Assessment of Generic Solar Thermal Systems for Large Power Applications

Volume I

Analysis of Electric Power Generating Costs for Systems Larger than 10 MWe

November 1980

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ASSESSMENT OF GENERIC SOLAR
THERMAL SYSTEMS FOR LARGE POWER
APPLICATIONS

VOLUME I

ANALYSIS OF ELECTRIC POWER GENERATING
COSTS FOR SYSTEMS LARGER THAN 10 MWe

W. J. Apley	J. A. Fort
S. P. Bird	B. A. Garrett-Price
D. R. Brown	W. P. Patton
M. K. Drost	T. A. Williams

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Pacific Northwest Laboratory
Richland, Washington 99352

FOREWORD

During the past 2 1/2 years the Pacific Northwest Laboratory (PNL) has performed a comparative analysis of solar thermal conversion concepts. The purpose of this analysis is to characterize, evaluate, and rank the principal solar thermal power concepts under consideration in the U.S. Department of Energy's (DOE) Solar Thermal Power Program, on the basis of an engineering and economic analysis of alternative power plant configurations. A five-volume report on the analysis of small electric power systems (1 to 10 MWe) was issued in 1979-80, consisting of:

- Volume I Executive Summary
- Volume II Identification and Characterization of Concepts for Analysis
- Volume III Analysis of Concepts
- Volume IV Comparative Ranking of Concepts
- Volume V SOLSTEP - A Computer Model for Solar Plant System Simulations.

As a follow-on to the small power systems analysis, two tasks were established for evaluating large power systems. Task 1 involved analyzing the costs for generating electric power from concepts in configurations larger than 10 MWe. Task 2 includes the analysis of thermal energy costs from solar thermal concepts in configurations larger than 50 MWt. A two-volume report on this analysis of large power systems (greater than 10 MWe) will be issued in 1980-81, consisting of:

- Volume I Analysis of Electric Power Generating Costs
- Volume II Analysis of Thermal Energy Production Costs.

All the comparative studies have been sponsored by DOE's Division of Solar Thermal Energy Systems, Office of Solar Industrial Applications.

SUMMARY

Under the sponsorship of the U.S. Department of Energy's Division of Solar Thermal Energy Systems, the Pacific Northwest Laboratory performed a comparative analysis of solar thermal conversion concepts that are potentially suitable for development as large electric power systems (50 to 200 MWe). Cogeneration and solar/fossil hybrid systems were beyond the scope of this study.

Seven generic types of collectors, together with associated subsystems for electric power generation, were considered. The collectors can be classified into three categories: 1) two-axis tracking (with compound-curvature reflecting surfaces), 2) one-axis tracking (with single-curvature reflecting surfaces), and 3) nontracking (with low-concentration reflecting surfaces). All seven collectors were analyzed in conceptual system configurations with Rankine-cycle engines. In addition, two of the collectors were analyzed with Brayton-cycle engines, and one was analyzed with a Stirling-cycle engine. With these engine options, and the consideration of both thermal and electrical storage for the Brayton-cycle central receiver, 11 systems were formulated for analysis.

Conceptual designs developed for the 11 systems were based on common assumptions of available technology in the 1990 to 2000 time frame. No attempt was made to perform a detailed optimization of each conceptual design. Rather, designs best suited for a comparative evaluation of the concepts were formulated. Costs were estimated on the basis of identical assumptions, ground rules, methodologies, and unit costs of materials and labor applied uniformly to all of the concepts.

The computer code SOLSTEP was used to analyze the thermodynamic performance characteristics and energy costs of the 11 concepts. Year-long simulations were performed using meteorological and insolation data for Barstow, California. Results for each concept include levelized energy costs and capacity factors for various combinations of storage capacity and collector field size.

Multiattribute utility methodology was used to rank the 11 concepts. The levelized energy cost (LEC) and capacity factor (CF) were calculated using SOLSTEP. The other plant characteristic (attribute) used in the ranking process, forced outage rate (FO), was determined individually for each of the concepts. To quantitatively establish the importance to decision makers of each attribute used in the ranking, 48 interviews were conducted with personnel from the Electric Power Research Institute and 24 utilities in the West and Southwest. Value indexes for the 11 concepts were calculated and used to rank the concepts and to determine statistically significant differences between concepts.

When conclusions were made based on a comparison of levelized energy cost only,

- at low capacity factors in which no storage is employed, four concepts (PFCR/R, PFCR/B, PFDR/B, and PFDR/S) had significantly lower costs while two concepts (LFDR-TR and LFCR) had significantly higher costs. The LCNT concept yielded prohibitively high energy costs.
- At higher capacity factors (0.4 to 0.7), one concept (PFCR/R) had a significantly lower cost while six concepts (LFDR-TR, PFCR/B-EES, LFCR, PFDR/S, LFDR-TC, and PFDR/B) had significantly higher costs. The LCNT concept again yielded prohibitively higher energy costs.
- At the lowest energy cost for each concept, regardless of capacity factor, one concept (PFCR/R) had a significantly lower cost, three concepts (LFDR-TR, LFDR-TC, and LFCR) had significantly higher costs, and one concept (LCNT) had a prohibitively higher energy cost.

When the eleven concepts were ranked on all three attributes (LEC, CF, FO) used together,

- for all power levels, the PFCR/R was ranked highest at optimal, minimum LEC, and 0.7 capacity factors. The FMDF and PFDR/R shared second and third places at these capacity factors. There was, however, no statistically significant difference among the PFCR/R, FMDF/R, and PFDR/R at these capacity factors.

- For all power levels, the LCNT was ranked lowest due to its extremely high levelized energy cost.

- For all power levels where no storage was available, the PFDR/S was ranked highest, with the PFDR/B ranked second highest.

Based on the findings of this study, four recommendations are offered:

1. The Point Focus Central Receiver/Rankine concept with molten salt as the transport and storage fluid should receive highest priority for commercial development as a large electric power plant.
2. The line focus systems (distributed and central receiver) should receive reduced priority for development as large electric power plants.
3. The LCNT should not be developed as a large electric power plant.
4. Predictions of performance for solar thermal concepts should be reported on the basis of a standard day, standard site (for example, Middletown, U.S.A.). Energy cost estimates should be based on annual performance.

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ASSESSMENT OF GENERIC SOLAR THERMAL SYSTEMS
FOR LARGE POWER APPLICATIONS

VOLUME I

ANALYSIS OF ELECTRIC POWER GENERATING
COSTS FOR SYSTEMS LARGER THAN 10 MWe

1.0 INTRODUCTION

Under the sponsorship of the U.S. Department of Energy's (DOE) Division of Solar Thermal Energy Systems, Office of Solar Industrial Applications, the Pacific Northwest Laboratory (PNL) performed a comparative analysis of solar thermal conversion concepts. The purpose of this study was to characterize, evaluate, and rank the principal solar thermal power concepts under consideration in the DOE Solar Thermal Power Program, based on an engineering and economic analysis of alternative power plant configurations. Task 1 involved the analysis of costs for generating electric power from concepts in configurations larger than 10 MWe. Task 2 will include the analysis of thermal energy costs from solar thermal concepts in configurations larger than 50 MWt. This first volume of the PNL report documents the work performed on Task 1.

1.1 STUDY PURPOSE

The primary purpose of this study is to provide DOE with an independent, objective assessment of the principal solar thermal conversion concepts that have the potential for achieving commercial success as large electric power systems (greater than 10 MWe). This evaluation was performed as a follow-on study to an assessment of 1- to 10-MWe solar thermal plants conducted previously for the U.S. Department of Energy (Laity et al. 1979). The results of this assessment will serve as guidance for DOE in making decisions on which concepts warrant priority attention for further technology development.

1.2 STUDY SCOPE

Seven generic types of collectors, together with associated subsystems for electric power generation, were considered in this study. The collectors can be classified into three categories: 1) two-axis tracking (with compound-curvature reflecting surfaces), 2) one-axis tracking (with single-curvature reflecting surfaces), and 3) nontracking (with low-concentration reflecting surfaces).

These collectors can be combined with various energy transport, energy storage, and power conversion subsystems to formulate conceptual systems for electric power generation. In this study, attention was restricted to configurations that are potentially suitable for development as large power systems in the long term (1990 to 2000), with initial commercialization by the mid-1980s. Cogeneration and solar/fossil hybrid systems were beyond the scope of this study.

All seven types of collectors were analyzed in conceptual system configurations with Rankine-cycle engines. Because they can operate at particularly high concentration ratios, two of the collectors were also analyzed with Brayton-cycle engines. In addition, one collector was analyzed with Stirling-cycle engines.

1.2.1 Principal Tasks

The four principal subtasks included in this study are as follows:

- Subtask 1 – Determination and Characterization of Concepts for Analysis:
The objectives of this subtask were to determine the solar thermal concepts that would be analyzed, and to acquire and evaluate the information available on each.
- Subtask 2 – Systems Analysis: Each of the alternative concepts selected in Subtask 1 was analyzed to determine the levelized energy cost required for operation at nominal power levels of 50, 100, and 200 MWe.

- Subtask 3 – Sensitivity Analysis: The effect on each of the alternative concepts of varying annual capacity factor was determined. In addition the effect of alternative cost assumptions was assessed.
- Subtask 4 – Concept Ranking: The concepts were ranked on the basis of attributes determined in the analyses performed as part of Subtasks 2 and 3, together with preference data for the attributes obtained from interviews with utility industry representatives. Multiattribute utility methodology was used to perform the ranking.

1.2.2 Limitations

Within the constraints imposed by the performance characteristics of the solar collector subsystems, the operating conditions (e.g., turbine inlet temperature) for alternative concepts that work on the same cycle (e.g., Rankine) were the same. This facilitated the identification of differences among concepts that could be attributed to the different collector subsystem designs. No attempt was made to perform a detailed optimization of each conceptual design. Rather, designs best suited for a comparative evaluation of the concepts were formulated.

2.0 CONCEPTS ANALYZED

The initial step in evaluating the alternative solar thermal power systems was to identify those concepts that best represented the advanced generic types currently being proposed. A similar process was used in the assessment of solar options for small power systems applications. Where possible, the concept configurations used in the assessment of solar options for small power systems applications were also used in the assessment of solar options for large power systems. The configurations selected for analysis can be classified on the basis of three major characteristics--tracking method, thermodynamic cycle, and energy storage method. Table 2.1 presents the seven generic collector systems and includes the nomenclature used to identify the individual concepts. Because the Brayton thermodynamic cycle with electric energy and thermal energy storage was considered for the Point Focus Central Receiver and the Brayton and Stirling cycles were also included for the Point Focus Distributed Receiver, 11 generic concepts were actually analyzed as part of the overall performance and economic evaluation.

In assessing solar options for application to 1- to 10-MWe power systems, several different configurations of each of the generic concepts were evaluated. The configurations resulting in the lowest energy cost were identified. These lowest-cost configurations are also used in the assessment of solar options for large power systems. The following sections describe those configurations that result in the lowest energy cost. One additional concept--a central receiver based on the design proposed by McDonnell Douglas for Barstow, California--was analyzed. The Barstow design analysis permitted comparison with the results of other studies and does not represent a generic concept.

2.1 TWO-AXIS TRACKING

Two-axis tracking concepts use concentrators and receivers that can be oriented individually or collectively to enable focusing the sun's image on a receiver. The capability to track the sun's diurnal motion in both azimuth and altitude allows for very high concentration ratios. The availability of high

TABLE 2.1. Concepts Selected for Analysis

<u>Concept</u>	<u>Energy Conversion Subsystem</u>	<u>Energy Storage Subsystem</u>	<u>Symbol</u>
<u>TWO-AXIS TRACKING</u>			
Point Focus Central Receiver	{ Rankine	Thermal	PFCR/R
	{ Brayton	Electric	PFCR/B-EES
	{ Brayton	Thermal	PFCR/B-TES
Point Focus Distributed Receiver	{ Rankine	Thermal	PFDR/R
	{ Brayton	Electric	PFDR/B
	{ Stirling	Electric	PFDR/S
Fixed Mirror Distributed Focus	Rankine	Thermal	FMDF
<u>ONE-AXIS TRACKING</u>			
Line Focus Central Receiver	Rankine	Thermal	LFDR
Line Focus Distributed Receiver			
• Tracking Collector	Rankine	Thermal	LFDR-TC
• Tracking Receiver	Rankine	Thermal	LFDR-TR
<u>NONTRACKING</u>			
Low-Concentration Nontracking	Rankine	Thermal	LCNT

concentration ratios means that higher system working fluid temperatures may be obtained, producing better Rankine-cycle efficiencies, and allowing the use of alternative thermodynamic cycles (Brayton and/or Stirling). Three two-axis tracking concepts were considered: the Point Focus Central Receiver, the Point Focus Distributed Receiver, and the Fixed Mirror Distributed Focus concept.

