Marcus and Wohlers, 1964).

Electrical energy may be stored as chemical energy in electrical storage batteries or their equivalents. Several types of battery systems can be used for these applications, including lead-acid, nickel-iron and nickel-cadmium batteries. The efficiencies of these systems range from 60 to 80 percent (ratio of energy output to energy input), at low discharge rates and moderate charge rates, depending on the battery. Larger systems may not be able to use conventional battery storage systems because of the degree of daily cycling and the magnitude of the expected storage requirements.

It is also possible to electrolyze water with solar-generated electrical energy. The stored oxygen and hydrogen can be converted to electricity in a fuel cell when energy is needed (Bacon, 1964). These storage systems are expensive. They may be considered for special low-capacity applications, such as auxiliary power supply for space vehicles, isolated telephone repeater power supplies, instrumental power supplies, etc. (Duffie and Beckman, 1974).

Any comparison of storage media and storage methods must consider the characteristics of the associated solar collectors, the nature of the loads to be expected in the process, the probable weather cycles, and the costs and time-dependence of solar radiation availability (McDaniels, 1979). The optiumum capacity of an energy storage system depends upon these characteristics along with the degree of reliability needed for the process, the manner in which auxiliary energy is supplied, and an economic analysis that determines how much of the total (usually yearly or seasonal) loads should be carried by solar and how much by the auxiliary energy source (Duffie and Beckman 1974).

### A-2.7 Process Heat Application

STES efficiencies depend upon the ability to utilize as much of the energy captured as possible. The more heat extracted, the higher the efficiency of the system. Approximately one-half of current U.S. manufacturing end use demand is for industrial process heat (IPH) at a wide range of temperatures. Each STES technology has a distinct range of temperature output capabilities (Figure A-7), many of which overlap. The use of a particular solar collector and heat transfer system, therefore, depends upon site specific factors, such as local climate conditions, process requirements and cost. A computerized routine, PROSYS/ECONMAT has been developed for comparison and selection of appropriate solar collectors and heat transfer systems at the Solar Energy Research Institute (SERI) (Brown, et al., 1980).

Solar central receivers can develop extremely high temperatures necessary for IPH requirements (260°C (500°F)). The thermal energy collected by solar receivers could be transported by liquid sodium or a molten salt to produce steam or hot air for industrial processes (Brown, 1980). Parabolic troughs are well suited to IPH requirements of temperatures below 260°C (500°F). Energy from these facilities could be efficiently transferred to the industrial process by hot oil.

Parabolic dish systems may be best suited to IPH requirements that have relatively small dispersed loads. Each module is capable of producing as much as 220,000 Btu/hr (Lucas, 1979). The most likely configuration of small systems would be 1 to 20 modules located close to the area of energy demand. Parabolic dish systems may be used for specialized applications such as high temperature toxic waste incineration systems where the waste is incinerated at the receiver at approximately 1315°C (2400°F) (Brown, et al., 1980).

Several factors that favor solar IHP applications are given in Table A-6. (Hooker, et al., 1980). One problem with solar IPH applications is that many large heat-consuming industrial processes operate 24 hours a day at closely regulated temperatures. However, some of these processes may be able to use solar generated IPH when insolation is available to reduce fossil fuel or conventional electrical energy demands. For processes which have continuous energy requirements that exceed the capacities of practical storage systems, auxilliary fossil generation may be used at night, or during extensively cloudy weather.

STES process heat systems could also be used for preheating, reducing overall fuel requirements of an industrial process. Solar preheating systems may supply as much as 27 percent of the industrial process heat of continuous operations, and up to 40 percent elsewhere (Hooker, et al., 1980).

Another potentially large STES market is the direct use of high temperature solar radiation for powering fuel and chemical manufacturing processes. Direct use of high temperature solar radiation implies focusing and concentrating the solar beam through transparent quarts windows directly on the chemical reactants. Based on early investigations, it is likely that by the year 2000 many entirely new fuel and chemical processes will have been

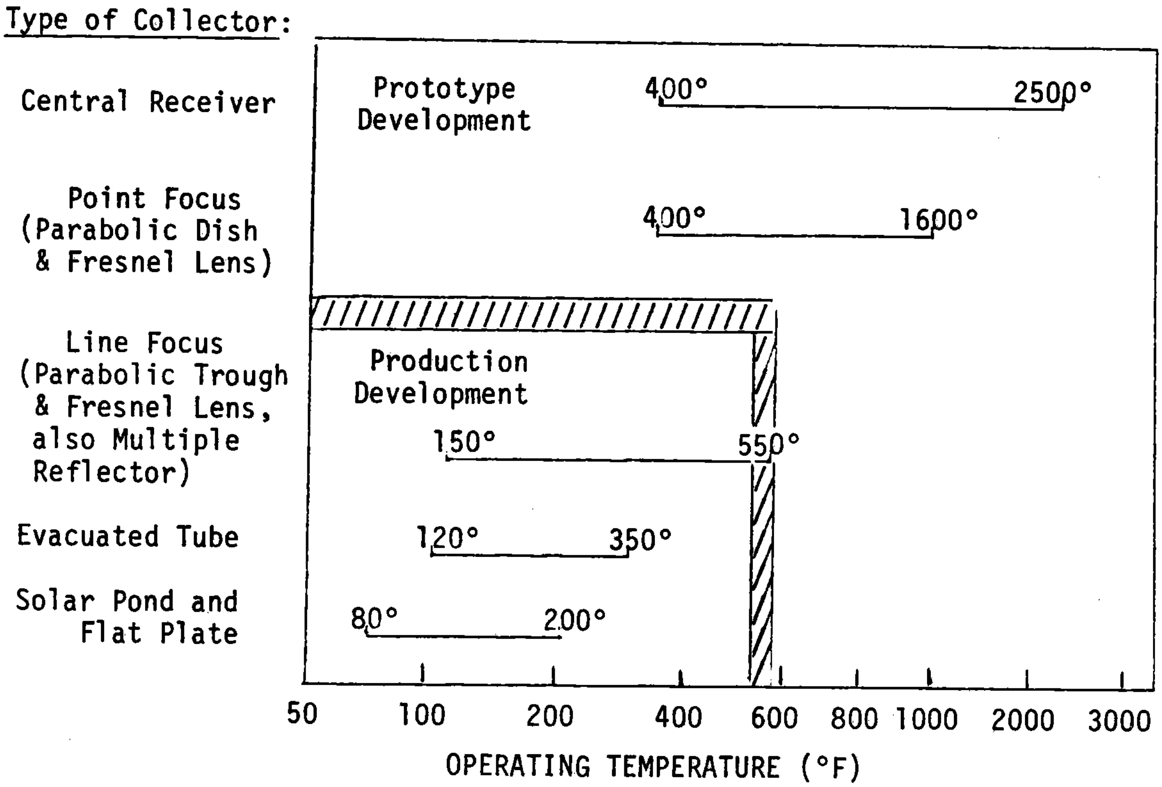


Figure A-7 Practical Operating Temperatures Ranges of Several Types of Thermal Collectors for Industrial Process Heat (Reference: Brown, 1980)

## Table A-6

## Factors Favoring the Application of Solar IPH Systems
(Hooker, et al., 1980)

### Environmental Factors

- High insolation levels - either total or directed, depending on the solar technology proposed
- High ambient temperatures - to reduce thermal losses (particularly for nonconcentrating collectors) and to allow the use of water as a heat transfer fluid
- A pollution-free microclimate - so that collector surfaces will not become coated with dust or corrode
- A polluted macroclimate or area with strict air pollution regulations - where no additional air pollution emissions are allowed and where such controls are a restraint on levels of production

### Process Factors

- Low-temperature process - so that the cheapest type of collector, operating at a high efficiency, can be employed
- Continuous, steady operations (24 hr/day, 7 days/week) where exact temperature control is not critical
- Liquid heating application as opposed to air or steam heating
- Built-in process storage - to reduce fluctuations in the thermal output of the collectors, and which can act as a reservoir of heat produced by the solar system (during the weekend, or long summer evenings)
- Easy retrofit of the solar system - so as to minimize costs
- Inefficient fuel usage, not easily rectified - so that energy delivered from the solar system replaces more than the equivalent Btu content of fossil fuel.

devloped to take advantages of STES high-power, high-temperature solar fluxes (Kreith and Kreider, 1978).

## A-3.0 CURRENT APPLICATIONS

### A-3.1 Central Receiver

### General Description

Figure A-8 provides a drawing and diagram of a central receiver system. A field of guided mirrors or heliostats reflect solar radiation to a single central receiver with a small absorber mounted above ground on a central tower (Wyman, et al., 1980). A central receiver system includes the following components:

> Heliostat arrays are flat or slightly focused mirrors which are controlled to reflect incident sunlight onto a receiver. The heliostats are continually focused on the receiver during the day. Some heliostat concepts use steel frame construction and glass mirrors. Some heliostats are curved, others are flat. One heliostat concept consists of a stretched mylar plastic diaphragm enclosed in a pressurized dome. Its distinctive features include a lightweight reflector, and drive assembly and the transport enclosure. Sample prototype heliostats are shown in Figure A-9.
>
> Receiver. The receiver transmits the solar thermal energy reflected from the heliostats to a working fluid such as steam, air, helium, molten metal or eutectic salts. The working fluids transmit the thermal energy to a single point (i.e., turbine/generator) to do useful work.
>
> Towers are used to elevate the solar energy receiver above the heliostat array. Powerplants under 10 MWe capacity can use either a steel or concrete tower. Powerplants larger than 10 MWe require a concrete tower.

### Example - Barstow, California, 10 MWe Solar Central Receiver Demonstration Plant

#### General Description

The Barstow demonstration plant has a radial staggered heliostat layout, capable of generating 10 MWe net directly from insolation and 7 MWe net from thermal storage (Figure A-10). Water/steam is the primary working fluid for a single-pass-to-superheat external receiver (steam generator) located on top of a 91-meter tower. Thermal storage is provided by a dual-media, rock and oil, thermocline type, sensible heat storage system. Control of the plant is primarily automatic, with the capabilty for manual operator override (Hallet and Gervais, 1979).