2.1.1 Point Focus Central Receiver (PFCR)

Point Focus Central Receiver concepts employ a large array of mirrors that track the sun in two axes, redirecting the incident radiation onto a receiver located on the top of a fixed tower. The general system is shown in Figure 2.1; however, it is important to note that the field shape can change

FIGURE 2.1. Point Focus Central Receiver Concept

dramatically when cavity receivers are considered. The same heliostat and support assembly were used for all PFCR cases. The selected design was very similar to both the Solaramics and McDonnell Douglas (MDAC) prototype heliostats shown in Figure 2.2, with a 49-m² aperture area. Each heliostat has an individual tracking mechanism and foundation.

Two thermodynamic cycles--Rankine and Brayton--were considered for the Point Focus Central Receiver. Both electric energy storage and sensible heat thermal energy storage were considered for the PFCR concept using a Brayton-cycle engine. These are described in the following subsections.

2.1.1.1 PFCR/Rankine Cycle

The Rankine-cycle PFCR used a four-sided cavity receiver with molten draw salt as both the heat transport and thermal storage fluid. The energy conversion subsystem used a heat exchanger/boiler assembly to produce steam for

FIGURE 2.2. Point Focus Central Receiver Heliostat

driving a conventional turbine. Full rated power was available at all times because the molten salt extracted from storage was at the same temperature (538°C) as that coming from the field. The storage subsystem used molten salt arranged to form a thermocline. The draw salt was contained in an insulated tank.

2.1.1.2 PFCR/Brayton Cycle (Electric Storage)

The Brayton-cycle PFCR (electric storage) employed a cavity receiver with air as the energy transport medium. Receiver exit temperature was maintained at 816°C (1500°F). The heated air was supplied to a gas turbine located immediately adjacent to the tower at ground level. Electric storage was provided by an advanced Redox battery subsystem. This subsystem consisted of anode and cathode electrolytic fluids separated by a sheet of membrane material. The fluid reactants were stored in tanks and pumped to the flow cells when needed.

2.1.1.3 PFCR/Brayton Cycle (Thermal Storage)

The Brayton-cycle PFCR (thermal storage) employed a cavity receiver with air as the energy transport medium. Receiver exit temperature was maintained at 816°C. The heated air was supplied either to the thermal energy storage or to the gas turbine located immediately adjacent to the tower at ground level. The thermal energy storage was provided by sensible heat storage in a medium consisting of 98% alumina with silicate binder. The medium was contained in steel pressure vessels.

2.1.2 Point Focus Distributed Receiver (PFDR)

The Point Focus Distributed Receiver concepts employ an array of parabolic dishes that track the sun in two axes, redirecting the incident radiation onto individual cavity-type receivers located at the focal point of each separate parabolic concentrator. A generic plant concept is shown in Figure 2.3. Rankine, Brayton, and Stirling cycles were evaluated. For the Rankine cycle, a transport fluid was circulated through the receivers and piped to a central power generating facility. The Brayton and Stirling concepts used an electric transmission system to transport the electric energy from the engines to a

FIGURE 2.3. Point Focus Distributed Receiver Concept (Jet Propulsion Laboratory)

central storage facility. The same parabolic concentrator (100-m^2 aperture area) and support assembly were used for all Point Focus Distributed Receiver cases. However, some reinforcement was necessary for concepts with an engine as well as receiver mounted at the focal point.

2.1.2.1 PFDR/Rankine Cycle

The Rankine-cycle PFDR used molten draw salt as both the heat transport and thermal storage fluid. The heated molten salt was piped to a central energy conversion facility where a heat exchanger/boiler assembly was used to produce steam to drive a conventional turbine. Full rated power was available at all times because the molten salt extracted from storage was at the same temperature (454°C) as that coming from the field. The use of molten draw salt at this temperature eliminated the need for stainless steel piping. This resulted in a substantial cost saving in the large piping system required for the PFDR/Rankine-cycle concept. The storage subsystem used molten salt, arranged to form a thermocline. The molten salt was contained in an insulated tank.

2.1.2.2 PFDR/Brayton Cycle

The Brayton-cycle PFDR used a small closed-cycle turbine with 816°C air as the working fluid. An optimal turbine size of 20.0 kWe was determined. The electricity generated at the collector was transported by the electric energy transport subsystem to a central power conditioning station and then to the demand grid. Electricity generated above demand levels was then used to charge a central Redox electrochemical storage device.

2.1.2.3 PFDR/Stirling Cycle

The Stirling-cycle PFDR consisted of a 22.5-kWe free-piston engine coupled to a linear alternator. A liquid metal receiver was used to produce a hot-end external temperature of 816°C .

The electricity generated at the collector was transported by the electric energy transport system to a central power conditioning station and then to the demand grid. Electricity generated above demand levels was used to charge a central Redox electrochemical storage device, identical in all respects to the Redox battery used in the Brayton-cycle PFDR.

2.1.3 Fixed Mirror Distributed Focus (FMDF)

The Fixed Mirror Distributed Focus concept is a large bowl-like structure consisting of individual mirror panels attached to a criss-cross concrete frame. The entire bowl is canted 15° to the south. A boom/crane assembly maintains the tube-wound, cylindrical receiver within the moving focal region of the bowl during all daylight hours. Each bowl is 200 ft in diameter. The plant includes a number of distributed bowls as shown in Figure 2.4. The energy is extracted from receivers and piped to a central electric generating facility.

The Rankine-cycle FMDF used molten draw salt as both the heat transport and thermal storage fluid. Brayton and Stirling cycles were not analyzed due to large receiver thermal losses at the high temperatures that would be required by the power conversion cycle. The heated molten salt was piped to a central energy conversion facility where a heat exchanger/boiler assembly was used to produce steam for driving a conventional turbine. Because the molten salt extracted from storage was at the same temperature (454°C) as the salt coming from the field, full rated power was available at all times. The use of molten draw salt at this temperature eliminated the requirement for stainless steel piping. Consequently, considering the large piping system necessary for the FMDF/Rankine-cycle concept, a considerable cost saving was possible. The storage subsystem used molten salt, arranged to form a thermocline, contained in an insulated tank.

2.2 ONE-AXIS TRACKING

One-axis tracking concepts use linear concentrators that can rotate around one axis to track the sun's diurnal motion. In general, one-axis tracking does not achieve the very high concentration ratios available with the two-axis tracking concepts. However, one-axis tracking requires a less complicated and potentially less expensive collector. Three one-axis tracking concepts were considered: the Line Focus Central Receiver concept, the Line Focus Distributed Receiver with a Tracking Receiver, and the Line Focus Distributed Receiver with a Tracking Collector.

FIGURE 2.4. Fixed Mirror Distributed Focus Concept

2.2.1 Line Focus Central Receiver (LFCR)

The Line Focus Central Receiver concept (Figure 2.5) uses an array of rectangular single-axis heliostats to focus incident solar radiation onto an elevated line central receiver. The heliostats are arranged in a concentrator field on the north side of the receiver. The heliostats, which have adjustable focal lengths, track the sun automatically and concentrate the insolation on the receiver.

The cavity-type line receiver is mounted on towers, with sufficient length to absorb the energy collected in the heliostat field. Molten draw salt is supplied to the receiver sections by the transport subsystem piping network, then returned at 454°C to the central generation facility. By restricting the maximum molten salt temperature, it was possible to use carbon steel rather than more expensive stainless steel piping. This proved cost-effective for the extensive LFCR transport and storage piping subsystems. At the central generation facility, a heat exchanger/boiler assembly was used to produce steam for driving a conventional Rankine-cycle turbine. Full rated power was available at all times, because the molten salt extracted from storage was at the same temperature as that coming from the field. The storage subsystem used molten salt, arranged to form a thermocline, contained in an insulated tank.

2.2.2 Line Focus Distributed Receiver – Tracking Collector (LFDR-TC)

The Line Focus Distributed Receiver – Tracking Collector concept uses a collector segment consisting of a single-curvature concentrator that focuses solar insolation on a fixed linear receiver. The collector is rotated around one axis to track the sun's diurnal motion. The concentrator is a parabolic trough; the receiver consists of a glass-enclosed, selectively coated receiver tube as shown in Figure 2.6.

The collector segments are placed in standard modules arranged to form the collector field. Energy is transported from the collector field by a heat transfer oil, Caloria HT43®. The transport subsystem consists of the piping,

®Trademark of the Exxon Co., Houston, Texas.

FIGURE 2.5. Line Focus Central Receiver Concept

FIGURE 2.6. Line Focus Distributed Receiver - Tracking Collector Concept

pumps, and accessories necessary to transport the oil to the collector field, then return the heated oil to the central energy conversion facility. The returning oil temperature is 304°C (580°F).

Energy collected in the field can be either stored in the thermal storage subsystem or immediately used in the energy conversion subsystem. The thermal storage subsystem uses a mixed-media oil and rock thermocline storage.

The energy conversion subsystem is a steam Rankine cycle; steam is generated in a heat exchanger/steam generator assembly that uses the hot oil as a heat source. The hot oil can be supplied either directly from the field or from storage. Because the oil extracted from storage is at the same temperature as that coming from the field, there is no reduction in performance efficiency or power output when operating from storage.

2.2.3 Line Focus Distributed Receiver – Tracking Receiver (LFDR–TR)

The Line Focus Distributed Receiver – Tracking Receiver concept uses a fixed mirror concentrator that produces a sharp line focus regardless of the sun's position (see Figure 2.7). The receiver is moved in a circular arc to track the focal line. The segmented concentrator is a concave array of long, narrow, flat mirror facets fixed to a concrete support. The movable receiver consists of a selectively coated enclosed receiver tube with a compound parabolic secondary concentrator.

Molten draw salt is supplied to the receiver sections by the transport subsystem piping network, then returned at 454°C to the central generation facility. By restricting the maximum molten salt temperature, it was possible to use carbon steel rather than more expensive stainless steel piping. This proved cost-effective for the extensive LFDR–TR transport and storage piping subsystems. At the central generation facility, a heat exchanger/boiler assembly was used to produce steam to drive a conventional Rankine-cycle turbine. Full rated power was available at all times, because the molten salt extracted from storage was at the same temperature as that coming from the field. The storage subsystem used molten salt, arranged to form a thermocline, contained in an insulated tank.

FIGURE 2.7. Line Focus Distributed Receiver - Tracking Receiver Concept

2.3 NONTRACKING CONCEPT (LCNT)

Nontracking systems, such as flat plate collectors, are capable of producing maximum operating temperatures $\sim 93^{\circ}\text{C}$ (200°F) greater than ambient. Because higher temperatures are required to enable more efficient electric power production, some form of concentrating mirror must be included as part of a stationary collector. While several different nontracking configurations have been proposed, the compound parabolic concentrator (CPC) collector with a Rankine energy conversion subsystem appears to provide the highest operating temperature with the smallest number of seasonal axial tilt changes.

The CPC collector uses a compound parabolic concentrator to redirect incident solar radiation onto a selectively coated tubular vacuum receiver. The CPC is a nonimaging concentrator, allowing a more precise concentration than do conventional mirrors. However, there is also a corresponding tradeoff between achievable concentration ratio and number of tilt adjustments required per year. The system used in this study is a truncated 7.2x CPC with an effective net concentration of 5.25, requiring only 12 tilt adjustments per year. Because of significant increases in thermal losses at higher operating temperatures, the CPC collector heat transfer fluid was constrained to an exit temperature of 232°C (450°F).

As shown in Figure 2.8, the CPC segments are placed in standard modules arranged to form the collector field. Energy is transported from the collector field by Caloria HT43 heat transfer oil. The transport subsystem consists of the piping, pumps, and accessories necessary to transport the oil to the collector field and then return the heated oil to the central energy conversion facility.

Energy collected in the field can be either stored in the thermal storage subsystem or immediately used in the energy conversion subsystem. The thermal storage subsystem uses a mixed-media oil and rock thermocline storage. Because the same oil is used for the transport and storage subsystems, heat exchangers are not required for charging storage.

The energy conversion subsystem is a steam Rankine cycle in which steam is generated in a heat exchanger/boiler assembly that uses the hot oil as a

FIGURE 2.8. Nontracking Compound Parabolic Concentrator

heat source. The hot oil can be supplied either directly from the field or from storage. Because the oil extracted from storage is at the same temperature as that coming from the field, there is no reduction in performance efficiency or power output when operating from storage.

2.4 BARSTOW PLANT (PFCR/R-B)

One additional concept was considered. A Point Focus Central Receiver/Rankine cycle configuration similar to that proposed by McDonnell Douglas for Barstow was analyzed. This concept was included because many other studies have included performance and economic evaluations of the Barstow design. The analysis of the Barstow design would provide a convenient method of comparing the results of this study with those of other studies.

The Barstow Rankine-cycle PFCR uses an open receiver with water/steam as the heat transport fluid. The energy conversion subsystem uses steam directly from the receiver to drive a conventional turbine. The storage subsystem uses a combination of oil and rock arranged to form a thermocline. The oil and rock is contained in an insulated tank. Steam from the receiver is used to charge storage by means of oil/steam heat exchangers. Energy is extracted from storage by generating steam in a heat exchanger/boiler assembly. Because the maximum operating temperature of the oil is 310°C (590°F), the steam generated during discharge is limited to a temperature of 282°C (540°F). The reduced steam temperature causes a reduction in turbine output so that the plant can produce approximately 70% of its rated output when operating from storage.

The Barstow design is one configuration of the PFCR/R concept; therefore, it is not a generic concept. The analysis of the Barstow design was limited to the 100-MWe, 6-hr size because this was the configuration considered in other studies.

2.5 SUMMARY OF CONCEPTS

A summary of the concepts evaluated and their primary operating parameters appears in Table 2.2.

TABLE 2.2. Summary of Concept Characteristics

Concept	Concentrator	Receiver	Transport Subsystem	Storage Subsystem	Heat Engine	Heat Rejection
PFCR/R	49 m ² Heliostat	Cavity	1000°F draw salt	1000°F draw salt	950°F steam turbine	Dry cooling tower
PFCR/B-EES	49 m ² Heliostat	Cavity	Electric	Redox battery	1500°F closed cycle	Dry cooling tower
PFCR/B-TES	49 m ² Heliostat	Cavity	1500°F air	1500°F ceramic brick	1500°F closed cycle	Dry cooling Tower
PFDR/R	11 m Paraboloidal Dish	Cavity	850°F draw salt	850°F draw salt	800°F steam turbine	Dry cooling tower
PFDR/S	11 m Paraboloidal Dish	Cavity	Electric	Redox battery	1500°F free piston	Air heat exchanger
PFDR/B	11 m Paraboloidal Dish	Cavity	Electric	Redox battery	1500°F closed cycle	Air heat exchanger
FMDf	61 m Hemispherical Bowl	Open	850°F draw salt	850°F draw salt	800°F steam turbine	Dry cooling tower
LFDR	Linear Heliostat	Open	850°F draw salt	850°F draw salt	800°F steam turbine	Dry cooling tower
LFDR-TC	Parabolic Trough		580°F oil	580°F oil and rock	540°F steam turbine	Dry cooling tower
LFDR-TR	Segmented Trough		850°F draw salt	850°F draw salt	800°F steam turbine	Dry cooling tower
LCNT	5.25x Compound Parabolic Concentrator		450°F oil	450°F oil and rock	420°F steam turbine	Dry cooling tower
PFCR/R-B	49 m ² Heliostat	Open	1000°F steam	590°F oil and rock	950/540°F steam turbine	Dry cooling tower

Nomenclature: PFCR/R – Point Focus Central Receiver/Rankine Cycle

PFCR/B-EES – Point Focus Central Receiver/Brayton Cycle – Electric Energy Storage

PFCR/B-TES – Point Focus Central Receiver/Brayton Cycle – Thermal Energy Storage

PFDR/R – Point Focus Distributed Receiver/Rankine Cycle

PFDR/S – Point Focus Distributed Receiver/Stirling Cycle

PFDR/B – Point Focus Distributed Receiver/Brayton Cycle

FMDf – Fixed Mirror Distributed Focus

LFDR – Line Focus Central Receiver

LFDR-TC – Line Focus Distributed Receiver – Tracking Collector

LFDR-TR – Line Focus Distributed Receiver – Tracking Receiver

LCNT – Low Concentration Nontracking

PFCR/R-B – Point Focus Central Receiver/Rankine Cycle – Barstow

3.0 FORMULATION OF CONCEPTS FOR ANALYSIS

It was necessary to formulate conceptual designs for each of the 11 generic concepts to serve as a basis for estimating system performance and cost. This section describes the approach and results of this formulation.

3.1 DESIGN AND PERFORMANCE CONSTRAINTS

Five major engineering ground rules were established at the outset of this study. They were selected to ensure that the results of the study were comparable to those determined by PNL for small solar thermal electric systems in the 1- to 10-MWe range (Laity et al. 1979).

First, three plant sizes would be investigated: 50, 100 and 200 MWe. The 50-MWe plant size was selected as a logical next step up from the 10-MWe plant analyzed in the small power systems study. The 200-MWe size was selected as an upper limit because it was felt that any diseconomies of scale that might appear in larger plants would become apparent at this power level.

Second, the energy output from each plant would be characterized in terms of a plant capacity factor, defined as

$$CF = \frac{\text{Total net energy generated in a year (kWh)}}{\text{Rated capacity (kW) x number of hours in a year}}$$

For this study the capacity factor does not include unscheduled outages or scheduled maintenance outages. That is, the total net energy produced assumes that the plant can operate whenever insolation is available. The effect of plant availability is considered in a separate attribute, which is discussed in Section 6.1.2. For each generic concept, the plant's performance was analyzed over a range of capacity factors. Results will be presented at capacity factors of 0.4 and 0.7, as well as for the capacity factors corresponding to the optimal plant configuration with no storage capacity and the overall least-cost plant configuration.

Third, the plants were designed in strictly solar electric configurations. Solar/fossil hybrid operation and electricity/process heat cogeneration were not considered.

Fourth, the plants were assumed to be connected to a utility grid. The grid was assumed to be large enough to take all available plant output up to the nominal plant rating. This ground rule eliminated the need for the plants to match daily or seasonal load variations.

Finally, the plants' performance would be estimated using insolation and meteorological data from Barstow, California. These data were collected by WEST Associates in 1976 and provided to PNL by the Jet Propulsion Laboratory.

In addition to the five major ground rules, PNL imposed several constraints on the formulation of conceptual designs. These constraints served to ensure that the concepts were evaluated on equal technological bases and to make the engineering analysis tractable.

Descriptions of the collector components (concentrator and receiver) were based on designs currently proposed for each generic concept. Selection of specific aspects of any single design was based on the extent to which the design represented the generic concept and the amount of design information that was available. In all cases, designs for particular concepts were uniformly modified to reflect structures, optical coatings, selective surfaces, and other features that could be expected by the 1990 to 2000 time frame.

Common subsystems and components were used as much as possible with all of the generic concepts. Several subsystems--for example, energy storage subsystems or Rankine heat engine units--could be used by more than one concept. In these cases a common design was developed for the subsystem and used with all concepts for which it was appropriate.

The final constraint was an attempt to minimize extensive suboptimization of design parameters for specific subsystems. Previous studies were relied upon to establish appropriate values for operating parameters such as pressure, temperature, and collector field layout features. Exceptions to this constraint, as required, are noted in the descriptions of the various plant components that appear in the rest of this section.

3.2 COLLECTOR SUBSYSTEM

The collector subsystem, which consists of the concentrator and receiver, is the basic building block of the solar thermal system. To accurately model the transient ambient conditions affecting overall plant performance, it is necessary to characterize collector performance to an appropriate level of detail. The optical performance of the concentrator and thermal performance of the receiver need to be accurately determined for both the steady-state and transient case. The models and analysis used to determine the collector performance are described in more detail in Laity et al. (1980a).

3.2.1 Concentrator Optics

For every generic concept the optics must be determined for different field arrangements, ground cover ratios, tower heights, N-S and E-W mirror separation distances, and tilt angles. The particular configuration can then be costed and simulation runs conducted until optimal performance and cost numbers are obtained. Economics and optical performance are not independent quantities; although the optical performance directly determines the system cost, the cost of individual subsystems and services will also determine the positioning, cleaning frequency, potential tracking accuracy, and, therefore, the overall optical efficiency. Because the economic and performance simulation was conducted based on data for 1976 at Barstow, California, collector optics calculations were required at that location for all expected altitude and azimuth angles.

3.2.1.1 Point Focus Central Receiver

Concentrator optical performance for small and medium-size Point Focus Central Receiver systems was calculated with the assistance of a team at the Solar Energy Laboratory, University of Houston, under the direction of Dr. Lorin Vant-Hull. Using component performance and cost data provided by PNL, concentrator optical performance for optimally configured heliostat fields and tower heights was determined. Where appropriate, optical efficiency values were scaled to larger plant field sizes when comparable studies were available. Sandia Laboratories-Livermore provided field layout and optical performance data for large central receiver plants, determined using the MIRVAL computer code (Leary and Hankins 1979). Where a Barstow-type central receiver plant was

considered, information available from McDonnell Douglas (Hallet and Gervais 1977), Martin Marietta (Blake et al. 1977), and Honeywell (Powell et al. 1977) was used for comparison.

3.2.1.2 Point Focus Distributed Receiver

Concentrator optical performance for the Point Focus Distributed Receiver systems was determined using a PNL-developed computer code SHADE (Apley 1979). The same optical efficiencies were not obtained for all Point Focus Distributed Receiver concepts. Parabolic concentrators employing small Brayton or Stirling heat engines at the focal point are interconnected by electrical wiring, while the Rankine concept, which heats the working fluid at the receiver and then transports the fluid to a central electric generating facility, uses an extensive network of piping. Because piping is more expensive than wiring, Brayton and Stirling heat engine concentrators can be located farther apart for the same cost. The farther apart the individual concentrators, the higher the optical efficiency.

3.2.1.3 Fixed Mirror Distributed Focus

Concentrator optical performance for the Fixed Mirror Distributed Focus concept was obtained from the major proponents of the Crosbyton Project (Texas Tech University and E-Systems, Inc.). Two methods were used to validate the predictions made by the concept proponents:

- An independent assessment of a stationary reflector with a tracking absorber (Clausing 1976) was compared to the information obtained from Texas Tech University and E-Systems, Inc.
- PNL staff evaluated the optical performance models used by Texas Tech University and E-Systems, Inc.

3.2.1.4 Line Focus Central Receiver

Concentrator optical performance for the Line Focus Central Receiver concept was determined using a PNL-developed computer program. The PNL calculations for similar field sizes examined by FMC Corporation provided results that were comparable to data generated by the FMC Line Focus Central Receiver Code (Laity et al. 1980a).

3.2.1.5 Line Focus Distributed Receiver - Tracking Collector

Concentrator optical performance for the Line Focus Distributed Receiver - Tracking Collector concept was determined using a PNL-developed computer program. North-south, east-west, and polar axis orientations were analyzed. The N-S system provided for the most economic energy absorption within the constraints of this study. This conclusion was supported by similar analyses by Honeywell and Black & Veatch (Powell et al. 1977, p. 67). A parabolic trough design closely resembling the Hexcel Solar Collector was chosen because that collector was the most efficient yet tested at the Sandia Collector Module Test Facility, effective March 1978 (Dudley and Workhoven 1978, p. 21). Calculations by the PNL code were compared with theoretical determinations by JPL (Caputo 1975) and Black & Veatch (1977), as well as with the experimental results obtained at the Sandia Test Facility.

3.2.1.6 Line Focus Distributed Receiver - Tracking Receiver

Concentrator optical performance for the Line Focus Distributed Receiver - Tracking Receiver concept was determined using a PNL-developed computer program. The Fixed Mirror Solar Concentrator (FMSC) design proposed by General Atomic was used for this study. The PNL code calculations were compared with theoretical determinations by General Atomic (Russell et al. 1976; Schuster et al. 1979), calculations conducted using the General Atomic analytical code SUNPOW, and experimental performance testing at the Midtemperature Solar Systems Test Facility (Workhoven and Dudley 1978).