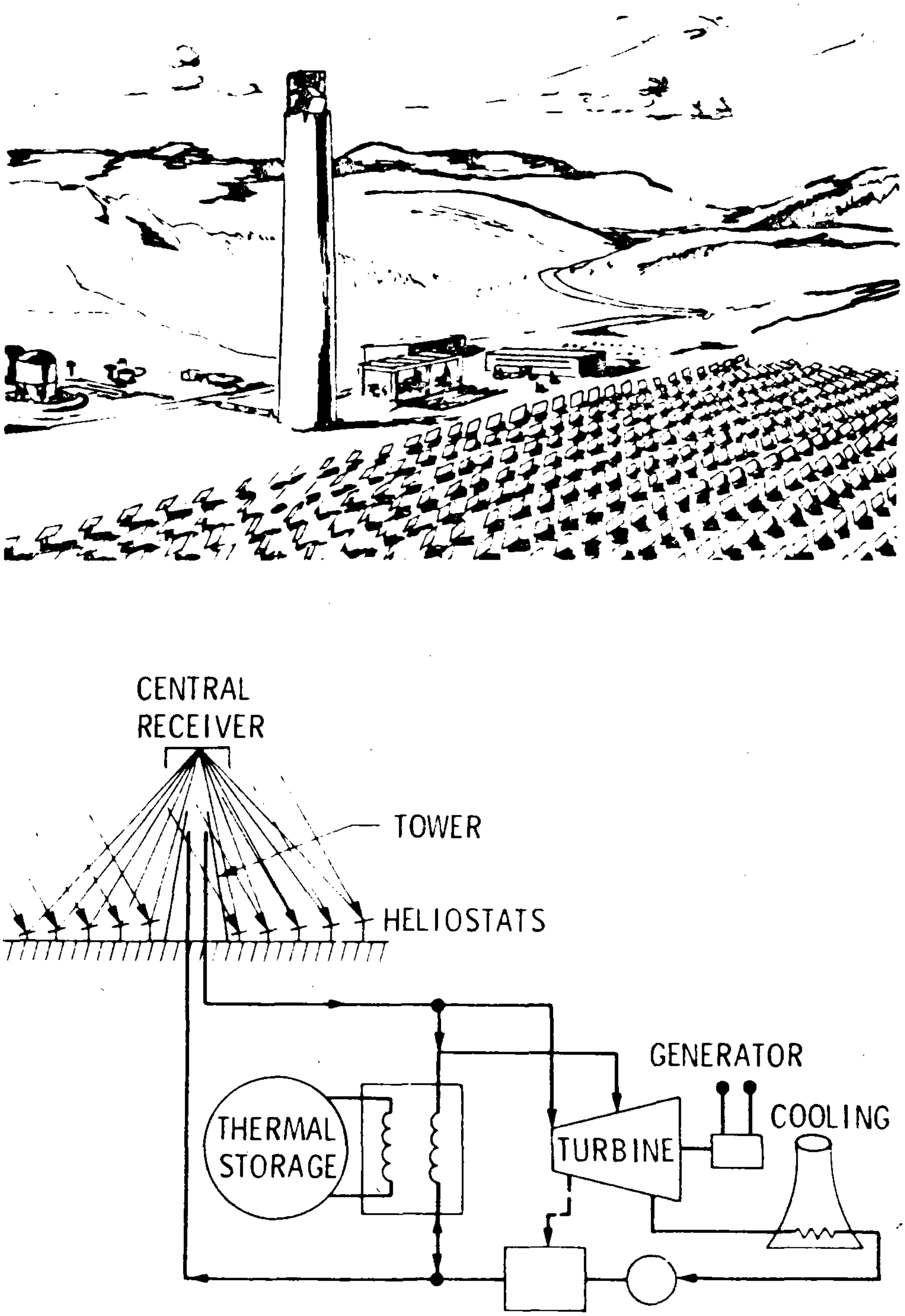
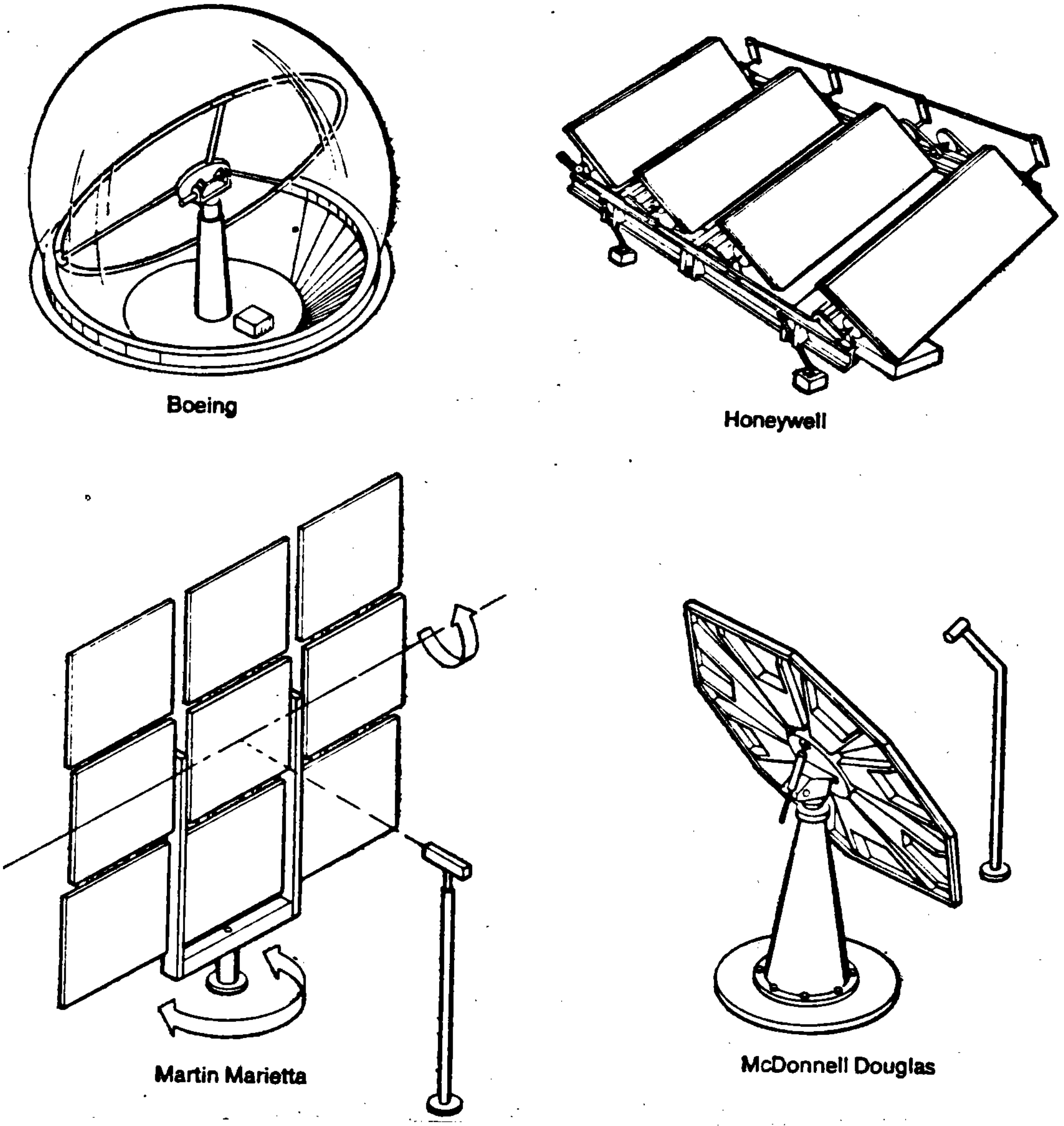


Figure A-8 Point Focus Central Receiver Concept
Reference: DOE, 1978


Boeing

Honeywell

Martin Marietta

McDonnell Douglas

Figure A-9 Four Basic Heliostat Concepts
Reference: OTA, 1978

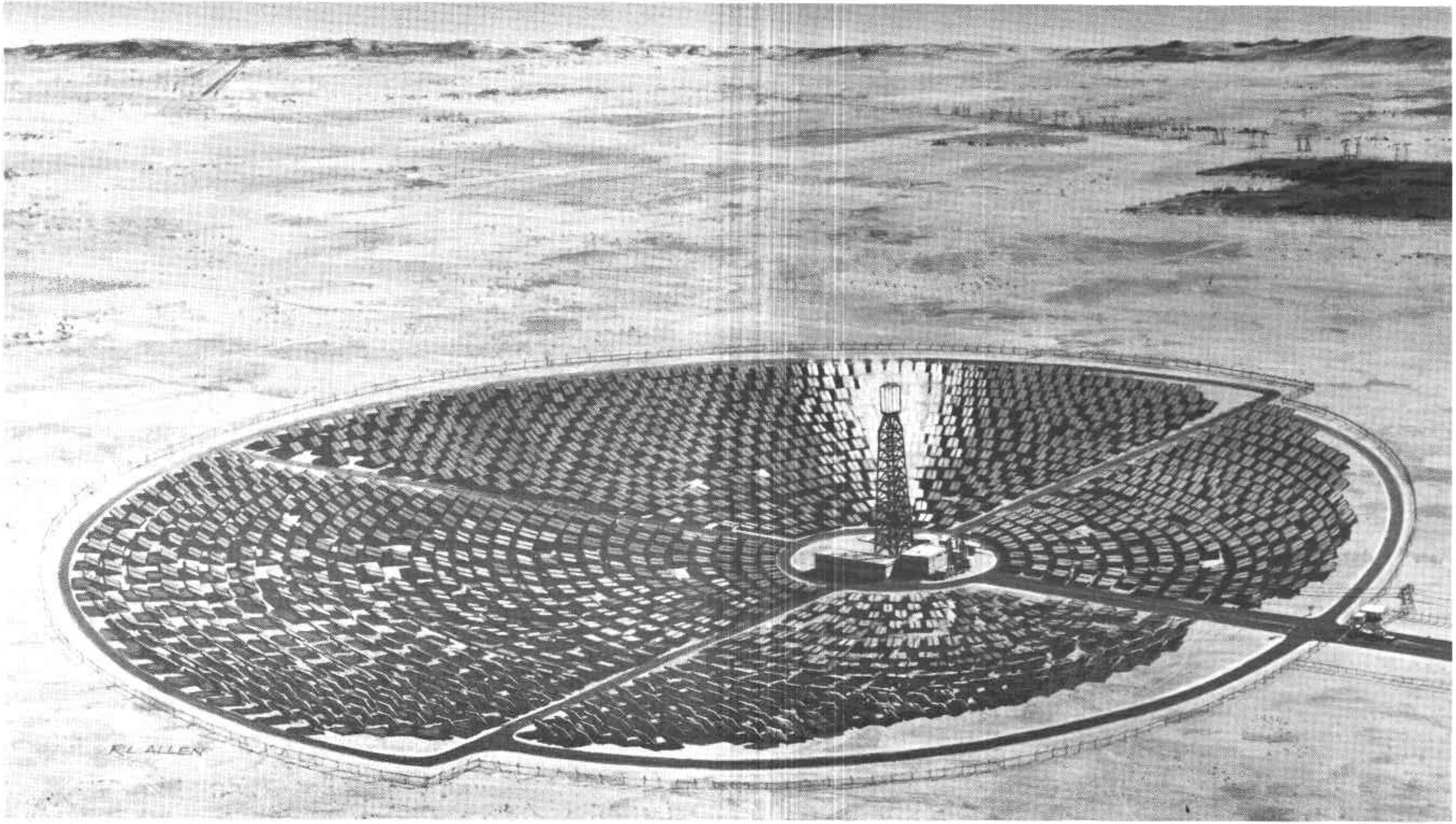


Figure A-10 Artist's Concept - Barstow 10 MWe Central Receiver
Reference: McDonnell-Douglas, 1980

## Barstow Pilot Plant System Requirements

| | |
|---|---|
| • Plant rating and sizing | (1) 10 MWe net for 4 hour on worst design day<br>(2) 10 MWe net for 8 hours on best<br>(3) 7 MWe net for 4 hours from thermal storage |
| • Thermal storage maximum charge rate | Equivalent to thermal power required for 10 MWe net power generation |
| • Plant design life | 30 years |
| • Plant availability | 0.90 excluding insolation considerations |
| • Operational flexibility | Capability for eight steady-state operating modes |
| • Operator capability | (1) design for single operator<br>(2) design to operate individual subsystems |

The thermal storage charge rate is designed to accommodate the maximum thermal power generated from the receiver (approximately 35 MW thermal) at summer solstice.

## Thermal Storage Subsystem

The thermal storage subsystem incorporates a sensible heat storage approach using dual media (liquid and solid) using the thermocline principle to provide a constant-temperature source, independent of residual energy. The rationale for selection was:

- Sensible heat has low technical risk.
- Dual media (inexpensive rocks and hydrocarbon fluid) reduces cost.
- Thermocline principle (sharp thermal gradient) reduces storage volume and tank costs.
- Operation in single state reduces complexity (Hallet and Gervais, 1979).

The electrical power generating subsystem consists of a nominal 12.5 MWe (gross) turbine-generator set that uses wet cooling for heat rejection. The electrical power generating subsystem includes an in-line demineralizer and polisher for maintaining feedwater quality, a low-pressure feedwater heater, a deaerator for oxygen removal, and two high-pressure feedwater heaters for improved cycle efficiency.

The turbine generator requires a dual admission configuration. Two steam throttles utilizing receiver and thermal storage steam are required. There will be a governor system for dual steam inputs suitable for throttle valve ratio control between steam sources. The gross electrical ratings that the turbine-generator must meet are:

12.5 MWe - driven by receiver steam
8.0 MWe - driven by thermal storage steam
2.5 MWe - minimum output

After construction is completed, the pilot plant will be tested for a 5-year period to determine operating and maintenance characteristics of the facility.

### A-3.2 Parabolic Dish

#### General Description

Parabolic dish solar thermal energy systems are also known as point focusing distributed receiver modules and employ two-axis tracking concentrators to generate temperatures ranging from 90-1650°C (200-3000°F) (Figure A-11). Four applications are feasible: electric power generation, process heat supply, total energy systems and fuel/chemical production. A system may be composed of clusters of identical 20 to 20 kWe modules. Approximately 400 modules will be needed for a typical 10 MWe system. (One 25 kW module x 400 modules = 10 MW electric system. The system is assumed to be rated at its peak power output.) A master control system is needed to synchronize the modules and provide for automatic operation. In thermal applications each module will produce approximately 80 kW thermal (250,000 Btu/hr).

Modules designed to generate electricity are made up of three subsystems; a concentrator, a receiver, and a power conversion unit. Automatic control systems enable each module to accurately track the sun. The concentrator is a dish-shaped parabolic mirror, although fresnel lens concentrators are being considered for potential use. Solar radiation is converted to heat then transferred to the working fluid of an organic Rankine engine contained within the module structure. The heat engine is mechanically linked to an electric generator.

The receiver, which is basically a heat exchanger, is mounted near the focal point of the dish and transfers heat through a suitable working fluid (see Figure A-11). The electric power conversion unit consists of a heat engine, alternator and associated controls. Each module may supply power directly to an electric utility grid. However, several modules (a dish cluster) may be used to drive a larger turbine generator mounted on the ground (Lucas, 1979).

For process heat, fuels and chemicals applications, a heat transport subsystem is required. The need for power conversion is eliminated since the thermal output is used as a direct source of energy. For industrial process heat, insulated pipes transport a heat transfer fluid from the receiver to the area of use. The modularity of the parabolic dishes can be used to minimize field-installed piping and to adapt to specific site requirements.

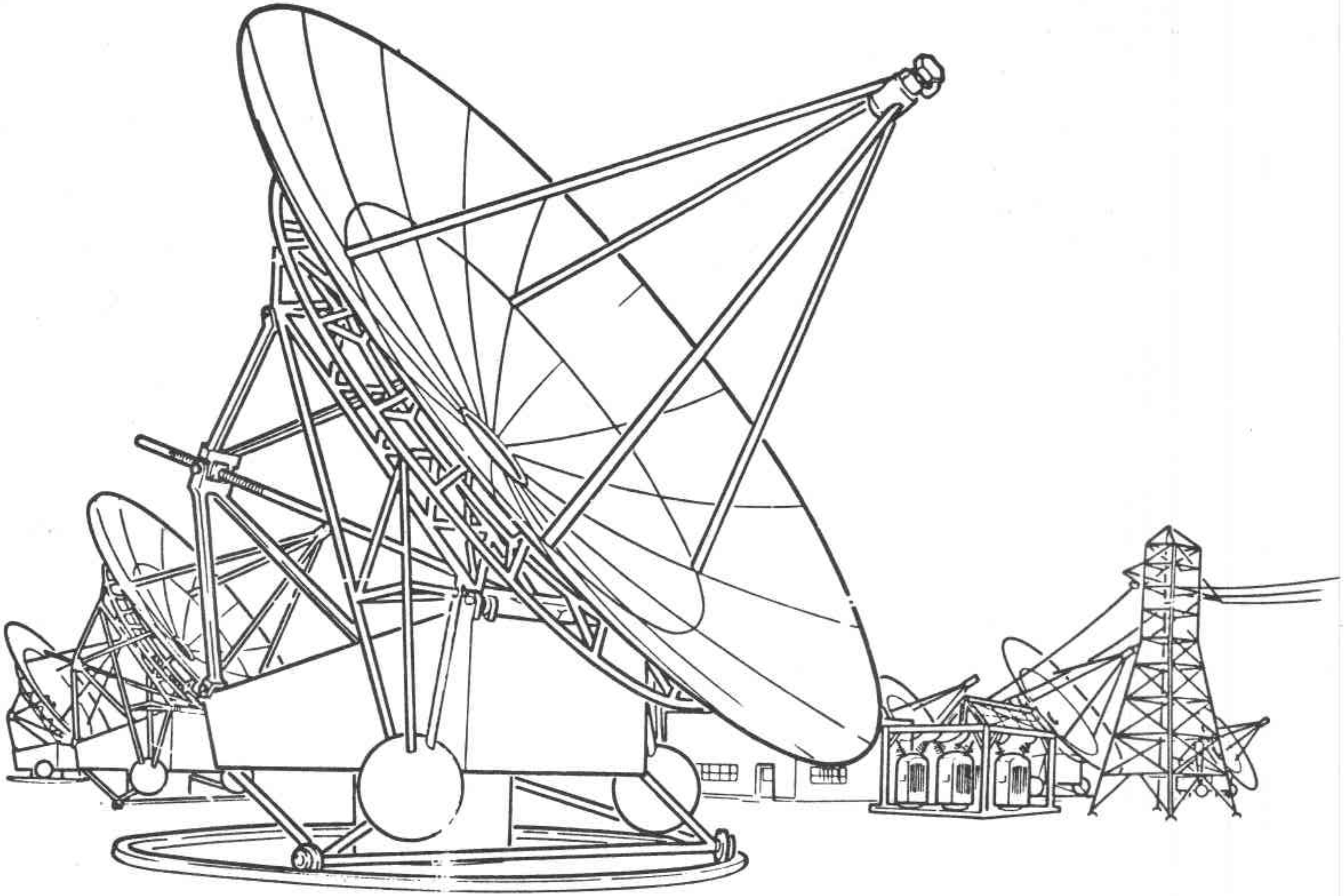


Figure A-11 Point-Focus Distributed Receiver Concept
Reference: JPL, 1978

## Example - Small Community Solar Thermal Power

A parabolic dish system using distributed generation will be the first solar thermal application specifically designed as a source of electric energy for small communities in the United States (Figure A-12).

The Small Community Solar Thermal Power Experiment System is a 1 MWe power plant designed to meet the needs of a municipality presently dependent on oil or gas generated electricity and looking for an alternative energy supply. It will be the first system level test of the parabolic dish concept in a small community. Thus, the primary objective of the demonstration is to determine system feasibility. If successful, the systems will be standardized to industrial specification for full-scale introduction.

The Small Community System uses a concentrator with a reflective film bonded to a reinforced plastic substrate. The receiver is designed to heat an intermediate heat transfer fluid (a new approach under development by Ford Aerospace and Communications Corporation). The concentrator is a parabolic dish design by General Electric. The Jet Propulsion Laboratory is managing power plant design and development. Table A-6 and A-7 lists the low cost concentrator design characteristics and the organic rankine engine specifications.

### Table A-7

### Low Cost Concentrator Design Characteristics
(Marriott and Kicenuik, 1980)

- 12 m. diameter
- Thermal output: 66 kWt @ 0.283 m. aperture when illuminated by 800 $W/m^2$ at a 22 mpg wind speed
- Tracking accuracy requirement: +0.12°
- Automatic acquisition
- Lifetime, 30 years
- Focal point weight capability: 1500 lb.
- Optical reflectance: 0.78 min.

The community selected for the demonstration will provide the land for the experiment. The local electric utility will be responsible for the interface with the electric grid. It is anticipated that the plant will be operated in an experimental mode for at least one year.

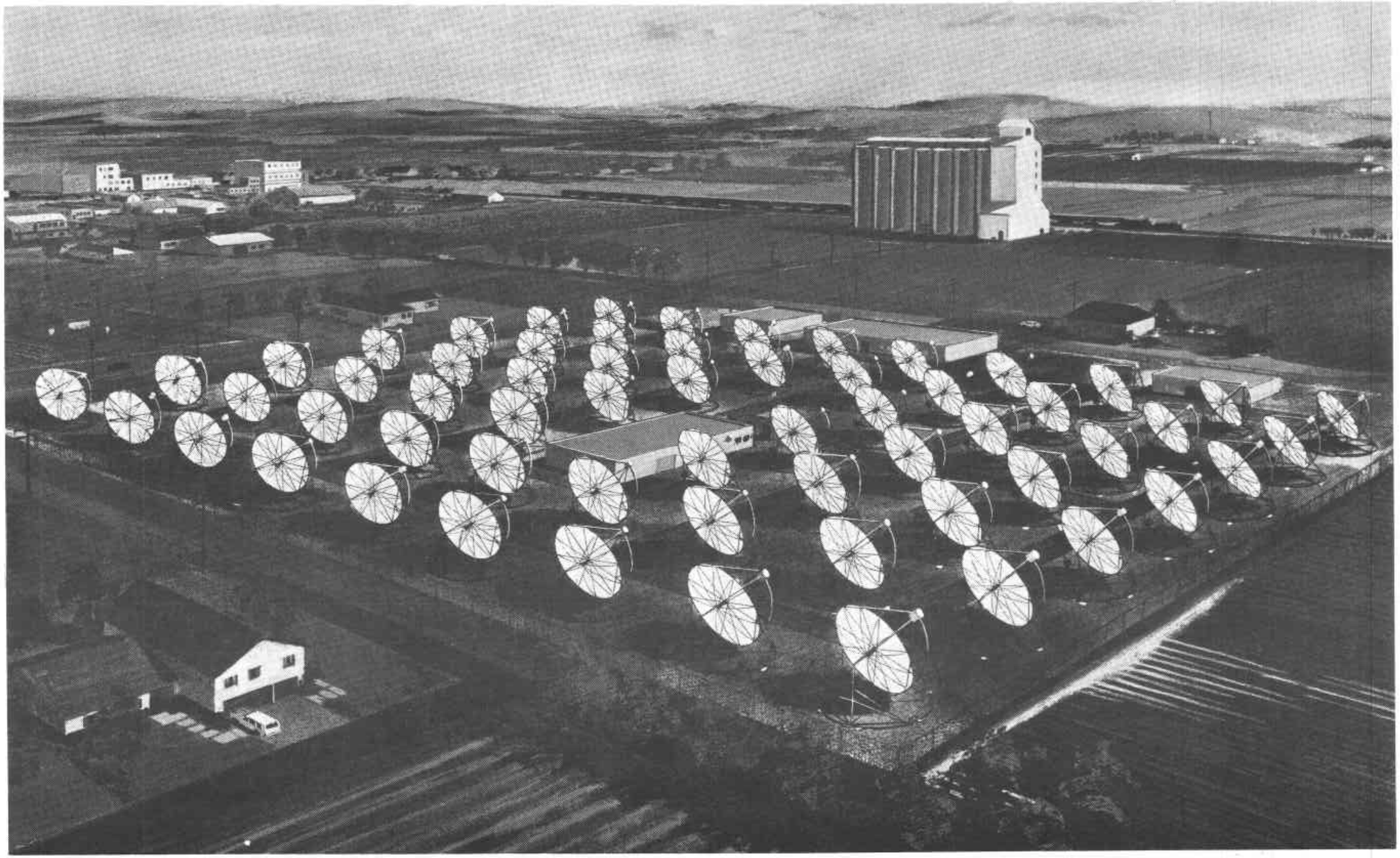


Figure A-12 Small Community Solar Thermal Power Programs
Reference: Marriott & Kiceniuk, 1980

## Table A-8

## Organic Rankine Engine Specifications
(Marriott and Kicenuik, 1980)

### General

- Hermetically-sealed with integral electrical alternator (AC-DC-AC system)
- Capable of operating at 10° to 90° elevation
- Uses forced air-cooled condenser
- To be mounted at dish focal point
- Working fluid: Syltherm 800 or HITEC

### Functional

- Power output is 16.5 kWe with input to engine inlet
- Capable of operating at 82 kWth, periodically
- Net efficiency (heat in electricity out) is 25%

## A-3.3 Parabolic Trough

### General Description

This system focuses incident solar radiation onto a linear receiver, containing a heat transfer fluid. Thermal energy is then converted to electricity via a turbine. The parabolic trough is the most widely accepted linear focusing collector.

Parabolic trough collectors maintain their position relative to the sun with a one-axis tracking system. The tracking orientation can be polar or horizontal. Most parabolic trough collectors can concentrate solar radiation to 40 times that of normal incident radiation. This concentrating ability allows the heat transfer fluid to achieve temperature from 315-480°C (600-900°F).

The receiver, which absorbs the radiation from the collector is located on the focal line of the parabolic trough. There are two types of linear receivers; cavity and cylindrical. Cylindrical receivers are most commonly used when high operating temperatures are desired (OTA, 1978). A sample parabolic trough is illustrated in Figure A-13.

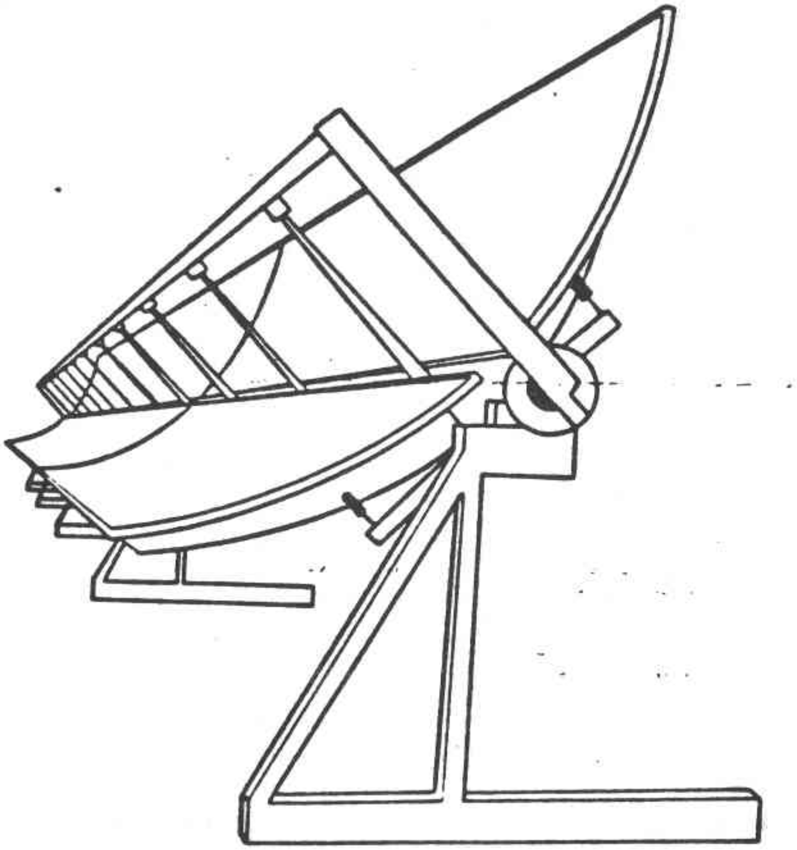


Figure A-13 Line Focus Distributed Receiver
Tracking Collector
Reference: SERI, 1980

### Example - Coolidge Project

The "Coolidge Project" (Figure A-14) is a 150 kWe solar system in Coolidge, Arizona, which provides power for deep-well irrigation pumping in the summer months (Anonymous. Solar Thermal Report, 1980). This system consists of a collector field of 23,040 $ft^2$ parabolic trough solar collectors. The solar radiation concentrated by these collectors heats a working fluid (Caloria-HT-43) to temperatures of 288°C (550°F). After passing through a heat exchanger, this energy is transfered to toluene which is vaporized to drive an organic Rankine cycle turbine.