3.2.1.7 Low Concentration Nontracking

Optical performance for the Low Concentration Nontracking concept was determined using a PNL-developed computer program. A 5.25x compound parabolic concentrator (CPC) similar to designs proposed by the University of Chicago, Argonne National Laboratory, and Arthur D. Little was evaluated as the base system (Cole, Schertz, and Teagan, 1977a; Collares-Pereira et al. 1978). Calculations by the PNL code were compared with theoretical determinations by Argonne National Laboratory and Arthur D. Little and, with modifications, were similar to experimental results obtained by Argonne National Laboratory for a 1.5x concentrator (Cole, Schertz, and Teagan 1977b, p. 11; Laity et al. 1980a).

3.2.2 Receiver Performance

The thermal efficiency of the receivers used for the generic systems has a major effect on the overall system performance. Thermal losses are strongly dependent on the working fluid temperature, and only secondarily affected by power level. Therefore, for a particular system configuration, the thermal loss is more a fixed quantity than a fixed percentage. This means that thermal losses have a much larger percentage impact during early morning or late afternoon operation when total incident energy is less.

As with the concentrator subsystems, every attempt was made to use actual heat loss data or to compare PNL-determined thermal losses with other calculated or experimentally derived information. In addition, similar assumptions regarding available receiver material absorptivities, emissivities, and heat transfer coefficients were made. If special selective absorbers were considered for some receiver designs, they were considered for all applicable designs. To better match actual operating conditions, the receiver losses (convection, radiation, and conduction) were included in the simulation code as functions of ambient temperature and wind speed. Also, because thermal losses are not linearly proportional to system operating temperature, calculated thermal loss values were determined by integrating losses along the receiver length, not by selecting some arbitrary average temperature or evaluation point.

3.2.3 Annualized Efficiency

The performance of collector systems is often quantified in terms of a single number: the peak or design point collector efficiency. This number can be misleading, as many collectors perform well at the design point, but have greatly reduced off-design performance. It is also possible to determine an annual average collector performance value that includes the effects of off-design performance. This number is defined as the total energy delivered to the receiver working fluid divided by the total available insolation in a year. The annual average collector efficiency more accurately reflects the performance that could be expected in an actual energy system. PNL estimates of both peak and annual average collector efficiency for each of the concepts appear in Figure 3.1.

FIGURE 3.1. Annualized Collector Efficiency for 100-MWe Plants with 0.4 Capacity Factor

The peak and annual average efficiencies point out some interesting characteristics of the collectors. Two-axis tracking systems (point focus central receiver and point focus distributed receiver) exhibit the highest annual average performance because of their ability to completely track the sun's motion. The point focus distributed receiver has the best performance of all because it eliminates any cosine losses. Line focus systems have the potential for high design point efficiencies, but suffer in annual average performance because of one-axis tracking.

The information in Figure 3.1 must be used with caution. No single number or small group of numbers can be used to adequately characterize collector performance. The PNL analysis employed a detailed specification of collector performance (see Section 5.1) and a time-step performance simulation (in contrast to average performance values and efficiency trains). The peak and annual average efficiency values in Figure 3.1 are not inputs to the analysis, but results calculated in the performance simulation. They are provided only for relative, qualitative comparisons.

3.3 TRANSPORT SUBSYSTEM

The transport subsystem includes the equipment necessary to transport energy from a distributed source to a central location. Concepts that generate thermal energy in distributed receivers use a thermal transport subsystem. Concepts that generate electric energy at distributed receivers use an electric transport subsystem. Three thermal transport subsystems were considered: molten salt, oil, and hot air. An electric energy transport subsystem was considered for application with the PFDR/S and PFDR/B concepts.

3.3.1 Molten Salt Transport Subsystem

Molten salts such as HITEC or draw salt have been widely used and their properties are well defined. Molten salts have the advantage of being able to operate at high temperatures without decomposition or high vapor pressure. In addition, a molten salt transport subsystem can be combined with a molten salt storage subsystem, eliminating the need for heat exchangers to charge storage as well as the resulting temperature drop. Molten salts have several disadvantages. They freeze at temperatures above ambient, are expensive, and are incompatible with carbon steel at elevated temperatures. Draw salt was used for the molten salt in this study. Draw salt is considered to be compatible with carbon steel up to 454°C (850°F). Draw salt can be used at temperatures up to 538°C (1000°F), but stainless steel piping would be required.

Two types of molten salt transport subsystems were considered. A high-temperature system (538°C) was used with the PFCR/R concept because an extensive piping system was not required so the use of stainless steel pipe could

be economically justified. An intermediate-temperature (454°C) system was used for all distributed concepts, eliminating the need for stainless steel piping.

The transport subsystem supplies cold molten salt to the collector field and returns hot molten salt to the central generating complex. All distributed concepts have collectors arranged in modules; hence, the transport subsystem is divided into module supply, module return, and module internal piping. Molten salt does not experience a phase change so once-through heating can be used with confidence. Isolation valves are included on individual collectors and modules to allow for collector maintenance. Expansion loops and flexible couplings are included to permit thermal expansion.

The transport subsystem includes a feed pump with sufficient head to overcome the pressure drop in the transport system and the receivers. A carbon steel, motor-driven centrifugal pump with a pump efficiency of 75% was used. The central receiver transport subsystem includes a draw salt head recovery turbine to recover the work required to pump draw salt from ground level to the receiver.

Molten salts have a melting point substantially above ambient temperature so provisions for preventing freezing are included. A drain tank and a purge system are included in the design to permit draining of the system during periods of no insolation or plant outage. A heated mixing tank with a solid draw salt storage facility is included to allow for adding makeup draw salt and for initially charging the system.

The piping system was sized using standard methodology. All piping was assumed to be of Schedule 40 carbon steel with appropriate flanges and fittings. All valves were specified as #600 class carbon steel gate valves. Insulation was specified as calcium silicate with appropriate lagging. Insulation thickness was based on optimal insulation thickness given in Perry, Chilton, and Kirkpatrick (1963).

3.3.2 Heat Transfer Oil Transport Subsystem

The oil transport subsystem uses current technology with a relatively inexpensive heat transfer fluid, which exhibits good thermal properties. The

primary disadvantage of using heat transfer oil as a working fluid is that it decomposes at high temperatures. Above 304°C (580°F) the decomposition rate is intolerably high. This limits the oil transport subsystem to lower temperature applications. The only concepts with sufficiently low maximum operating temperatures are the LCNT (CPC), operating at 232°C (450°F), and the LFDR-TC, which operates at 304°C (580°F).

In all distributed receiver concepts, the collectors are arranged in standard modules and the modules are arranged to form the collector field. The transport subsystem must supply low-temperature oil to the modules, distribute it through the module internal piping, and return it to the central generating facility. The subsystem consists of three components: module access piping, module distribution piping, and the feed pump.

The heat transfer oil does not experience a phase change, so once-through heating can be used with confidence. In addition, the same fluid is used as the working fluid in both the transport and storage subsystems. Therefore, oil can be supplied directly from, and returned directly to, storage, eliminating a storage charging heat exchanger loop. Isolation valves are included where appropriate to allow for collector maintenance. Expansion loops and flexible couplings are included to permit thermal expansion.

The transport subsystem includes a feed pump with sufficient head to overcome the pressure drop in the transport system and the receivers. A carbon steel motor-driven centrifugal pump with a pump efficiency of 75% was used.

The piping system was sized using standard methodology. All piping was assumed to be of Schedule 40 carbon steel with appropriate flanges and fittings. All valves were specified as #600 class carbon steel gate valves. Insulation was specified as calcium silicate with appropriate lagging. Insulation thickness was based on optimal insulation thickness given in Perry, Chilton and Kirkpatrick (1963).

3.3.3 Hot Air Transport Subsystem

The hot air transport subsystem is used with the PFCR/B concepts to transport 815°C (1500°F) air from the receiver to ground level. The transport subsystem is not extensive and consists of the piping to and from the receiver.

Appropriate valves, expansion loops, and flexible couplings are included. The piping is internally insulated with an Inconel liner. Compressors are not included in the transport subsystem because they are an integral part of either the storage or heat engine.

3.3.4 Electric Transport Subsystem

The energy storage subsystem is located after the energy conversion subsystem in the PFDR/S, PFDR/B, and PFCR/B concepts. The PFDR/S and PFDR/B are distributed generation concepts that use a field of collectors, each with a small heat engine. These concepts require a transport subsystem that collects the electric energy from the field and transports it to either the energy storage subsystem or the utility grid. The PFCR/B consists of one Brayton-cycle engine located at the base of the tower. The transport subsystem for the PFCR/B includes the piping necessary to transfer energy to the engine at the tower's base.

In both the PFDR/B and PFDR/S concepts, the collectors are arranged in standard modules, which are in turn arranged in supermodules; the supermodules are arranged to form the collector field. The transport subsystem collects the electric energy generated at the collectors, increases the voltage to levels suitable for the utility grid, and supplies the energy to the storage subsystem or the utility grid. The heat engine generators are either small ac induction generators or small linear alternators. Because the output of the linear alternator is single-phase, one-third of the machines would have to be placed on each phase of the three-phase utility system. In both cases the transport subsystem is ac; this requires that the energy storage subsystem have a rectifier/inverter for converting the ac power to dc power used for battery storage.

The standard module has seventy-eight generators in parallel, each at 440 v. A 440-v bus is located in each module. The bus receives the input from the generators and feeds it to a step-up transformer, which provides 13.8 kv power. Sixty-four modules are combined to form one supermodule. At the supermodule substation a step-up transformer converts the 13.8-kv power to 110-kv power for export. Each supermodule includes its own batteries and rectifiers/inverters for energy storage.

3.4 POWER CONVERSION SUBSYSTEM

Two approaches to the energy conversion subsystems were considered: distributed generation and central generation. In the distributed generation concepts, the energy conversion subsystem is located at the collector and a large number of small heat engines is required. The central generation approach has only one heat engine, and the energy collected in the collector field is transported to the heat engine in the energy transport subsystem. Stirling-cycle engines and small Brayton-cycle engines were considered for distributed generation. Rankine-cycle heat engines and large Brayton-cycle engines were considered for central generation.

3.4.1 Stirling-Cycle Energy Conversion Subsystem

The Stirling-cycle energy conversion subsystem has four major components: the receiver, the engine, the generator, and the heat rejection subsystem. The engine location has been discussed in other studies; an engine located at the focus of the concentrator has been determined as the optimal arrangement. This arrangement requires that the receiver, engine, and generator be located at the focus of the concentrator, with the heat rejection unit located on the ground adjacent to the collector.

The receiver is an integral part of the engine design. Therefore, the receiver's heat transfer components were considered as part of the energy conversion subsystem. Liquid metal transfers thermal energy from the receiver directly to the Stirling engine heater tubes.

The Stirling engine receives heat from the receiver in the Stirling engine heater tubes and rejects heat to oil, which acts as a heat sink. The oil is cooled in the heat rejection unit. The Stirling engine converts heat to work in the form of a reciprocating shaft, which transmits work to the generator, where the work is converted to electric energy. The Stirling engine receives thermal energy at 816°C (1500°F) and ultimately rejects heat to ambient conditions.

The characteristics of the Stirling engine used in this study are based on a review of current Stirling engine technology and are representative of the MTI free-piston engine. The Stirling engine will have a free piston, coupled

directly to a linear alternator. Free-piston machines with linear alternators were chosen over kinematic Stirling engine designs because of the potential for increasing engine life. A parametric analysis was conducted using engine size as a variable. The optimal engine size was determined to be 22.5 kWe.

The Stirling engine will have a heater tube external temperature of 816°C (1500°F) and will reject heat to cooling oil at a nominal temperature of 30°C (86°F). Other auxiliaries include the cooling oil pump and controls. In addition, the Stirling engine and generator must provide electric power to operate the heat rejection unit.

The Stirling engine nominal efficiency is estimated to be 36%. This includes the Stirling engine efficiency of 41.8%, linear alternator efficiency of 90%, and parasitic losses of 5%. The actual Stirling engine efficiency is affected by ambient temperature and part-load operation.

3.4.2 Small Brayton-Cycle Energy Conversion Subsystem

The Brayton-cycle energy conversion subsystem consists of four major components: the receiver, the engine, the generator, and the heat rejection subsystem. The receiver, engine, and generator are located at the focus of the concentrator. The heat rejection unit will be located on the ground adjacent to the collector.

The receiver is an integral part of the Brayton engine. Therefore, the heat transfer components of the receiver were considered as part of the energy conversion subsystem. The receiver uses liquid metal heat pipes to transfer thermal energy from the receiver directly to the Brayton engine heater.

The Brayton engine receives heat at 816°C (1500°F) in the heater and rejects heat to oil, which acts as the heat sink. The oil is cooled in the heat rejection unit. The Brayton engine converts heat to work in the form of a rotating shaft. Work is transmitted to the generator, where it is converted to electric energy. The Brayton engine receives thermal energy at 816°C (1500°F) and ultimately rejects heat to the atmosphere.

The Brayton-cycle engine used in this study is a closed-cycle engine with a recuperator. As with the Stirling engine, a parametric analysis was

conducted using engine size as a variable. The engine is rated at 20-kWe output and will use air as the cycle working fluid. The Brayton engine will drive an induction generator. Appropriate excitation must be included to render the generators operable at all loads and to ensure power output quality comparable to that of other types of generators. A condenser will be used to provide appropriate excitation. A nominal efficiency of 0.32 was used for the small Brayton cycle.

3.4.3 Rankine-Cycle Energy Conversion Subsystem

The Rankine-cycle energy conversion subsystem consists of four components: the Rankine-cycle heat engine, the generator, the heat rejection subsystem, and the steam generator.

Rankine-cycle energy conversion subsystems were characterized for plants with net outputs of 50, 100, and 200 MWe. In sizing the Rankine-cycle engine, parasitic loads were included.

The Rankine-cycle heat engine is a conventional steam power cycle, based on performance and cost information provided by vendors. Accessories include feedwater heater, feedwater booster pump, feedwater pump lubrication system, steam seal system, and controls.

The generator is a three-phase, four-pole synchronous unit driven by the turbine. The generator is assumed to be air-cooled and equipped with a brushless exciter.

Waste heat from the Rankine cycle is rejected to atmosphere in an ammonia dry cooling system. Exhaust steam from the turbine is condensed in an ammonia condenser/reboiler. As the steam condenses, heat is transferred to the ammonia, which is vaporized. The vapor ammonia is piped to an air-cooled heat exchanger, where the ammonia is condensed and returned to the plant. The ammonia dry cooling system was designed and costed using computer codes developed at PNL.

Five cycles were considered. Table 3.1 presents cycle inlet conditions and assumed net cycle efficiency at the design back pressure of 3.5 in. Hg. The low-temperature cycle could potentially use an organic working fluid such as toluene, but the small power systems study showed that at 216°C (420°F) the

TABLE 3.1. Alternative Rankine-Cycle Characteristics

Cycle	Inlet Conditions		Main Steam Pressure (MPa)	Net Cycle Efficiency (%)			Applicable Concept
	Main Steam Temperature (°C)	Reheat Steam Temperature (°C)		50 MWe	100 MWe	200 MWe	
1	510	510	12.75	38.2	38.5	39.1	PFCR/R
2	427	427	10.00	35.8	36.0	36.0	PFDR/R, FMDF, LFCR, LFDR-TR
3	274	274	2.41	26.7	26.9	27.1	LFDR-TC
4	216	216	0.69	20.9	21.2	21.3	LCNT
5 (Field)	510	--	10.00	--	35.0	--	} PFCR/R - Barstow
(Storage)	216	--	2.41	--	25.0	--	

toluene cycle has only a small increase in efficiency when compared to a steam cycle. In addition, the availability of large (50- to 200-MWe) toluene cycle components is uncertain.

3.4.4 Large Brayton-Cycle Energy Conversion Subsystem

The large Brayton-cycle energy conversion subsystem uses a closed-cycle Brayton engine with air for a working fluid. The energy conversion subsystem includes three components: the Brayton-cycle heat engine, the generator, and the heat rejection unit.

The Brayton engine uses a dual shaft arrangement with an intercooled compressor. The engine consists of a compressor drive turbine, power turbine, recuperator, precooler, low pressure compressor, intercooler, and high pressure compressor. The cycle operates with turbine inlet conditions of 3.45 MPa (500 psia) and 816°C (1500°F), and an overall pressure ratio of 4.75.

The generator is a three-phase, 60-Hz, four-pole synchronous unit rated at 13.8 kV with a power factor of 0.9. The generator is air-cooled and equipped with a brushless exciter.

The precooler and intercooler in the Brayton engine are water-cooled. The heated water is circulated to a dry cooling tower.

It was assumed that the largest Brayton engines readily available would be 100-MWe units. Therefore, the 200-MWe plant uses two 100-MWe units. The energy conversion efficiency of the Brayton engines, including heat rejection system auxiliary loads, is 0.418 at 50 MWe and 0.420 at 100 MWe.

3.5 STORAGE SUBSYSTEM

With respect to the energy storage subsystem, the concepts analyzed in this study can be classified into one of two types: 1) those with energy storage between the collector subsystem and the energy conversion subsystem, and 2) those with energy storage after the energy conversion subsystem. The concepts with storage between the collector subsystem and the energy conversion subsystem collect and store thermal energy. Concepts with storage after the energy conversion subsystem must store electrical energy. In this study three

types of thermal energy storage were considered: molten salt, oil and rock, and air/brick. Redox battery electric energy storage was the only electric energy storage considered.

3.5.1 Molten Salt Storage

Several attributes of molten salts such as draw salt make them attractive sensible heat storage media. Molten salts can operate at high temperature without decomposition or high vapor pressure. In addition, a molten salt storage subsystem can be combined with a molten salt transport subsystem. This combination would eliminate the storage charging heaters and the resulting temperature drop.

Molten salt storage subsystems also have several disadvantages. First, molten salts freeze at temperatures well above ambient. Second, they are incompatible with carbon steel at high temperatures. Third, molten salts are more expensive than other sensible heat storage media.

Two molten salt storage subsystems were considered for this study. A high-temperature molten salt system was considered for application with the high-temperature molten salt transport subsystem in the PFCR/R concept. This storage subsystem uses draw salt with a maximum temperature of 538°C (1000°F). An intermediate-temperature molten salt storage subsystem was considered for application with the intermediate-temperature molten salt transport subsystem. It uses draw salt with a maximum temperature of 454°C (850°F). The intermediate-temperature system can be built using carbon steel exclusively. The high-temperature system must use stainless steel for high-temperature components. The draw salt is contained in an insulated tank with the inlets and outlets arranged to form a thermocline between the hot and cold salt.

The thermal storage subsystem does not include heat exchangers for charging storage because molten salt is pumped directly from the thermal storage tank to the field and returned directly to the top of the thermal storage tank. A storage discharge loop is required to transfer the thermal energy from the molten salt and rock storage to the water/steam used as the working fluid in the Rankine engine. The storage discharge loop includes piping, molten salt discharge pump, a preheating heat exchanger, boiler, and superheating heat exchanger.

Because the degradation rate of molten salts such as draw salt is low at storage system operating temperatures, the fluid maintenance unit is not required. The ullage maintenance unit is still required to maintain an inert gas cover over the heat transfer molten salt in the storage tank. Provisions for preventing the freezing of the molten salt during long outages will be included. These would include heat tracing of pipes and storage tanks. Another method is to add water at an appropriate rate during the cooling period to assure that the molten salt mixture remains in liquid form (Hallet and Gervais 1977, p. 6-35).

Hot molten salt in the thermal storage tank is maintained at 454°C (850°F) and the cold molten salt is maintained at 257°C (494°F), so cold molten salt is supplied to the field at 254°C (489°F) and returns at 454°C (850°F). Similarly, hot molten salt at 454°C (850°F) is supplied to the discharge loop heat exchangers and returns at 257°C (494°F). The molten salt and water steam conditions exiting each discharge heat exchanger are given in Figure 3.2.

3.5.2 Oil and Rock Storage Subsystem

The oil and rock storage subsystem is used with the oil transport subsystem in which oil is heated in the field and returned directly to the thermal energy storage subsystem. The low-temperature oil and rock storage subsystem

FIGURE 3.2. Intermediate-Temperature Molten Salt Storage System

is used only with the LCNT concept, operating at 232°C (450°F). The intermediate-temperature oil and rock storage subsystem is used with the LFDR-TC, which operates at 304°C (580°F).

The oil and rock storage subsystem uses an oil and rock thermocline storage medium. The oil and rock are contained in an insulated steel tank where a substantial fraction of the volume is filled with inexpensive rock. The remaining tank volume is filled with more costly oil. Thermal energy is stored as sensible heat in the oil and rock. Hot oil is added or removed from the top of the tank; cool oil is added or removed from the bottom of the tank. This maintains the segregation (or thermocline) between the hot and cold oil in the tank.

The thermal storage subsystem does not include heat exchangers for charging storage because oil is pumped directly from the thermal storage tank to the field and returned directly to the top of the thermal storage tank. A storage discharge loop is required to transfer the thermal energy from the rock and oil storage to the water/steam used as the working fluid in the Rankine engine. The storage discharge loop includes piping, an oil discharge pump, a preheating heat exchanger, boiler, and superheating heat exchanger.

Heat transfer oils tend to degrade at elevated temperatures. Above 304°C (580°F) the degradation rate is very high and heat transfer oils cannot be successfully used. Below 304°C (580°F) degradation still occurs but at a substantially reduced rate. The low-temperature oil and rock storage subsystem operates at a temperature low enough to preclude major degradation problems. However, during operation the products of degradation must be removed and replacement oil added (Hallet and Gervais 1977, p. 4-65).

Two additional components are required to remove the oil degradation residue. The fluid maintenance system filters the oil to remove suspended solids, distills a side stream to remove high boiling polymeric compounds, and adds fresh makeup fluid to replace decomposed fluid (Hallet and Gervais 1977, p. 4-85). The ullage maintenance unit, in addition to maintaining an oxygen-free gas above the heat transfer fluid, also must remove the volatile fractions of the products of degradation that evaporate into the ullage space above the heat transfer fluid (p. 4-66).

The hot oil temperature in the thermal energy storage tank is 231°C (447°F) and the cold oil is at 181°C (358°F), so cold oil is supplied to the field at approximately 178°C (350°F) and returns at 233°C (450°F). Similarly, hot oil is sent to the discharge heat exchangers at 231°C (447°F) and returns at 181°C (358°F). The oil and water/steam conditions exiting each discharge heat exchanger are given in Figure 3.3.

3.5.3 Air/Brick Thermal Storage

The air/brick thermal storage subsystem is used with the hot air transport subsystem in which air is heated in the central receiver of the PFCR/B cycle and returned either to the Brayton-cycle heat engine or to the air/brick thermal storage subsystem. The air/brick thermal storage subsystem is used only with the PFCR/B-TES concept.

The air/brick thermal storage subsystem uses alumina bricks for the storage medium. The bricks are stored in an internally insulated steel pressure vessel. During charging, hot air from the receiver is blown through the alumina brick matrix, transferring heat to the bricks. During discharge, air from the Brayton-cycle heat engine is blown through the brick matrix and heated. The maximum exit temperature of air during discharge is 810°C (1490°F).

FIGURE 3.3. Low-Temperature Oil and Rock Storage Subsystem

The storage subsystem included an axial flow storage compressor to circulate air from storage to the receiver during charging. Other control valves and shutoff valves may be positioned as needed. Storage consists of a number of identical modules each capable of storing approximately 375 MWht.

3.5.4 Redox Battery Electric Storage

The generic concepts with small Brayton- and Stirling-cycle heat engines and one large Brayton-cycle concept use electric energy storage. The electric energy storage subsystem consists of the batteries, ac/dc converters, and miscellaneous equipment such as monitoring, cooling water, makeup water, and wiring systems. The ac/dc converters convert the ac power from the energy conversion subsystem to dc power, which can be stored in the batteries.