The 150 kWe generated from this plant operates three deep well pumps capable of lifting water from a depth of 380 feet at a rate of 1400 gallons per minute. The water from these wells is used to irrigate 200 acres of cotton. The system also contains sufficient thermal storage capacity to provide sufficient energy for 6 hours of turbine generator operation. About 70 percent of the annual electric requirements for a 100-home community could be provided by the system (Grall, 1980). A schematic of the facility is shown in Figure A-15.

In addition, this facility will provide data for subsystem characterization and full-system operation. The focus of the testing program is as follows:

(1) evaluation of thermal storage subsystems

(2) evaluation of on the safety interlocks and malfunctioning lockouts

(3) operational evaluation - full power and adjusted rates (sun/cloud cover)

(4) responses of system to meteorological phenomena will be noted (clouds, rain washing)

## A-3.4 Fixed Mirror (Hemispherical Bowl)

### General Description

This concept employs fixed reflectors with an east-west (sometimes southward) orientation that are arranged along the circumference of a circle. These reflectors focus incoming radiation along a focal line that follows a circular path coincident with the shift in sun position. The receiver (absorber) moves with the focal line to intercept the concentrated solar radiation (see Figure A-16).

### Example - Crosbyton, Texas (Texas Tech University and E-Systems

The world's largest hemispherical bowl is under construction in Crosbyton, Texas (Figure A-17). The 65 foot dish reflector is a fixed (nontracking) hemispherical mirror that gathers and concentrates sunlight onto a cylindrical receiver. This prototype will be used for initial testing. There are plans to build 10 full-scale 200 foot dishes (called solar gridirons) that will provide 5 MWe for the Crosbyton community of 2500 (see Figure A-18).

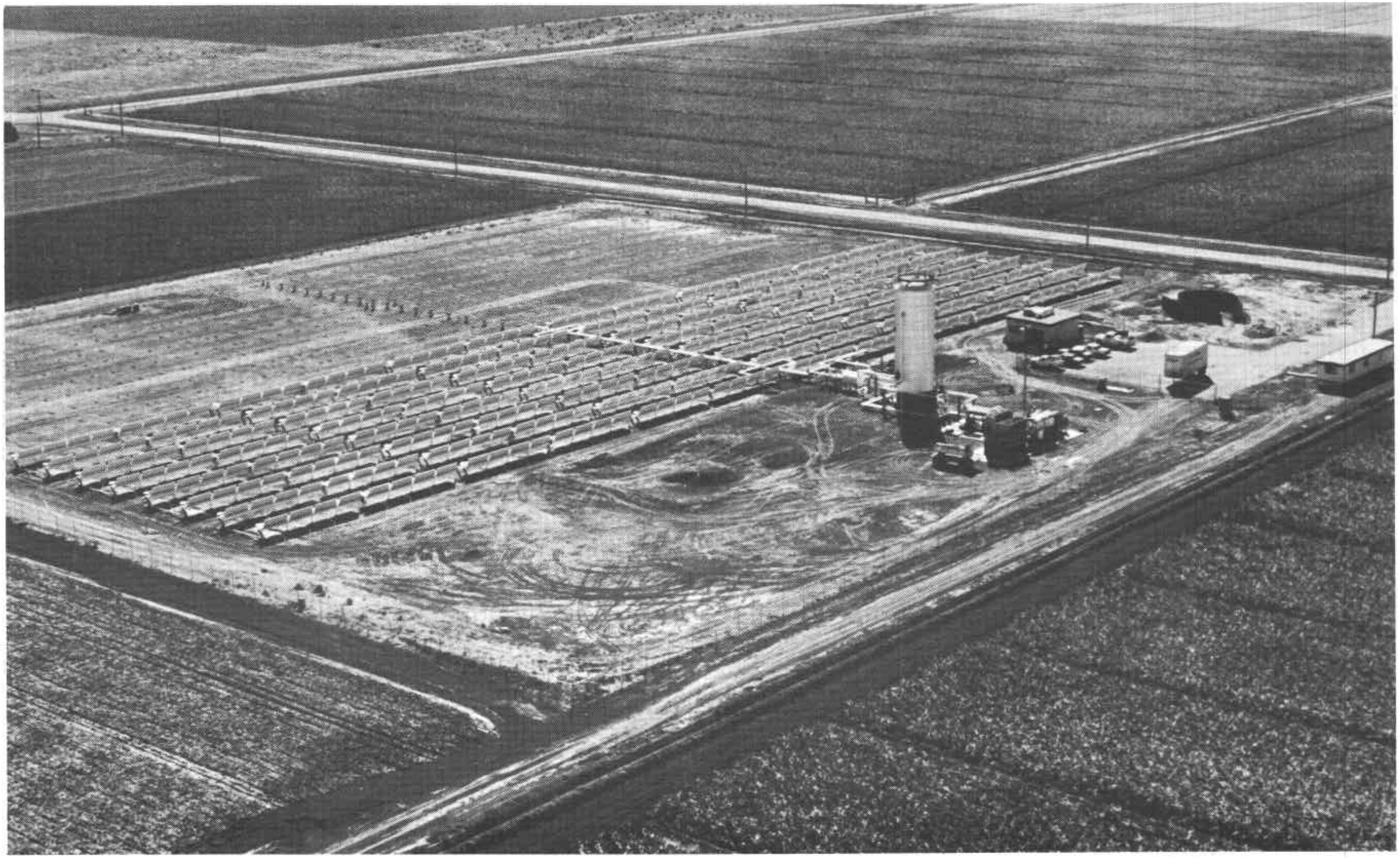


Figure A-14 Solar Irrigation Project - Coolidge, Arizona
Reference: SERI, 1980

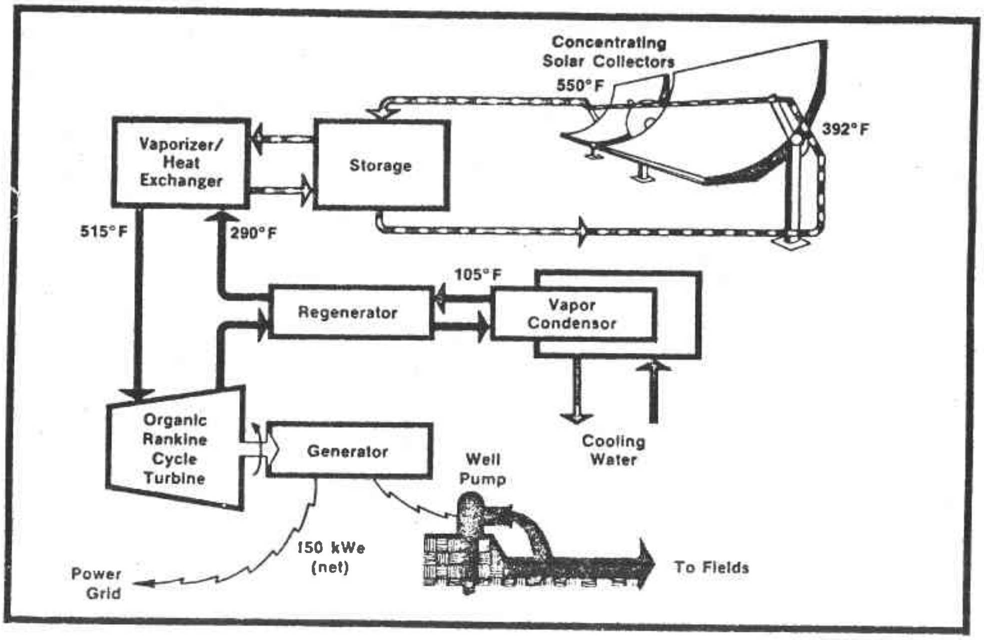


Figure A-15 Schematic of the Coolidge Facility
Reference: Solar Thermal Report, 1980

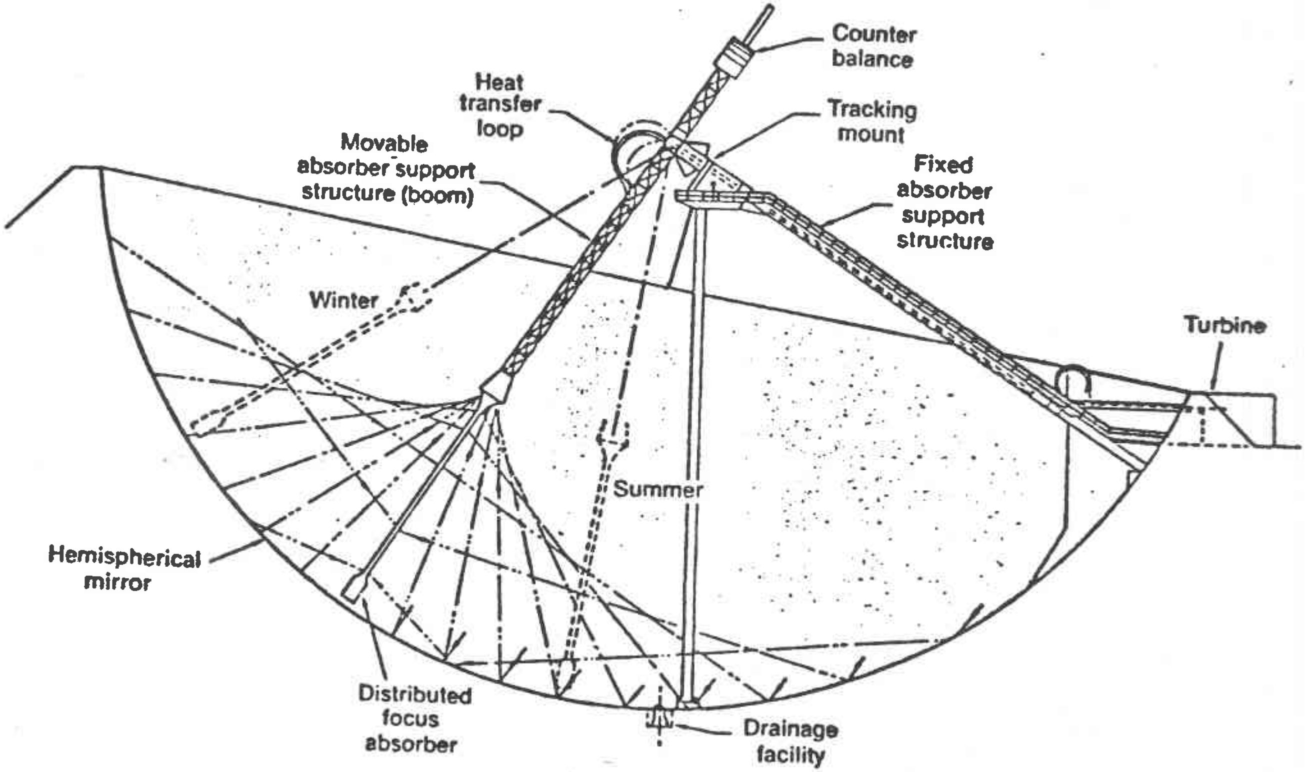


Figure A-16 Cross-Section of Stationary Hemisphere Concentrator
Reference: Truscello, 1978