The Redox battery system is an electrochemical storage device under development by NASA-Lewis Research Center, Oak Ridge National Laboratory, and others. It uses the reduction and oxidation of two fully-soluble Redox couples [acidified chloride solution of chromium ($\text{Cr}^{+2}/\text{Cr}^{+3}$) and iron ($\text{Fe}^{+2}/\text{Fe}^{+3}$)] for discharging and charging. The chemical reactions take place in a flow cell where the fluids are separated by a sheet of membrane material. The reactants are stored in tanks and pumped to the flow cells when needed.

4.0 ESTIMATION OF COSTS

Solar thermal power plant costs are categorized as capital investment, capital replacement, and operating and maintenance costs. Costs were first estimated for specific design points and were then used to generate cost estimating scaling relationships (CESRs) for plant components. The CESRs can be a function of one or more variables, typically concentrator area, plant power rating, energy conversion generating capacity, or storage capacity. The development of CESRs was an essential task in the large power systems study. These relationships allowed analysis of large numbers of plant configurations at a level of detail corresponding to the specific design point estimates. The design point estimates required the integration of ground rules and assumptions, unit costs for materials and labor, and estimating methodologies. Standardization of these four parameters ensures comparability among concepts.

The overall goal of the cost estimating task was to provide estimates of solar thermal power plant costs for large systems comparable to the costs generated in the small power systems analysis. This required using the same ground rules, cost estimating methodologies, and, in many cases, unit costs, as were used in the previous study. Some components, such as concentrators, are identical in both the small and large power systems studies and thus required no reestimating. Other components, such as Rankine-cycle energy conversion equipment, required new estimates because the equipment had changed significantly due to increased power levels. Draw salt thermal storage represents a component where new estimates were necessary due to an actual design change. In summary, component costs identical to those in the small power systems study were used where applicable. Components requiring new estimates used identical ground rules and estimating methodologies and similar sources and unit costs. New estimates were also reported in mid-1978 dollars, as was done in the small power systems study.

Sources of cost information came from other DOE contractors, including Boeing, Martin Marietta, McDonnell Douglas, and Honeywell, as well as Rockwell, Sandia-Livermore, Sandia-Albuquerque, and Jet Propulsion Laboratory. Cost estimating manuals (Robert Snow Means Co. 1976; Guthrie 1974; Peters and

Timmerhaus 1968; Dodge 1977), along with contacts with several equipment and materials vendors, provided other cost estimating data.

4.1 ECONOMIC GROUND RULES AND ASSUMPTIONS

Standardized ground rules and assumptions are very important in generating normalized cost estimates for alternative solar concepts. Seemingly minor changes in these basic inputs can cause very large changes in estimates of both individual component costs and the overall levelized energy cost for the plant. The need for consistent ground rules and assumptions requires that component cost information found in other studies be carefully interpreted before being used to compare concepts.

In determining overall costs, the most important assumptions and ground rules relate to the assumed maturity levels and production rates for items currently not being mass produced, such as collectors. In general, costs for items produced by a mature, established industry are lower than those for identical items produced by a developing industry. Similarly, an item's cost tends to be inversely proportional to its production rate; as production rate increases, costs will decrease. These trends result from many factors; foremost are the effects of learning and economies of scale in materials, labor, and capital investments.

A standard collector production level of 1.2 million m^2 of aperture area per year was used in evaluating collector costs. For the PFCR concepts, this is equivalent to a production rate of approximately 25,000 heliostats per year. All costs were developed assuming that a commercial solar industry had existed for several years, which avoids burdening concepts with one-time development costs, and reflects costs that are stabilized in a commercial, competitive market.

As much as possible, economic ground rules and assumptions were kept consistent with those used in the small power systems analysis to guarantee that the effects of increased power level, and not the effects of different economic assumptions, were being compared. Ground rules and assumptions were modified whenever required by the size of the power plants being considered. As an

example, assumptions regarding the operation and maintenance of very small power plants around 1 MWe were felt to be inappropriate for analyzing plants in the 200-MWe range. The principal economic ground rules and assumptions used in this study are summarized in Table 4.1.

4.2 CAPITAL INVESTMENT COST ESTIMATIONS

Capital investment costs include all costs incurred during plant construction and represent the major expenditures for solar thermal power plants, far exceeding costs due to operation and maintenance and capital replacement. Capital investment comprises six cost categories: collector, energy transport, energy conversion, energy storage, other plant, and indirect and contingency. In turn, each category is composed of a number of component and subcomponent costs as shown in Table 4.2. The subcomponent cost account level generally represents the level of detail for individual item estimating.

Component cost estimating relationships were developed from specific design point cost estimates. Design points might be at specific concentrator field sizes, plant power ratings, storage capacities, or generating capacities. Design point estimates result from applying estimating methodologies to the ground rules, assumptions, and unit cost information derived from cost estimating manuals, vendor contacts, and other studies. Cost estimating methodologies vary among cost categories and components due to the nature of each item. Costs for off-the-shelf items were estimated based on current unit cost information, while less conventional items required analyzing the impact of increased production and technological improvements as well. Where possible, component costs were estimated independently of other studies. However, because of the large number of components and the scope of this project, some components were assembled from estimates available in other studies. Using estimates from previous studies required the utmost care in interpretation of the studies' methodology and results to retain comparability with the PNL estimates.

4.2.1 Collector Cost Estimating

Solar collectors are both the most distinguishing characteristic and most significant cost element of a solar thermal power plant, and are, thus, by far

TABLE 4.1. Economic Ground Rules and Assumptions

Category	Ground Rules and Assumptions
Solar Industry	<ul style="list-style-type: none"> • Concepts are analyzed assuming the power system operates as part of a commercial electricity production industry. • Capital investment costs for concepts are estimated assuming sophisticated fabrication, assembly, construction, and installation techniques. • Technological and economic risk as they may affect investment decisions for solar thermal small power systems are not considered. • R&D costs, development subsidies, and all other costs associated with solar thermal industry commercialization are not included. • Cost estimates do not include the effects of investment tax credits or other incentives. • Power plant decommissioning costs are not included in estimates.
Collector Manufacturing	<ul style="list-style-type: none"> • Concentrator costs are estimated assuming a reference production rate of 1.2×10^6 m²/year concentrator reflective aperture area. • Collector manufacturing facilities are assumed to consist of highly automated processes, thereby minimizing production labor. Manufacturing process technology is assumed to be current state-of-the-art. • Collector cost estimates include manufacturing facility indirect costs, overhead, and allowances for a required return on investment. • Allowances for sales taxes, working capital, and manufacturing facility personnel training are included. • Manufacturing facility lifetime is 15 years. • Effective state and federal income tax rate burdened on manufacturing facility profits is 0.52. • Effective other taxes burdened on manufacturing facility profits are 0.02.
Large Power Systems Plant Operation and Maintenance	<ul style="list-style-type: none"> • Unscheduled maintenance requirements are assumed to be minimal. • Concentrator cleaning is performed monthly. • Plant control schemes are highly automated, requiring little interface with plant operators. • Operators are required for plant operations, and are present whenever the plant is operating. Operators perform scheduled maintenance when not actively involved in plant operations. • Owner home office expenses are not included in cost estimates. • All required maintenance, with the exception of overhauling heat engines, is performed using an in-house maintenance crew.
Economic Inputs	<ul style="list-style-type: none"> • Levelized energy costs are calculated using methodologies described in Doane et al. (1976). • Power licensing, construction, and start-up periods are assumed to be 4 years. • Capital recovery factor = 0.094 • Fixed charge rate = 0.157 • Nominal capital escalation rate = 0.06 • Nominal O&M expense escalation rate = 0.07 • Nominal general inflation rate = 0.06 • Cost of capital = 0.086 • Power system lifetime = 30 years • First year of power system commercial operation = 1985 • Base year of price levels = 1978

TABLE 4.2. Capital Investment Cost Accounts

<u>Cost Category</u>	<u>Components</u>	<u>Major Subcomponents</u>
Collector	Concentrators	Materials, labor, fixed charges, manufacturing profit, field costs
	Receivers	Absorbers, towers
Energy Transport	Thermal transport	Pipe, pumps, valves, storage tank, transport medium
	Electric transport	Transformers, cable, switchgear
Energy Conversion	Heat engines	Steam turbines, large Brayton engines, recuperators, small Brayton engines, Stirling engines, generators, turbine buildings
	Heat rejection	Condenser, piping, cooling tower, precooler, intercooler, heat exchanger
	Steam generator	
Energy Storage	Containment	Vessels, insulation
	Circulation equipment	Pipe, pumps, valves
	Medium	
Other Plant	Structures	Administration building, control building, maintenance building, storage building
	Land and site improvements	Land, surveying, grading, graveling roads, soil stabilizer
	Power conditioning	
	Instrumentation and control	Master control, interface (between master and field control), non-concentrator control
	Spare parts	Collector-related Noncollector-related
	Service facilities	Communications, fire protection, lift trucks and transportation, water treatment, air and water distribution, electricity distribution

the largest single contributor to levelized energy cost for all concepts analyzed. With the exceptions noted below, collector costs used in this analysis were taken from the previous small power systems analysis (Laity et al. 1979, 1980b). These estimates were independently generated at PNL, based upon a comparative analysis of the manufacturing and field installation costs for each collector concept. The use of comparative collector cost estimates generated by a single estimating team is highly desirable because it ensures that all costs are estimated using identical assumptions, cost estimating methodologies, ground rules, and unit costs for materials and labor.

Receiver costs for the PFDR/B receiver were modified from those used in the small power systems analysis based upon reviews of the previous design and cost estimates. It was concluded that differences in the receiver requirements for the PFDR/B and PFDR/S concepts were minor enough so that cost differences between the two receivers would be minimal. Therefore, the receiver cost for the PFDR/B concept was adjusted to be equal to the receiver cost for the PFDR/S concept.

Central receivers, as used in the PFCR/B, PFCR/R, and PFCR/R-Barstow concepts, vary in size as concentrator field size changes. Because of the tremendous size difference between small and large power system configurations, cost estimating relationships developed for the small power systems study (Laity et al. 1979, 1980b) were no longer valid and had to be reestimated. Cost components for central receivers include the absorber unit and the tower. Absorber costs were estimated for each of the above three concepts with separate tower costs estimated for Brayton and Rankine systems.

Absorber costs were based largely on a Boeing PFCR/B design (Davidson et al. 1978) with PNL modifications to their first plant costs based on expected cost reductions occurring to a maturing industry. Subsequent cost estimates for PFCR/R and PFCR/R-Barstow absorbers were calculated based on comparing heat transfer area and structural requirements of cavity-gas (Brayton), cavity-molten salt (PFCR/R) and external steam (PFCR/R-Barstow) absorbers. Overall cost scaling relationships for these components were developed from estimated cost scaling parameters for individual subcomponents of the absorbers.

Tower costs are a function of several variables including height, design wind velocity, horizontal and vertical acceleration limits, and receiver weight. The scope of this study precluded any detailed analysis of tower costs that would include all of the relevant variables. Tower design variables specified are for survival wind velocity of 90 mph and horizontal and vertical acceleration limits of 0.25 g. Separate tower cost estimating relationships, both functions of tower height, were developed for Brayton and Rankine concepts to account for the difference in absorber size and weight. Tower cost design points were obtained primarily from work done by Stearns-Roger for Sandia-Livermore, as well as from other central receiver studies (Davidson et al. 1978; Rockwell 1979).

4.2.2 Energy Transport Cost Estimating

Energy transport subsystems can use either thermal or electrical energy transport. Cost estimates were developed by aggregating individual component estimates based upon transport subsystem designs for each concept. A standardized unit cost base was developed for all energy transport components, using information obtained from cost estimating manuals, construction cost estimating guides, and contact with vendors. Because standardized unit costs and cost estimating methodologies were used in estimating costs, differences in energy transport costs among the concepts reflect design differences only.

The major components of thermal energy transport subsystems are fairly standard, off-the-shelf items such as piping runs, valves, pumps, and insulation. Cost estimates for the piping runs were based upon specifications of pipe diameter, schedule, construction material, and total length. Pipe run costs summarize installed costs for pipe, pipe supports, and fittings. Insulation costs were tabulated for each pipe size, based upon the pipe diameter and required insulation thickness. Costs for valves and pumps were based upon the number and type required.

Electric transport costs include the cost of all equipment associated with transporting electricity from the heat engines to the electric storage subsystem or to the power conditioning station. Major components of electric transport systems are transmission cable, transformers, and switchgear. All components of electric energy transport subsystems are conventional hardware. Costs

were estimated for each subsystem component on an installed basis and were then aggregated to obtain the overall cost. The component cost estimates are shown in Appendix A.

Electric transport costs show no economies of scale with respect to field size. Electric transport costs account for less than 2% of the levelized energy cost for both the distributed Brayton and Stirling concepts. The cost of electric transport contributes between 1 and 3 mills/kWh to the levelized cost of energy.

4.2.3 Energy Conversion Cost Estimating

Large power system concepts employ Rankine, Brayton, and Stirling heat engine technologies. Two concepts, the PFDR/S and PFDR/B, have distributed energy conversion, while the remainder have central conversion. Of the central systems, all use Rankine energy conversion except for the Brayton thermal and electric concepts.

Rankine heat engines in the 50- to 200-MWe range can be fairly described as off-the-shelf items and are subject to conventional cost estimating techniques. Stirling engines, on the other hand, represent more of an advanced technology with very limited current production or development. Open-cycle Brayton engines are used extensively, but the closed-cycle design used in this study is at an earlier stage of development.

Costs for Brayton and Stirling engines are estimated on the basis of an assumed mass production rate corresponding to the already assumed collector production rates. For the distributed systems, with one heat engine for every collector, the engine production rate is equal to the collector production rate. For the central Brayton systems, engine production rate is equivalent to the number of power plants that can be constructed from the assumed collector production rate. Because of the distributed nature of energy conversion for the PFDR/S and PFDR/B systems, costs identical to those used in the small power systems study (Laity et al. 1980a) were directly applicable to this study. However, considerable differences in the size range of the central energy conversion systems (as compared to the small power study) required reestimating these costs.

Components of Rankine energy conversion systems include turbogenerator, steam generator, condenser, piping, cooling tower, and turbine building. The steam generator is included with energy conversion costs rather than storage costs because, for all Rankine concepts except the PFCR/R-Barstow, a steam generator is required even with no storage. Large Brayton energy conversion components include turbomachinery, recuperator, precooler, intercooler, generator, cooling tower, and turbine building. Distributed Brayton and Stirling energy conversion machinery consists of an integrated heat engine-heat rejection-generator unit, with an air/oil heat exchanger providing the heat rejection capacity.

Boeing was the primary source for central Brayton turbomachinery and accessory equipment costs (Davidson et al. 1978). Many other sources were also consulted. Rankine turbogenerator costs were estimated based on contacts with several vendors, estimates from other DOE contractors' reports, and a report prepared for Sandia-Livermore by General Electric (Oganowski and Muller 1980). Dry cooling technology was employed for heat rejection; these costs were estimated by the BNW-I dry cooling optimization code (Braun et al. 1977). Steam generator costs for the Rankine systems were estimated from data by Guthrie (1974). Turbine building cost estimates were based on unit cost data from R. S. Means (1976) and Guthrie (1974) as well as on information extracted from several other reports, especially those of Powell et al. (1977) and United Engineers & Constructors (1977).

4.2.4 Energy Storage Costs

Energy storage subsystem cost estimates were developed assuming that energy storage technology has been demonstrated and is available for commercial application. This assumption is apparently valid because the majority of storage system components are conventional, commercially available hardware, with costs unlikely to be affected by the commercial development of energy storage subsystems. Where possible, subsystem costs were developed by aggregating conventional component costs developed from vendor quotes, cost estimating guides, and other current cost information. Estimates for energy storage

subsystems are reported in either 1977 or 1978 dollars. Those reported at 1977 price levels were escalated to 1978 levels by SOLSTEP during computer simulation.

Installed capital costs were estimated for four types of energy storage systems: 1) oil/rock thermal storage, 2) draw salt thermal storage, 3) Redox battery electric storage, and 4) air/brick thermal storage. The estimating assumptions, methodologies, and results for each of these systems are discussed in the following four subsections.

4.2.4.1 Oil/Rock Thermal Storage

Costs for storage subsystems using oil/rock storage media include the installed equipment costs of tanks and tank insulation, piping and pipe insulation, pumps, valves, fluid ullage and maintenance equipment, and the cost of the oil. The cost of the rock was assumed to be negligible.

Cost estimating methodology from Guthrie (1974) was used to estimate component costs. That is, the component base cost derived from Guthrie relationships was multiplied by a material and labor factor, which accounts for the costs of installation labor and additional materials used for interfacing the component with other process equipment. This adjusted base cost was then updated to 1977 dollars using Marshall and Stevens Equipment Cost Indices (Kohn 1978). Component costs were estimated at two storage temperatures (450°F and 580°F), three nominal power levels (50, 100, and 200 MWe), and three storage capacities (3, 6, and 18 hours). Total storage system costs were calculated as the sum of the installed component costs at each temperature, power rating, and storage capacity. Trivariate regression analysis was used to derive an expression for storage subsystem capital costs as a function of nominal plant power rating (MWe) and storage capacity (kWht) for each temperature.

Estimated costs for the intermediate- and low-temperature oil/rock storage systems are summarized in Appendix A. The cost of the heat storage medium (Caloria HT43) dominates storage subsystem costs. The overall oil/rock storage costs show economies of scale with respect to power rating.

A detailed comparison was made between costs estimated at PNL and other cost estimates reported in the literature. The former costs appear to be somewhat lower primarily because of differences in cost accounting and differences in media volume requirements. However, if these differences are taken into account, PNL costs are comparable to other estimates. Differences in media volume requirements occur because the PNL storage design uses rock in conjunction with the heat transfer oil, which greatly reduces the volume of oil required to achieve a given storage capacity.

4.2.4.2 Draw Salt Thermal Storage

Costs for draw salt thermal storage systems include the installed equipment costs of tanks and tank insulation, piping and pipe insulation, pumps, valves, and the draw salt storage medium.

Component costs were developed using the same methodology used for oil/rock systems. Component costs were aggregated to obtain total subsystem installed capital costs at two temperatures (538°C and 454°C), three nominal plant power levels (50, 100, and 200 MWe) and three storage capacities (3, 6, and 18 hours). Then, trivariate regression analysis was used to obtain an expression for storage subsystem capital costs as a function of nominal plant power rating (MWe) and storage capacity (kWht) for each temperature.

The intermediate- and high-temperature draw salt storage system cost estimates are summarized in Appendix A. The cost of the draw salt dominates storage subsystem costs. The overall draw salt storage costs show diseconomies of scale with respect to power level primarily because a two-tank, rather than one-tank, system must be used at the large storage capacities.

Draw salt storage costs determined by PNL were compared to DOE cost goals (Radosevich 1980) and to other cost estimates reported in the literature. Cost differences arise primarily from differences in cost accounting and differences in the unit cost of the storage medium. As with the oil/rock storage costs, PNL reports turbine and heat exchanger costs in the energy conversion account, and aggregates indirect costs for all subsystems in a cost account for the whole plant. Inclusion of these costs in the DOE cost goals and in the cost estimates of other reports leads to comparable draw salt storage costs.

4.2.4.3 Redox Battery Electric Storage

Cost estimates for Redox battery electric energy storage subsystems were based upon information in other studies and discussions with R&D personnel (NASA 1979). Cost estimates for Redox batteries were developed assuming expected technological breakthroughs had occurred. Storage cost estimates for Redox batteries encompass two areas: the cost related to the power output of the system, expressed in \$/MW, and the cost associated with the discharge capability of the system, expressed in \$/kWh.

4.2.4.4 Air/Brick Thermal Storage

Cost components for air/brick thermal storage systems include those for pressure vessels, storage medium (refractory brick), insulation, compressors, and auxiliaries, all on a completely installed basis. The PNL design is based largely on a design presented by Boeing, with adjustments made to allow for PNL-calculated required storage mass and compressor sizes.

Cost estimates for the components of air/brick storage were developed based on information from Boeing (Davidson et al. 1978), vendors, and cost estimating manuals (Guthrie 1974; Peters and Timmerhaus 1968). Costs are intended to represent multiple unit production rather than first unit or one-of-a-kind construction. Costs were estimated for a base unit which provides 535 MWht or 150 MWhe of storage for the PFCR/B-thermal concept. Scaling of the cost estimate for the base unit was considerably different than for thermal storage subsystems, because storage time or capacity rating was extended by a modular technique, adding additional base units of storage. This modular approach resulted in a constant unit cost for storage regardless of plant power level or storage subsystem size.

The base unit provides a minimum amount of storage, with additional storage requirements costing the same amount in \$/MWhe. Some cost reductions, over current state-of-the-art prices, were assumed to occur with increased production, as stated in the introduction to Section 4.2.4.

4.2.5 Other Plant Costs

Other plant costs represent those major capital expenditures necessary to complete electric power plant construction, but which are not part of the

collector, energy transport, energy storage, and energy conversion subsystems. Other plant components include structures, land and site improvements, power conditioning, instrumentation and control, spare parts, and service facilities. The technology or design used for each of these components is very similar among concepts as opposed to the differences among concepts in the other subsystems. Cost differences among concepts due to other plant costs result from differing quantity requirements of subcomponents rather than employing differing technology. Thus, other plant components are relatively poor cost differentiators among concepts.

Many references were consulted in estimating costs of other plant components; some were used for two or more of the components. References include studies by Carto (1977), United Engineers & Constructors (1977), Powell et al. (1977), Acres American (1977), Hallet and Gervais (1977), Tracey et al. (1978), Springer et al. (1979), and Davidson et al. (1978). Cost manuals (Guthrie 1974; R. S. Means 1976; Peters and Timmerhaus 1968; Dodge 1977) were also consulted. Other references are cited in the component estimating descriptions that follow.

4.2.5.1 Structures

Structures costs were calculated based on the estimated floor area requirements for each building at each power level and the unit cost per square foot. Unit costs were developed for administration, control, maintenance, and storage buildings. The addition of an administration building to the structures component represents a change from the small power systems study where, because of the small plant size, no full-time administrative personnel were assumed to be needed. The turbine building cost is included in the energy conversion subsystem to be consistent with the small power systems study.

4.2.5.2 Land and Site Improvements

This other plant component includes the cost of the land, surveying, grading, road graveling, and soil stabilizer application. A raw land cost of \$5000/acre is a fixed assumption of the large power systems study. Changes were made from the small power systems study for the other subcomponents because of either new cost information, a new definition of the task, or both.

A major change involved the substitution of a soil seal stabilizer for gravel as the method for controlling dust. A cost estimate for this operation was obtained from Sta Soil Corporation.

4.2.5.3 Power Conditioning

Power conditioning or switchyard costs cover equipment such as bus ducts, breakers, disconnects and relays, transformers, fire equipment, coupling capacitors, surge arrestors, and other necessary electric gear. Costs estimated as a function of plant power rating are based upon information from Schulte (1977).

4.2.5.4 Instrumentation and Control

Instrumentation and control (I&C) costs are broken into master control, concentrator-related, and nonconcentrator-related subcomponents. Analysis of previous master control estimates showed little dependence of cost on variables such as power plant rating, collector field size, or variance among concepts. Thus, the master control system is represented by a fixed cost for all concepts but the LCNT, which was estimated to have a lower master control cost due to its nontracking collectors and a general decreased need for monitoring. Much of the concentrator-related control system is already included in the concentrator cost. Concentrator-related I&C costs account for the equipment that interfaces with the master control system and the concentrator field controllers. Relative costs among concepts were based on the tracking requirements and the concentrator area controllable by a single command. Nonconcentrator I&C costs are calculated as a percentage of receiver, storage, transport, structures, power conditioning, and energy conversion capital costs. All concepts use the same percentage, 3%, which is consistent with the small power systems study.

4.2.5.5. Spare Parts

The cost for power plant spare parts is calculated as separate percentages of collector and noncollector capital costs. Splitting the estimate into two parts reflects the different requirements of collector and noncollector systems. Limited quantities of collector-related spares will be necessary for two reasons: 1) for each concept (except for central receivers) there are multiple

units of identical collectors and parts will be interchangeable, and 2) the breakdown of one collector will not be as critical to plant operation as a breakdown in one of the other subsystems might be. Thus, the estimated number of collector spares required was less than noncollector spares, which leads to a lower percentage of capital costs for collectors as compared to noncollectors.