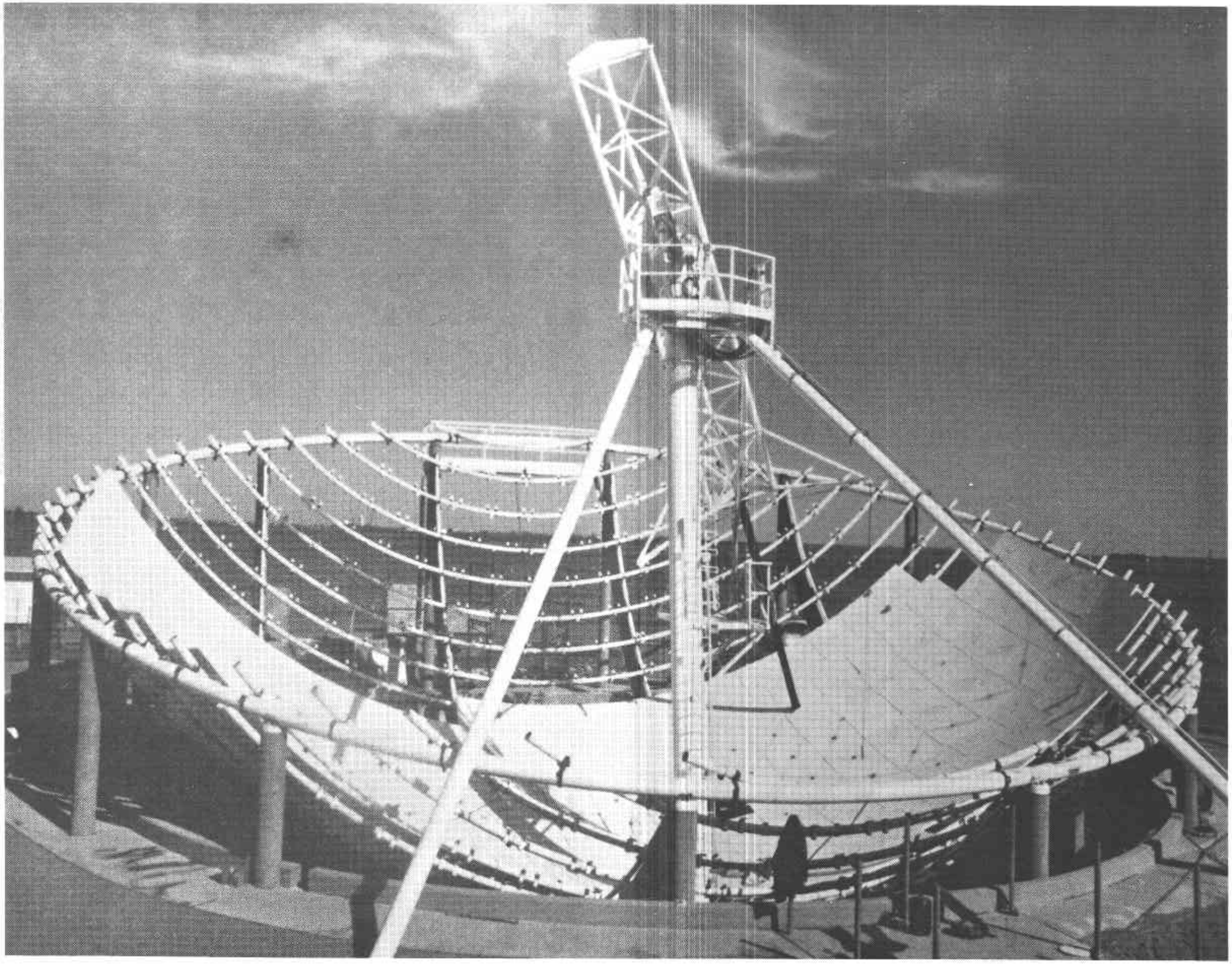


Figure A-17 Crosbyton Solar Power Project - 65 Foot Diameter Solar Gridiron
Reference: Texas Tech University, 1980

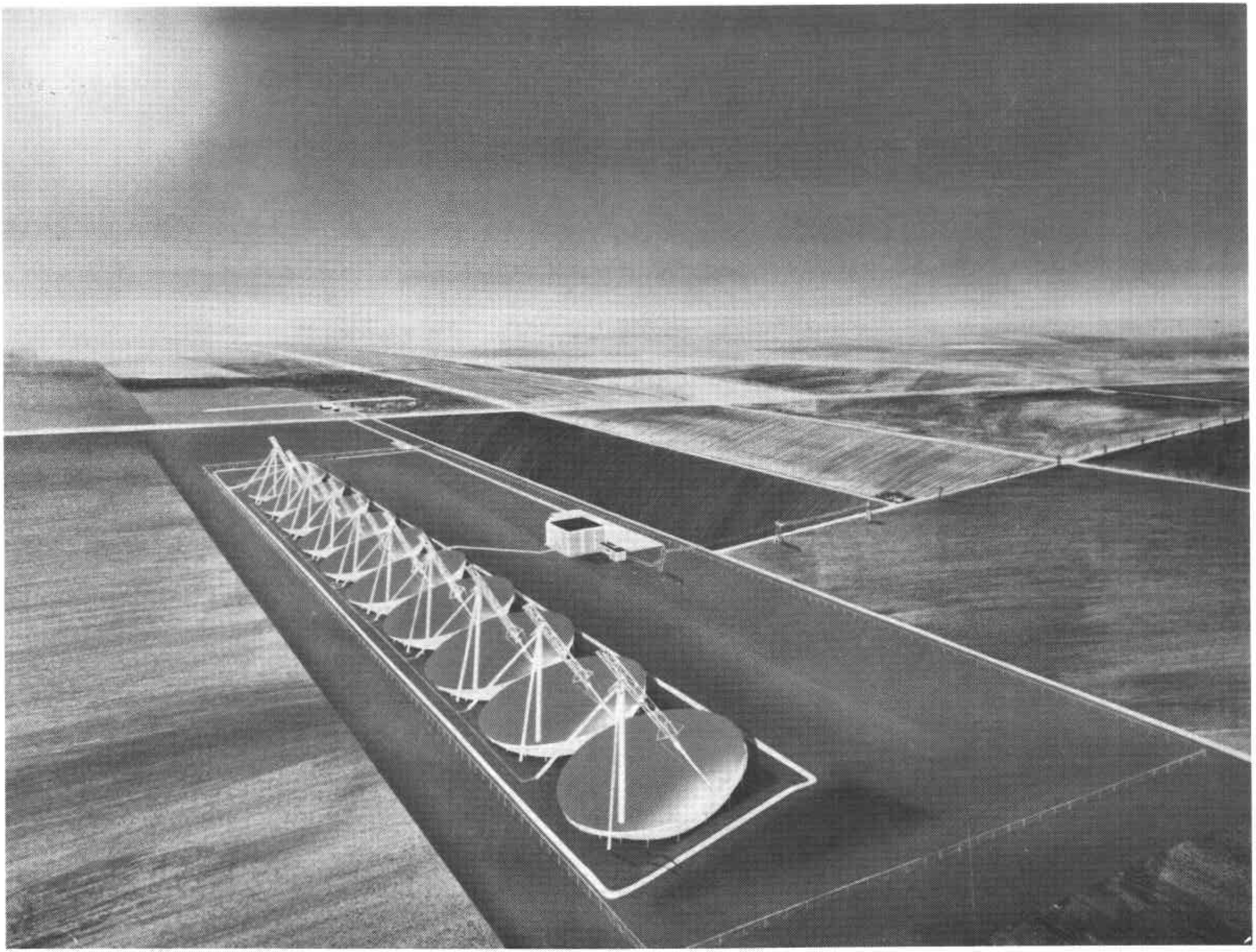


Figure A-18 Artist's Concept - Crosbyton Community Solar Power Project
Reference: SERI, 1980

The collector is expected to have concentration ratios of 600 and will be capable of 705°C (1300°F) operating temperatures. The collectors will heat water circulating in nickel alloy pipes and produce superheated steam to drive a turbine. The overall efficiency is expected to be around 15 percent.

Current research and testing include: 1) the assessment of sustained collector damage due to environmental factors such as hail, wind and sand, and 2) the development of a metal alloys for heat transfer and storage pipes that can withstand 540°C (1000°F) temperatures and survive the rapid cooldown in surface temperatures which occurs when the sun sets.

## A.4 References

Anonymous. "Major Demonstration Project Dedicated--The Coolidge Project." The Solar Thermal Report. Vol. 1:1:3.4 (1980).

Apley, W.J. Systems Analysis of Solar Thermal Power Systems. Battelle Pacific Northwest Labs., Richland, Washington (July 1978).

Bacon, F.T. "Energy Storage Based on Electrolyzers and Hydrogen--Oxygen Fuel Cells." Proceedings of the United Nations Conference on New Sources of Energy. (1964).

Brown, E.C., D.W. Hooker, A. Rabi, S.A. Stadjuher, and R.E. West. End Use Matching for Solar Industrial Process Heat. Final Report, SERI/TR-34-051 (January 1980).

Brown, K. The Use of Solar Energy to Produce Process Heat for Industry. SERI/TP-731-626, UC-62a,b,c (April 1980).

Caputo, R.S. and V.C. Truscello. "Solar Thermal Electric Power Plants: Their Performance Characteristics and Total Social Costs." In Proceedings of the International Energy Conversion Engineering Conference. Jet Propulsion Laboratory (September 1976).

CONAES. Domestic Potential for Solar and Other Renewable Energy Sources. Study of Nuclear and Alternative Energy Systems, Supporting Paper No. 6 (1979).

Crosbyton Solar Power Project. A 5 MW Electric Powerplant for Crosbyton. Texas Tech. University (November 1979).

Curto, P. Systems Descriptions and Engineering Costs for Solar-Related Technologies. ERDA/MITRE Corp., McLean, VA, Volume V: Solar Thermal Electric Systems (1977).

Duffie, J.A. and W.A. Beckman. Solar Energy Thermal Processes. John Wiley and Sons, New York (1974).

Eibling, J.A., R.E. Thomas and B.A. Laudry. An Investigation of Multiple Effect Evaporation of Saline Waters by Steam from Solar Radiation. Report to the Office of Saline Water, U.S. Dept. of the Interior (1953).

Energy Research and Development Administration (ERDA). Solar Thermal Electric: Solar Program Environmental Assessment. ERDA-77-47-4 (March 1977).

General Electric Space Division. Solar Thermal Energy-Large Scale Experiment at Shenandoah, Georgia. Phase III, Preliminary Design (September 1978).

Gintz, J.P. Cloud Cycle High Temperature Central Receiver Concept for Solar Electric Power. EPRI/Boeing Company Report (1976).

Grall, R. "No Gripes About the Hot Weather at DOE Solar Electric Powerplant." Energy Institute. 3416 (1980).

Hallet, R.W., Jr., and R.L. Gervais. "The Solar Ten Megawatt Pilot Plant." In Sun II: Proceedings of the International Solar Energy Society. Boer, K.W. and B.H. Glenn (eds.). Atlanta, Georgia, Vol. 2 (1979).

Holbeck, H.J. and S.J. Ireland. Siting Issues for Solar Thermal Power Plants with Small Community Applications. DOE/JPL-1060-78/2, Rev. 1 (February 1979).

Hooker, D.W., R.E. West and E.K. May. Industrial Process Heat Case Studies. SERI/TR-733-323, UC58 a,b, 59b (May 1980).

Jet Propulsion Laboratory (JPL). Assessment of the Potential of Solar Thermal Small Power Systems in Small Utilities. Final Report. JPL Central 95471 78-008-4-000 (1978).

____________. Annual Technical Report. Thermal Power Systems, Small Power Systems Application Project, Vol. 1: Executive Summary. DOE/JPL-1060-9 (January 1979).

Kreith, F. and J.F. Kreider. Principles of Solar Engineering. Hemisphere/McGraw-Hill, London (1978).

Lucas, J.W. Parabolic Dish Technology for Industrial Process Heat Applications. Jet Propulsion Lab., Pasadena, California (October 1979).

Marcus, R.J. and H.C. Wohlers. "Chemical Conversion and Storage of Concentrated Solar Energy." Proceedings of the U.N. Conference on New Sources of Energy. Vol. 1 (1964).

Marriott, A.T. and T. Kiceniuk. "The Small Community Solar Thermal Power Experiment." Proceedings of the 1980 Annual Meeting-AS/ISES. Vol. 3.1 (June 1980).

McDaniels, D.K. The Sun: Our Future Energy Source. John Wiley and Sons, New York (1979).

Office of Technology Assessment (OTA). Application of Solar Technology to Today's Energy Needs. Washington, D.C. (June 1978).

Rabl, A. "Optical and Thermal Analysis of Concentrators." In Proceedings, Solar Thermal Concentrating Collector Technology Symposium. Gupta, B.P. and F. Kreith (eds.). SERI, Golden, Colorado, DOE Contract No. EG-77-C-01-4042 (June 1978).

Samuels, G. and J.T. Meadow. MIUS Technology Evaluation: Prime Movers. Oak Ridge National Laboratory, CORNL-HUD/MIUS-II (1974).

Solar Energy Research Institute (SERI). Comparative Ranking of 0.1 - 10 MWe Solar Thermal Electric Power Systems: An Executive Overview. Vol. 1, SERI/TR-351-461 (February 1980).

Thornton, J.P., et al. Comparative Ranking of 1-10 MWe Solar Thermal Electric Power Systems: An Executive Overview. SERI, Golden, Colorado, SERI/TRE-35-238 (1979).

Truscello, V.A. "The Parabolic Concentrating Collector." In Proceedings, Solar Thermal Concentrating Collector Technology Symposium. Gupto, B.P. and F. Kreith (eds.). SERI, Golden, Colorado, DOE Contract No. EG-77-C-01-4042 (June 1978).

Ullman, A.Z., et al. Worker Health and Safety in Solar Thermal Power Systems. Volume V. Off-Normal Events. UCLA, ESE 12-/1215, Los Angeles, California (October 1979).

U.S. Dept. of Energy (DOE). Environmental Development Plan (EDP): Solar Thermal Power Systems. Washington, D.C., DOE/EDP-004 UC-11, 4, 62 (March 1978).

Wachtler, W.J., J.H. Price, R.L. Henry, and B.L. Hale. "Survey of Generic Types of Focusing Collectors for Large Scale Applications." In Proceedings of the ERDA Conference on Concentrating Solar Collectors, Georgia Insitute of Technology (September 1977).

Wyman, C., J. Castle, and F. Kreith. "A Review of Collector and Energy Storage Technology for Intermediate Temperature Applications." Solar Energy. 24:517-549 (1980).

# APPENDIX B: Annotated Bibliography

Alteseimer, J.H., and R.P. Blaunstein. "A Status Review of the Technology Assessment of Solar Energy Programs." In Sun II: Proceedings of the International Solar Energy Society. Boer, K.W. and B.H. Glen (eds.). Atlanta, Georgia (1979).

An assessment of the long range environmental, social and institutional impacts of large scale deployment of decentralized solar technologies. A survey of the technical status of various decentralized, renewable systems is presented along with discussion of their applications. Two national energy scenarios for the year 2000 are discussed with the conclusion that the impacts are complicated by the many types and possible combinations of renewable energy systems and applications.

Armstrong, M.D., and J.E. Armstrong. Community Impediments to Implementation of Solar Energy. Stanford Research Institute, Menlo Park, California (November 1979).

A study of the institutional community-level impedements to the widespread implementation of solar technologies by the year 2000. The report discusses many institutional problems expected to emerge when solar technologies are commercialized on a national scale. The study identifies and discusses the institutions most likely involved with solar installations, to provide a framework so that national policy can be formulated to achieve our nations solar energy goals.

Asbury, J.G. "Solar Energy and Electric Utilities: Should They Be Interfaced?" Science. Vol. 194:445-450 (February 4, 1977).

Evaluation of interface economics, including load management analyses. Concludes that central solar systems and conventional utilities are a poor technical match.

Ashworth, J.H. and J.W. Neuendorffer. Matching Energy Systems to Village-Level Energy Needs. Solar Energy Research Institute, Golden, Colorado SERI/TR-744-514 (June 1980).

This report provides analytic framework for identification and development of renewable energy projects (especially small-scale, decentralized renewable energy sources) in rural areas or developing countries.

Ashworth, J.H. Renewable Energy Sources for the World's Poor: A Review of Current International Developments Assistance Programs. Solar Energy Research Institute, Golden, Colorado, SERI/TR-51-195 (1979).

Reviews international development assistance programs, with particular emphasis on indigenous, renewable resources.

Ashworth, J., et al. The Implementation of State Solar Incentives: A Preliminary Assessment. Solar Energy Research Institute, Golden, Colorado (January 1979).

An examination of four major solar energy implementation programs, financial incentives, state funded research and demonstration, testing and certification, and land use planning for solar access.

Bezdek, R., *et al.* *Analysis of Policy Options for Accelerating Commercialization of Solar Heating and Cooling Systems.* George Washington University, Washington, D.C. (1977).

Comprehensive review of various incentives and recommendations for accelerating commercial utilization of solar energy.

Boobar, M.G., *et al.* *Commercial Applications of Solar Total Energy Systems.* Rockwell International, Atomics International Division, Canoga Park, California (July 1978).

Assesses commercial solar total energy system applications. Identifies optimal matches for near and intermediate term energy supply

Broufman, B.H., M. Schweitzer, S.A. Carnes, E. Peele, G. Samuels, Jr., and T.J. Williams. *Decentralized Solar Energy Technology Assessment Program: Research Plan.* Oak Ridge National Lab., Oak Ridge, Tennessee (May 1979).

The major purpose of the DOE Decentralized Solar Energy Technology Assessment Program is to assess the social, political, institutional, and life-style impacts of the widespread adoption of decentralized solar technologies. This report describes the major components and research plan of this program along with major responsibilities, timetable, and milestones.

Brown, K.C. *Applications and Systems Studies for Solar Industrial Process Heat.* Solar Energy Research Institute, Golden, Colorado, SERI/TR-351-481 (January 1980).

Overviews important aspects of SERI Industrial Systems and Applications Study Program. Reviews work completed during FY 1978 and 1979. Concludes with recommendations for future SERI IPH research. Report emphasizes need for continuing SERI market research.

Brown, K.C., *et al.* *End-Use Matching for Solar Industrial Process Heat: Final Report.* Solar Energy Research Institute, Golden, Colorado, SERI/TR-34-091 (January 1980).

Evaluates the effectiveness of end-use matching methodologies for IPH applications. The study found few competitive applications for solar IPH, given the current state of solar technologies and low fossil fuel costs. Several applications will become competitive as fuel costs increase and solar technology improves. The report recommends that future research focus on improving computer analysis techniques (PROSYS and ECONMAT) and applications.

Brown, K.C., P.A. Ketels, and S.A. Stadjuhar. *Industrial Applications Analaysis: Market Definition for Several Industries.* Solar Energy Research Institute, Golden, Colorado, SERI/TP-353-467 (1979).

Emphasized the increasing importance of identifying specific near-term solar thermal markets. These markets must be more adequately defined in terms of performance reliability and cost criteria to direct solar system engineering development and to provide such systems at a cost industry is willing to pay.

Bush, L.R. and P.K. Manjal. Future Solar Total Energy Markets for the U.S. Industrial Sector. Aerospace Corporation, Energy and Transportation Division, El Segundo, California, ATR-77 (7692-01)-2 (1977).

This study evaluates through performance analyses and trade-off studies, the technical and econmomic performance of solar total energy systems (STES). It also provides a comparison of the economic performance of STES relative to conventional systems, and determines of the amount of fuel displaced, potential size of future STES markets, degree of penetration and regional distribution of markets.

Business Week. "The Coming Boom in Solar Energy." p. 88 (October 9, 1978).

A report, primarily from the point of view of industry, about the developing solar energy market. The report includes an interview with James Schlesinger (the former Secretary of DOE), several supporting articles, and a discussion of federal and state subsidy programs. The article discusses President Carter's energy policies and the developing solar industry. Utility hesitancy to endorse solar systems is discussed.

Courier, K., et al. (eds.). Renewable Resources: A National Catalog of Model Projects. Center for Renewable Resources, Washington, D.C. (1980).

A summary and discussion of renewable resource projects throughout the U.S. Educational, urban, institutional low income, housing, legislative, utility, agricultural, industrial, commercial, state and financing programs are discussed.

Dole, S.H. Energy Use and Conservation in the Residential Sector: A Regional Analysis. Rand Corporation, Santa Monica, California, R-1641-NSF (June 1975).

This report characterizes energy use (1975) in the residential sector in 9 U.S. census regions by end use and fuel type. It provides a basis for evaluating the effects of various energy conservation measures in each U.S. region. Alternative energy conservation measures and governmental policies at various levels for encouraging conservation in the residential sector are also discussed.

Energy Research and Development Administration (ERDA). Solar Thermal Electric, Solar Program Assessment: Environmental Factors. ERDA-DOE, Washington, D.C., ERDA-77-47-4 (March 1977).

This report summarizes and ranks the major environmental issues associated with the development of solar heating, cooling and domestic hot water systems.

Foundation Center. The Foundation Directory. Published annually by the Foundation Center, Washington, D.C.

This directory lists all foundations, funding preferences and contact persons nationwide.

Gilmer, R.W. and R.E. Meunier. "Electric Utilities and Solar Energy: The Service Contract in a New Social Context." Mercer Law Review. Vol. 30:2 (1979).

This report contains discussion of the issues associated with the interface of solar technologies and utility management practices.

Gunn, A. *Sources of Funds for Solar Activities.* Center for Renewable Resources, Washington, D.C. (1979).

This report lists and briefly discusses the types and sources of funding at various levels of government, and in the private sector.

Hamrin, J. "Energy Saving Homes: Don't Bet on Technology Alone." *Psychology Today.* (April 1979).

A comparison of two California solar communities, one with predominantly young, well educated, liberal citizens, the other a retirement community. This study revealed that the younger community was more active and more successful in conserving energy because they took more interest in their activities and constantly reinforced their conserving behavior through a strong community association.

Hayes, J. and L.E. Smollen. *Sources of Capital for Community Economic Development.* Center for Community Economic Development, Cambridge, Massachusetts (1976).

Lists and briefly discusses the types and sources of funding available for community economic development.

Hershberg, A. and R. Schoen. "Barriers to the Widespread Use of Residential Solar Energy: The Prospects for Solar Energy in the United States Housing Industry." *Policy Sciences.* Vol. 5:453-468 (1974).

Small scale residential solar devices can reduce U.S. dependence on foreign sources of energy. The three primary barriers to commercialization are technical, economic, and institutional feasibility (diffusion of the innovation to the general public). The article discusses the characteristics of the U.S. housing industry with reference to the above factors using several specific examples. The last section discusses implementation strategies and concludes that present complexities inhibit cloud effective strategy implementation.

Hillhouse, K.H., *et al.* "Legal and Institutional Perspectives on Solar Energy in Colorado." *Environmental Law Institute*, Washington, D.C. (1977).

Evaluation of Colorado's institutional and regulatory structures relating to an emerging energy technology. Specific attention is given to utility regulations and to land use planning for solar utilization.

Hirst, E. and B. Hannon. "Effects of Energy Conservation in Residential and Commercial Buildings." *Science.* Vol. 205:656-661 (August 17, 1979).

Evaluates economic, net energy and employment effects of adopting different conservation programs and new technologies in residential and commercial buildings. Analyzes future trends in energy use using three scenarios which include variables in energy use, costs and employment.

Holbeck, H.J. and S.J. Ireland. *Siting Issues for Solar Thermal Power Plants with Small Community Applications.* Jet Propulsion Laboratory, Thermal Power Systems Small Power Systems Applications Project. Pasadena, California. Publication 78-75, Revision 1, (February 1979).

This report evaluates siting issues for small community utility STES applications of less than 10 MWe.

Holt, R. Renewable Energy Development: Local Issues and Capabilities. U.S. Department of Energy, Office of Solar Policy, Washington, D.C., DOE/PE/0017 (1980).

Examines issues associated with renewable energy development on the community level.

Hyatt, R.J. Legal and Institutional Implications of Providing Financial Incentives to Encourage the Development of Solar Technologies. Solar Energy Research Institute, Golden, Colorado, SERI/TR-62-269 (1979).

A comprehensive examination of incentives and their impacts on solar commercialization.

Institue of Gas Technology. Application Analysis of Solar Total Energy Systems to the Residential Sector: Volume IV - Market Penetration. Chicago, Illinois, ALO-3787-4 (July 1979).

Analyzes the application of solar total energy (STE) systems to appropriate segments of the residential sector and determines residential market potential for STE systems in the future.

Ireland, S. Regulations Applicable to Solar Thermal Power Plants: Interim Report. Jet Propulsion Laboratory, Small Power Systems Applications Project, Pasadena, California (March 1979).

Investigates the applicability of existing regulations to small power systems. Includes discussion of insolation, environmental impact assessment, utility applications and interfaces.

Jaffe, M. Protecting Solar Access for Residential Development: A Guidebook for Planning Officials. The American Planning Association, Chicago, Illinois (1978).

A manual for urban planners which discusses the use of conventional land use controls to protect solar access in new residential developments.

Johnson, S.B. Survey of State Approaches to Solar Energy Incentives. Solar Energy Research Institute, Golden, Colorado (July 1979).

A description and comparison of state legislative efforts in the following areas: property, income, exise and franchise taxation; loans; standards and warranties; building codes; solar access; utilities; and promotional activities.

Kendall, H. and S. Nadis. Energy Strategies: Toward a Solar Future. Ballinger Publishing Co., Cambridge, Massachusetts (1980).

Analyzes U.S. energy consumption by sector. Also evaluates all energy supply technologies with the conclusion that solar and conservation strategies hold considerable promise for the near and long term.

Ketels, P.A. and H.R. Reeve. Market Characterization of Solar Industrial Process Heat Applications. Progress Report - 2nd Quarter 1978-79. Solar Energy Research Institute, Golden, Colorado, SERI/PR-353-212 (December 1979).

An analysis and summary of available data sources and studies related to IPH to determine optimal industrial solar applications. The industrial analysis takes into account: energy use, technical requirements of industrial processes, geographic location, and investment criteria employed by industry.

Kreith, F. and D. Kearney. End Use Matching of Solar Energy Systems. Solar Energy Research Institute, Golden, Colorado (1979).

This report discusses end use matching as a methodology for identifying most cost-effective combination of process energy needs, solar collector technology, geographic location and economics. End use matching is described as a planning tool for determining where, and for what applications solar systems appear economically viable in the near and immediate term. End use matching is discussed in relation to 1st and 2nd laws of thermodynamics.

Laitos, J. Regulated Utilities and Solar Energy: A Legal-Economic Analysis of the Major Issues Affecting the Solar Commercialization Effort. Solar Energy Research Institute, Golden, Colorado (June 1979).

An analysis of public utility reactions to the impact of solar commercialization. Issues discussed include utility ownership, competition and rate structures for solar energy.

Levy, R.S. The Directory of State and Federal Funds for Business Development. Pilot Books, New York (1974).

A list of sources of funding for industrial development. Some of the sources can also be used to finance solar business activities.

Lonnroth, M., et al. Energy in Transition: A Report on Energy Policy and Future Options. University of California Press, Berkeley, California (1980).

Discusses the present energy situation in U.S. and Sweden. Examines the feasibility of various energy technologies in meeting the future demands.

Lovins, A. "Energy Strategy: The Industry, Small Business and Public Stakes." In Perspectives on Energy. L. Reudisili and M.W. Firebaugh, (eds), 2nd ed., Oxford University Press, New York (1978).

An economic and social overview of "soft" vs. "hard" energy production paths.

Marriott, A.T. and T. Kicenink. "The Small Community Solar Thermal Power Experiment." In AS/ISES Proceedings of the 1980 Annual Meeting. G. Franta and B. Glenn, (eds.). Vol. 3:1:519-523 (1980).

Following Phase 1 concept definition studies, STES Phase II effort includes design, development and verification testing of a STES power plant. The report focuses on Phase II and describes activities leading to a system design which will be applied to a community in 1983.

McDonnell Douglas Astronautics Company. Industrial Applications of Solar Total Energy. Final Report, Volume 1, Summary. MDAC-W, Huntington Beach, California (April 1977).

Defines solar energy systems that are technically and economically feasible and can satisfy all or part of selected industrial demands. The market potential of such systems are estimated. Emphasis is placed on application of STES where IPH, electrical, space heating and cooling demands can be satisfied at maximum possible efficiency.

Munson, R. "Ripping Off the Sun." Progressive. (September 1979).

This article discusses efforts on the part of larger corporations to control the growing solar industry. The advantages (sufficient capital, technological expertise, etc.) and disadvantages (possible inhibition of market through pricing, quality control, etc.) are discussed. The concentration of government solar research and development efforts in joint ventures with industry to develop large scale solar systems is criticized. The article calls for government restriction and regulation of large corporate control of the solar energy industry.

National Research Council. Domestic Potential for Solar and Other Renewable Energy Sources. Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences. W.H. Freeman & Co., San Francisco, California (1980).

Discusses the state-of-the-art of all energy supply technologies, the relative risks of energy systems, and U.S. energy policy in global economic context.

National Technical Information Service (NTIS). U.S. Department of Commerce, Washington, D.C.

Government clearinghouse for virtually all technical reports and government sponsored research.

Noll, S.A., F. Roach and L. Palmiter. "Energy Planning with Solar and Conservation: Individual Values and Community Choice." In Sun II: Proceedings of the International Solar Energy Society. Boer, K.W. and D.H. Glenn (eds.). Atlanta, Georgia (1979).

This report concludes that difficulty of shifting our energy resource base to renewable sources "lies in the conflict among individual private sector businesses, and government entities." These arise from the different priorities of each intensified by community externalities. A hypothetical illustrative example of community energy planning is given, indicating the data necessary for analysis (energy use, fuel types and cost) and possible programs (conservation retrofitting and solar passive design).

Office of Appropriate Technology. Sources of State and Federal Funding for Solar/Appropriate Technology Activities. Sacramento, California (1980).

A summary of funding sources at the state (California) and federal level for solar and other alternative technologies.

Office of Technology Assessment, U.S. Congress. Applications of Solar Energy to Today's Energy Needs. Washington, D.C. (1978).

A review of the on-site issues and impacts of solar thermal and electric systems including issues of utility integration, economics, land use, building and community design.

Pollack, P. Implementation of State Solar Incentives: Land Use Planning to Ensure Solar Access. Solar Energy Research Institute, Golden, Colorado (March 1979).

See Ashworth, John, et al.

Riley, J.D., et al. Standards, Building Codes, and Certification Programs for Solar Technology Applications. Solar Energy Research Institute, Golden, Colorado (July 1979).

Issues related to standards for solar technology applications are reviewed. Consumer protection, state and federal tax incentives, and the role of standards in creating or inhibiting incentives/innovations are discussed.

Ross, M.H and R.H. Williams. "The Potential for Fuel Conservation." In Perspectives on Energy. Reudisili, Land M.W. Firebaugh (eds.). (2nd ed.), Oxford University Press, New York (1978).

Summary and analysis of the energy conservation potential for the U.S. by economic sector.

Sim, S.R. "Environmental and Socioeconomic Aspects of Selected Dispersed Solar Electric Technologies." In Sun II: Proceedings of the International Solar Energy Society. Boer, K.W and B.H. Glenn (eds.). Atlanta, Georgia (1979).

A comparison of the environmental and socioeconomic impacts of dispersed solar electric technologies with those of conventional electrical generating systems. The report concludes that solar systems have less of an environmental impact, are more labor intensive (especially in the trades), and may experience difficulty in interfacing with utilities.

Schweitzer, M. Review of Legal and Institutional Issues in the Use of Decentralized Solar Energy Systems. Oak Ridge National Laboratory, Oak Ridge, Tennessee (April 1980).

This report examines the legal and institutional issues involved in the use of decentralized solar energy systems for the purpose of advising government planners and policymakers, the solar industry, solar researchers, and prospective solar users of current and future impediments and incentives to solar commercialization.

Five major issue areas were established: 1) prohibitions on the use of solar equipment, 2) regulation of the production and placement of solar systems, 3) solar access, 4) financial incentives and impediments, and 5) public utility interface.

Implementation options are available for all levels of government in resolving these impediments and instituting incentive programs. The appropriate actions will vary between different levels of government, but all can play an important role in the commercialization of solar technologies.

________. "Solar Energy and Land Use." In Environmental Comment. (May 1978).

An analysis of the land use implications of solar energy. Discussion topics include the amount of land required to support solar projects and public and private land use controls to facilitate solar system utilization.

Solar Energy Research Institute. Putting the Sun to Work in Industry. SERI, Golden, Colorado, SERI/SP-34-175R (1979).

An overview of the potential contribution of various solar technologies in industry.

Stadjuhar, S. An Applications Analysis for the Solar Industrial Process Heat Market. SERI, Golden, Colorado, SERI/TP-34-236 (1979).

Discusses the issues and impacts associated with industrial process heat applications of solar thermal energy systems through the use of the PROSYS/ECONMAT computer end use matching methodology.

Ullman, A.Z. and B.B. Sokolow. "On the Safety of Electric Power Generation." Solar Energy Fundamentals and Applications Symposium, 72nd Annual AIChE Meeting, San Francisco (November 1979).

An examination of the safety hazards of solar thermal power systems.

Ullman, A.Z. and B.B. Sokolow. "Worker Health and Safety in Solar Thermal Power Systems." Laboratory of Nuclear Medicine and Radiation Biology, UCLA, Los Angeles, California (October 1979).

Examines worker health and safety issues associated with solar thermal power system operation.

U.S. Department of Energy (DOE). Environmental Readiness Document: Small Thermal Power Systems. Washington, D.C. (August 1979).

This study addresses the uncertainties about environmental aspects of STES. Impacts and concerns are treated generically. Also, status reports of the technical and environmental R and D programs are provided.

Von Hippel, F. and R.H. Williams. "Toward a Solar Civilization." Bulletin of the Atomic Scientists. Vol. 12 (October 1977).

A discussion of the economic, environmental and social impacts of solar energy. Solar systems are very expensive, require large land areas and may suffer diseconomies in very small systems. The argument is made that solar programs need to be carried out on the community level to bring together the necessary resources for a successful program. Strong political support will be necessary to make innovative changes. The last section discusses the advantages of a solar transition in reducing U.S. vulnerability to cutoffs.

Wallenstein, A.R. Barriers and Incentives to Solar Energy Development: An Analysis of Legal and Institutional Issues in the Northeast. Northeast Solar Energy Center, Cambridge, Massachusetts (December 1978).

An analysis of the legal and institutional barriers to commercialization of alternative energy sources, with emphasis on solar energy. Discusses legal barriers or incentives to solar commercialization in nine states served by the NESEC.

Wasserman, H. "Energy's Point of No Return: Industry Hides from the Sun." The Nation (March 5, 1977).

This article discusses the institutional barriers and lack of adequate funding for solar energy development. The main reason for utility and energy industry hesitancy to support solar energy is their inability to collect revenues from them. The article discusses industry and labor opposition to solar systems and their support of nuclear power.

Yokell, M.D. The Role of Government in the Development of Solar Energy. Solar Energy Research Institute, Golden, Colorado, SERI/TR-52-138 (January 1979).

Discussion of the economic rationale for a federal solar energy subsidy program, the type of program required, and methods for determining proper funding levels.

# APPENDIX C: GLOSSARY

## C.1 Technical Terms

ABSORBER or ABSORBER PLATE - the part of a solar collector that receives the incident solar radiation and transforms it into thermal energy.

ABSORBANCE - ratio of the amount of radiation absorbed by an actual layer of material to the amount of radiation striking its surface. Since this property may vary with wavelength and angle of incidence, its value is usually given for normal incidence and is integrated over the solar spectrum.

ACCEPTANCE ANGLE - the limit to which the incident solar irradiance path may deviate from a normal drawn to the aperature, and still reach the absorber.

ANGLE OF INCIDENCE - angle between a ray striking a surface and a line perpendicular to that surface at the point of impact. Normal, or perpendicular, rays have zero angle of incidence.

ANGSTROM (A-) - unit of length, $10^{-10}$ m.

ANNUAL LOAD FRACTION - fraction of the annual heating needs supplied by solar energy.

APERTURE - operating or projected area of a solar collector, through which the solar radiation is admitted and directed to the absorber.

AUXILIARY ENERGY SUBSYSTEM - equipment using conventional energy sources to supplement the output provided by the solar energy system. It may be integrated directly into the solar energy system, or be completely separate from it and contain its own means for delivery of heating, cooling, and/or hot water to the building.

BASELOAD ELECTRIC PLANT - an electrical generation facility which is designed primarily to satisfy a continuous demand. Generally, capacity factors are 0.6 to 0.9.

BOWL (HEMISPHERICAL) - a solar concentrator design based on the optical properties of a fixed spherical mirror. A spherical mirror produces an image of the sun along a radial line through the center of the sphere.

BOWL SYSTEMS - solar energy systems which have bowl concentrators as their principal element.

BRAYTON CYCLE ENGINE - a heat engine which uses a gaseous working fluid. It is the thermodynamic cycle used in the jet engine.

BRITISH THERMAL UNIT (BTU) - the amount of heat required to raise one pound of water one degree Fahrenheit.

BUFFER STORAGE - energy storage which is designed to allow a solar energy system to operate smoothly under adverse solar conditions.

CALORIE - the amount of heat required to raise the temperature of 1 gram of water by 1 degree C. One calorie is equal to 4.2 joules.

CAPACITY CREDIT - in computing the value of a solar energy system a distinction is made between the value of fuel saved and the value of permanent facilities foregone as a result of using a solar energy system. The capacity credit is the component of value associated with the permanent facilities (generating capacity or boiler capacity) foregone.

CAPACITY, BASE LOAD - generating capacity that may be characterized by high fixed costs and low variable costs. It is generally associated with coal-fired and nuclear steam generation, with a capacity factor ranging from about 50 percent up to the unit's operating availability. Base load units are usually expected to run at, or near their capacity rating when they are not shut down for repair or maintenance.

CAPACITY, INTERMEDIATE LOAD - generating capacity with lower fixed costs and higher variable costs than base loaded capacity. It is often represented by units that have been moved out of base load operation and is characterized by a high degree of swinging between its minimum loading and its rated capacity to follow the utility's varying load.

CAPACITY, PEAK LOAD - generating capacity characterized by low fixed costs and high variable costs associated with units such as combustion turbine and diesels. Because of high costs, these systems begin operation only after base load and intermediate load systems are running. Peak load systems generally operate at a capacity factor below about 25 percent, and are designed for frequent, perhaps daily, startups and shutdowns. Peaking units are normally less efficient at partial loading than intermediate units, which will often be dispatched at partial loading to allow the peaking capacity to operate at full load.

CAPACITY FACTOR - the actual amount of electricity generated by a power plant during one year divided by the amount of electricity that would be generated by the plant during one year if it operated continuously at rated capacity.

CENTRAL RECEIVER SYSTEMS - a solar energy system design concept involving a large field of heliostats which are controlled to reflect the sun to a thermal receiver, located on top of a tall tower.

COLLECTOR EFFICIENCY (INSTANTANEOUS) - ratio of the amount of energy removed by the heat transfer fluid over a time period of less than five minutes, to the total solar radiation incident on the collector for the same period, under steady-state conditions (test method described by ASHRAE 93-77).

COMPOUND PARABOLIC CONCENTRATOR - solar collector using parabolic reflector segments to concentrate sunlight without forming an image of the sun on the receiving surface.

CONCENTRATION RATIO or CONCENTRATION FACTOR - ratio of radiant energy at the absorber of a concentrating collector to the intensity of the unconcentrated beam radiation at the collector site.

CONCENTRATOR (Collector) - an optical system which focuses sun rays to increase the flux density of solar radiation at a focal zone.

CONVERSION EFFICIENCY - the actual net output provided by a conversion device divided by the gross input required.

CONVERSION SYSTEM - a device or process that converts a raw energy form into another form of energy (e.g., conversion of wood into methanol or sunlight into electricity).

DEMAND - the amount of energy required to satisfy the energy needs of a stated sector of the economy.

DEMONSTRATION PLANT - an operating solar energy system designed to prove one or more aspects of the performance, operation or economic feasibility.

DIFFUSE SOLAR FLUX - solar radiation which arrives at a point indirectly from many directions rather than from a single point, i.e., after being reflected or refracted by intermediate objects or media (e.g., buildings, ground, clouds, air, or smog).

DIRECT RADIATION (INSOLATION) - solar radiation that arrives in a straight line from the sun and is not scattered by the atmosphere. It casts shadows and can be focused.

DISH (PARABOLIC) - a solar energy concentrator based on the optical reflecting properties on a parabolic surface of revolution. A parabolic mirror produces an image of the sun at its focal point.

DISTRIBUTED COLLECTOR SYSTEMS - collect sunlight on separate models, each with their own absorber to convert solar energy to thermal energy.

EFFICIENCY - ratio of the useful energy output to the energy input under given conditions, expressed in percent.

ENDOTHERMIC - a chemical reaction which absorbs heat.

ENERGY - the capacity for doing work. Its various forms such as thermal (heat), mechanical (work), electrical, and chemical can be transformed from one into another. It is measured in kilowatt-hours (kWh) or British thermal units (Btu), or in joules (J), where 1 joule = 1 watt-second.

EUTECTIC - a mixture of substances which has a melting point lower than that of any mixture of the same substances in other proportions.

EXOTHERMIC - a chemical reaction which yields heat (e.g., burning fuel).

FIELD EXPERIMENT - the concentration and testing of a solar energy system in an actual operating situation.

FIXED MIRROR DISTRIBUTED COLLECTOR SYSTEMS - two types: distributed focus-flat plate; low concentrating, non tracking (e.g., compound parabolic, vee-trough concentrators).

FRESNEL LENS - thin piece of plastic or glass containing tiny, carefully shaped grooves whose surfaces refract incoming light as desired, usually to a point or line focus.

GENERIC SYSTEM - the "typical" system, when there are numerous variations of the system being studied.

HEAT CAPACITY - amount of heat necessary to raise the temperature of a system or component by one degree (Btu/°F or cal/°C).

HEAT ENGINE - engine in which thermal energy is transformed into mechanical energy.

HEAT-TRANSFER MEDIUM - substance used to transport thermal energy (e.g., steam, air, organic fluids, helium).

HEAT RATE - a measure of a generating unit's thermal efficiency (Btu/kWh), computed by dividing the total heat content of the energy source (fuel) by the generated energy.

HELIOSTAT - device that orients a mirror to reflect sunlight in a specific direction, regardless of the sun's position in the sky.

HELIOTHERMAL - any process that uses the sun's radiation to produce heat.

HYBRID SYSTEM - an energy system which can be operated from either solar energy or fossil fuel interchangeably, or possibly simultaneously.

IPH (Industrial process heat) - medium to high temperature thermal energy used to drive industrial processes.

INSOLATION - radiation received from the sun. Total insolation includes both direct and diffuse radiation.

KILOWATT - unit of power that measures the rate at which energy is produced or used. A rate of one kilowatt maintained for one hour produces or uses one kilowatt-hour of energy (equal to 1000 watt-hours).

LANGLEY - unit of solar radiation intensity equivalent to 1.0 gram-calorie per square centimeter.

LINE FOCUS COLLECTORS - any one of several solar energy concentrators which produce an image of the sun along a line (e.g., parabolic troughs, spherical bowls, and linear Fresnel lenses).

MEGAWATT (MW) - one million watts - a common unit for specifying the capacity of an electric power plant.

MEGAWATTS ELECTRICITY (MWr) - one million watts of electricity.

MEGAWATTS THERMAL (MWT) - the amount of thermal energy equivalent to that supplied by a megawatt of electricity.

MOLTEN SALT SOLAR THERMAL SYSTEM - a solar thermal energy system which uses molten salt to transport and store thermal energy.

ONE AXIS/TWO AXIS TRACKING SOLAR-COLLECTOR SYSTEMS - characterized as relatively small modular units producing tens of kilowatts of electricity. The modules are factory mass-producible, deployable in multiples (depending upon the requirements of the application), and usable for providing thermal and/or electrical energy. The systems convert energy to electricity in a distributed manner, with small engines close to the solar collectors.

OPTICAL EFFICIENCY - the ratio of the transmitted or reflected radiation to the radiation incident on an optical system.

PARABOLIC FOCUSING COLLECTOR - type of concentrating collector which focuses beam radiation by means of a reflector with a parabolic cross section.

PARABOLIC TROUGH - a solar energy concentrator based on the optical properties of a cylindrical parabolic mirror. A cylindrical parabolic mirror produces an image of the sun on a line parallel to the axis of the cylinder.

PERCENT POSSIBLE SUNSHINE - the percent of daylight hours during which insolation is not obscured by clouds.

PHASE-CHANGE ENERGY STORAGE (PCES) - storage of heat energy in a material undergoing a reversible phase change such as melting, dissolving, or a change in crystal structure.

PHOTOVOLTAIC CELL - semiconductor device in which the absorption of light creates a separation of electrical charges. This results in an electrical potential that can be tapped by allowing electrons to flow through an external circuit. The net effect is direct conversion of light into electricity.

PILOT PLANT - a small scale installation of a system used to prove technical feasibility.

POINT FOCUSING PARABOLOID DISTRIBUTED COLLECTOR SYSTEM - a concentrator with a paraboloid dish reflector focusing on a cylindrical cavity receiver.

PROCESS HEAT - heat which is used in agricultural and industrial operations.

QUAD - one quadrillion ($10^{15}$ or 1,000,000,000,000,000) BTUs (British Thermal units).

RATED CAPACITY - the maximum power that an energy system is capable of producing.

RANKINE CYCLE ENGINE - a heat engine which uses a thermodynamic cycle involving the expansion of high pressure, high temperature vapors through a turbine or piston, and condensation of the vapor to a liquid before recirculating.

RECEIVER - absorbs reflected solar energy from the heliostats and transfers it to a working fluid.

RECEIVER EFFICIENCY - the ratio of energy removable from the receiver to the incident radiant solar energy at specified operating conditions of temperature and solar flux.

RECEIVER INTENSITY RATING - the level of direct normal solar intensity ($kW/m^2$) at which a solar thermal energy system reaches its rated thermal receiver power.

REPOWERING - retrofitting existing power plants or industrial processes with solar energy systems to reduce the use of fossil fuels.

SENSIBLE HEAT - heat which, when added to a material, causes a temperature increase.

SOLAR COLLECTOR - device designed to absorb incident solar radiation and transfer the energy to a fluid flowing in thermal contact with the absorbing surface.

SOLAR CONSTANT - intensity of solar radiation on an exposed surface normal to the sun, and located outside the earth's atmosphere at a distance from the sun equal to the earth's mean distance from the sun. The currently accepted value is 1353 $W/m^2$, or 429.2 $Btu/hft^2$.

SOLAR ENERGY - energy transmitted from the sun in the form of electromagnetic radiation in the wavelength region from 0.3 to 2.7 micrometers.

SOLAR THERMAL ENERGY SYSTEMS - systems which convert solar energy into electricity by collecting, concentrating and converting the sun's rays to heat and then to electricity by means of a heat engine or a thermodynamic conversion plant.

STAND ALONE - a system capable of supplying the required demands without the assistance of any other system.

STIRLING ENGINE - a very efficient external combustion engine which uses a gas as the working fluid.

STORAGE CAPACITY - amount of energy that can be stored by a solar heating system for use as the working fluid.

SUPPLEMENTARY HEAT - extra heat provided by a conventional furnace when the available solar energy is insufficient to maintain the desired temperature.

THERMAL EFFICIENCY - measurement of how efficiently a device changes heat into another energy form, e.g., the ratio of electric energy produced by a power plant to the amount of heat supplied to the plant.

THERMAL RADIATION - electromagnetic radiation emitted by any object according to its temperature and surface properties.

THERMOCHEMICAL CONVERSION PROCESS - any process which transforms an initial set of chemical reagents into a different product set of chemicals involving the application or deletion of heat energy.

THERMODYNAMIC CYCLE - any one of a number of processes for converting heat flow to mechanical work or mechanical work to heat flow.

TOTAL INCIDENT INSOLATION - total solar radiation received on a unit surface area over a specified period of time.

TRACKING COLLECTOR - collector that can rotate about one or two axes to face the sun; usually restricted to high-temperature concentrating collectors because of the complexity and cost of a tracking system.

TRANSMITTANCE - ratio of the radiation passing through a material to the radiation incident on the upper surface of the material.

VARIABLE SLAT - collectors which use segmented mirrors individually articulated to concentrate energy on a horizontally straight receiver.

WATT - unit of power (the time rate at which work is done), equivalent to 1 joule per second (1 joule = 0.001 Btu); also is the amount of work available from a current of 1 ampere at a potential of 1 volt.

## C.2 Legal, Regulatory and Economic Terms

ACCELERATED DEPRECIATION ALLOWANCES - accelerated depreciation for a given capital investment reduces the tax liability, mainly used by utilities and corporations.

GOVERNMENT TRANSFER INCENTIVES - government transfer of money, property, services or anything else of value to a private or public agency to provide a service or accomplish a task for the public benefit.

GUARANTEED OR INSURED LOANS - by placing the credit of a governmental entity behind the borrower, the risk to private lenders is reduced.

INCOME TAX CREDITS - a taxpayer (individual or corporate) reduces their net tax liability by a percentage of the cost of a solar system specified by law.

INVESTMENT TAX CREDITS - reduction of the tax liability of a solar manufacturer or business purchasing solar systems. May be a percent of system cost, mortgage, accelerated depreciation or support for research and development.

NEPA - National Environmental Policy Act (1970)

PUD (Planned Unit Developments) - developers offer a package of land uses and building designs in larger developments to minimize zoning and regulatory restrictions.

PURPA - Public Utility Regulatory Policy Act (1978).

Tax Exempt Bonds - Issuance of tax exempt bonds by a federal agency to encourage local or municipal initiatives.

TDR (Transfers of Development Rights) - Rights for development conferred on lots are transferable and can be sold independently of the land.