4.2.5.6 Service Facilities

Service facility costs, like spare parts, are calculated as separate percentages of collector and noncollector capital costs. Three of the facilities—communications, fire protection, and lift trucks and transportation—were ruled to be required for the entire plant. The other three facilities—water treatment, air and water distribution, and electric distribution—are required only in the noncollector subsystems. Cost estimating percentages varied among concepts for one of the facilities. Water treatment costs were higher for Rankine-cycle systems as compared to the Stirling or Brayton cycles, based on expected system water requirements. Electrical distribution was estimated by a flat percentage only, with no difference among concepts or power levels. Cost estimating percentages for other facilities varied only among plant power ratings.

4.2.6 Indirect and Contingency Costs

Indirect costs include the cost of engineering and supervision, construction expenses not directly involved with the materials and labor of actual plant installation, and the contractor's fee. A contingency factor is included to compensate for unpredictable events, such as bad weather, labor strikes, price changes, design changes, or other unforeseen expenses.

Indirect and contingency costs were estimated for the overall plant, rather than disaggregating them in the cost accounts of each subsystem. Indirect and contingency costs were estimated as percentages of direct capital costs. Estimating percentages were developed from a review of construction cost estimating guides, previous solar studies, and studies of other advanced energy concepts.

The estimating percentages for contingency costs and for indirect construction costs were assumed to be the same for each concept. The portion of indirect costs allocated for engineering and supervision varied among concepts, based on differences in complexity of design and construction.

4.3 CAPITAL REPLACEMENT COST ESTIMATING

The approach used to estimate replacement costs is based on maximum expected component lifetime, expected degradation of component performance, and component replacement cost. A detailed analysis to determine the optimal replacement time, based on the tradeoff between the cost of degraded component performance and the cost of component replacement, was considered beyond the scope of this study. If information indicates that a component has a maximum life less than the assumed 30-year lifetime, replacement was assumed to occur at the end of the component's assumed maximum life. If component degradation is expected, and if replacement costs are low, component replacement is assumed to occur at regular intervals. Unless otherwise specified, all components not addressed in this section are assumed to have a 30-year lifetime.

4.3.1 Energy Conversion Replacement

Stirling engine lifetime assumptions were developed from information provided by a consultant (Martini 1979), other studies (Fujita et al. 1978), and a developer (Mechanical Technology, Inc.). It is assumed that Stirling engines would require major overhauls after 15 years of operation. Each overhaul would involve detaching the engine in the field, shipping it to a repair facility, and installing a replacement engine. The capital replacement cost is the net cost of the overhaul process. That is, it accounts for the salvage value of the original engine, removal and installation labor costs, and the cost of a rebuilt engine replacement. Capital replacement costs were assumed to be 50% of the original engine cost.

Brayton-cycle engine lifetime assumptions were developed from information in the literature and contact with manufacturers. Small Brayton engines used in the PFDR/B concept are assumed to require a major overhaul every 15 years (Office of Technology Assessment 1978), which would be performed in a manner similar to the Stirling overhaul. As with the Stirling engine, the net capital

replacement cost is assumed to be half the cost of the original engine. Life-time estimates for the large Brayton engine used in the PFCR/B concept are based on information provided by AiResearch Manufacturing Company (1975). The time between overhauls for this engine is assumed to be 23 years, with the replacement cost equaling 40% of the original engine cost.

4.3.2 Storage Media Replacement

The periodic cost of replacing storage media is included as a capital replacement cost. For thermal storage systems, the annual replacement cost of the medium due to decomposition at elevated temperatures can be calculated from the annual weight loss percentage, the initial medium volume, and the unit cost of the medium.

For oil/rock systems, the decomposition rate is assumed to be 1 wt% per week at 304°C (580°F), and about 0.008 wt% per week at 232°C (450°F) (Aerospace Corp. 1978). Using information on the number of hours that the storage oil would be at the other maximum temperature (304°C or 232°C) for each storage capacity, an annual decomposition rate for each storage capacity was determined. A power curve is used to express the decomposition rate in terms of storage hours. The capital replacement cost is then simply the product of the decomposition rate, the storage volume (in terms of gal/kWh) and the unit cost of the oil, which is assumed to be \$1.10/gal.

Expected costs for fluid replacement are made somewhat uncertain by the lack of actual decomposition data for a large-scale, operating thermal storage system. Subsystem design techniques such as venting and fluid reprocessing show promise for reducing fluid decomposition rates but, at the same time, fluid reprocessing may itself contribute to a loss of heat transfer oil during the reprocessing, somewhat mitigating reduced costs due to lower decomposition rates (Beshore et al. 1979). Other factors affecting the overall uncertainty are the potential market value of waste products from the heat transfer oil degradation and the fact that fluid reprocessing will add a considerable operating cost to the thermal storage subsystem. Analysis of these factors was considered beyond the scope of this study.

The decomposition rate of draw salt is assumed to be 1% per year by volume. Again, the replacement cost is calculated as the product of the annual

volumetric decomposition rate, the initial storage volume, and the unit draw salt cost. The unit cost of draw salt is assumed to be \$1.43/gal (\$0.09/lb).

For Redox battery systems, capital replacement costs include the cost of hydrogen from an outside supply, which is fed to the rebalance cell to restore capacity, as well as the regeneration costs due to membrane crossover of iron and chromium ions. Membranes have already been developed that minimize this loss of capacity for periods up to 20 years (Thaller 1979). Therefore, Redox chemical replacement costs are expected to be small. This study assumed an annual replacement cost of \$0.09/kWh.

4.4 OPERATION AND MAINTENANCE COST ESTIMATING

The approach used to estimate O&M costs involved a detailed systems analysis of each major plant subsystem to determine the operation and maintenance requirements likely to occur.

Estimates were made of manpower requirements for plant control operations and for the maintenance tasks of each subsystem, assuming the plants are highly automated and designed to minimize unscheduled maintenance requirements. Based on the manpower requirements, operation and maintenance costs were calculated and then aggregated to obtain annual O&M expenditures.

Results of the PNL analysis indicate that between 7 and 12% of the levelized energy cost is attributed to O&M costs. The FMDF concept experiences the lowest O&M costs, because the least number of concentrator/receiver units is needed at a given plant capacity. The LCNT concept has the highest O&M costs because the largest number of concentrator/receiver units is needed to achieve a given plant capacity. Operating and maintenance costs experience economy-of-scale benefits with respect to power level for all of the concepts analyzed.

Other studies often use a more simplistic approach to estimate O&M costs; costs are estimated as a percentage of the initial capital investment. This type of estimate does not account for differences in maintenance requirements among subsystems and provides little information on the major contributors to the annual O&M expenditure. To provide a basis for comparison, O&M expenditures estimated by the systems approach discussed earlier were expressed in

terms of percentage of initial capital cost. Annual O&M expenditures range from 0.5 to 1.5% of the initial capital investment.

4.4.1 Direct Production Costs

Direct production costs consist of the costs for plant operators. To estimate direct production costs, a scenario was developed, which provides information on how a solar plant is likely to operate and how operation requirements may differ among plant concepts and power levels. Based on this scenario, the number of operators required was estimated for each concept at each power level. The annual production cost was then determined by multiplying the estimated number of operators by the annual wage per operator.

The plant operating scenario assumes that operators must be present whenever any of the plant subsystems are in use. Therefore, the average length of daily operation is the sum of the hours of collector field operation (average day length) and the hours of storage operation (nominal storage capacity in hours). An estimate was made of the number of operators needed to provide continuous monitoring during daily plant operations, with allowance for vacations, holidays, or any operating anomaly that may require additional manpower. Then, using multivariate regression analysis, an expression was derived for each concept to relate the number of operators required to the nominal power level (MWe) and the storage capacity (hr). These equations calculate the number of operators and then multiply this number by the annual wage to obtain annual direct production costs.

4.4.2 Maintenance Costs

Maintenance costs consist of the costs for the maintenance crew plus the cost of materials used to perform maintenance tasks. Maintenance crew costs include the costs of personnel used to perform both scheduled and unscheduled maintenance tasks. All scheduled and unscheduled maintenance, with the exception of overhauling heat engines, is assumed to be performed by an inplant maintenance crew.

The costs of scheduled maintenance are estimated for four subsystems: 1) the collector subsystem, 2) the storage subsystem, 3) the thermal transport

subsystem, and 4) the heat engine and auxiliaries subsystem. Scheduled maintenance costs are estimated either as a percentage of installed equipment costs or by aggregating the estimated cost of performing tasks specific to a subsystem. To estimate costs by the latter method, major maintenance tasks were identified. Then, the size of the maintenance crew was estimated for each task based on assumptions of the rate at which a task would be performed and the number of times per year the task would occur. Multiplying this estimate by the annual wage gives the annual scheduled maintenance cost for these subsystems. Scheduled maintenance costs, calculated by the preceding methods, were aggregated to obtain the annual plant scheduled maintenance expenditure.

The major scheduled maintenance tasks identified for the collector subsystem include cleaning, lubrication, and manual aligning or readjustment of collectors. Collector cleaning is assumed to occur monthly. Lubrication is assumed to occur quarterly and manual aligning and readjustment is assumed to occur monthly for the LCNT and quarterly for all other concepts. It is assumed that no specialized training will be required to perform routine collector maintenance tasks. An expression for each concept was derived for use in SOLSTEP, which relates the cost of scheduled collector maintenance to the field size.

Routine maintenance costs for storage subsystems were estimated as a percentage of the initial capital cost of the storage system. The estimating percentages were derived from the Electric Power Research Institute (1976) and Esselmann, Colburn, and Cronin (1979).

Major routine maintenance tasks for the thermal transport subsystems are valve testing, replacing and repacking, and pump maintenance. Valve testing and pump maintenance are assumed to occur quarterly. Information on valve failure rates was used to estimate the cost of replacing and repacking valves. Maintenance tasks for the thermal transport systems will require specialized personnel, such as pipefitters. An expression for routine thermal transport subsystem maintenance costs was derived, relating cost to the field size and the plant capacity factor.

Engine and auxiliaries subsystem routine maintenance includes minor heat engine maintenance, instrument maintenance, and electrical transport and plant

electrical system maintenance. These tasks are likely to be performed by personnel with specialized training, such as instrument technicians and electricians. An expression was derived to relate routine maintenance costs for engines and auxiliaries to plant nominal power rating for all concepts except the distributed Stirling and Brayton concepts. For these two concepts, the costs are related to field size as well as nominal power rating to account for electric transport maintenance costs.

Unscheduled maintenance costs are estimated as a percentage of installed equipment costs, with estimating percentages developed using information from cost estimating guides and from other solar studies. These costs were developed assuming that systems have been designed to minimize unscheduled maintenance requirements.

The cost of maintenance materials is also estimated as a percentage of the installed equipment cost. Again, estimating percentages were based on information from cost estimating guides and from other solar studies.

5.0 SYSTEMS ANALYSIS AND RANKING

The systems analysis integrated performance and cost estimates obtained from the engineering (Section 3) and economics (Section 4) tasks. The aim of the systems analysis was to estimate the system energy production cost that could be expected from each of the generic concepts.

The primary tool used in the systems analysis was a plant simulation computer model, SOLSTEP (Simulation Of Localized Solar Thermal Electric Production) developed at PNL as part of the small power systems study (Bird 1980). It is based on the framework of computer programs used in earlier solar thermal studies. Specifically, these were a set of programs developed by the Aerospace Corporation in 1975 that were subsequently consolidated and modified at the California Institute of Technology's Jet Propulsion Laboratory (Caputo 1977; Fujita et al. 1977; El Gabalawi et al. 1978).

The code simulates the operation of a solar thermal plant design on a macroscopic, subsystem basis. Concentrator, receiver, energy transport, electric power generation, and energy storage subsystems are considered in simple, yet complete models. The code accounts for collector optical performance variations with respect to the time of day and time of year. Other aspects of concentrator and receiver performance can be treated as functions of component power level, ambient air temperature, and wind speed. The power generation subsystem model accounts for the effects of ambient air temperature, partial load operation, auxiliary power demands, and engine standby and startup energy requirements. Both central and distributed generation systems may be modeled using either electric or thermal energy storage systems.

In this study the plant designs were analyzed using the 1976 Barstow, California solar insolation and meteorological data compiled by the Aerospace Corporation. The code does, however, have the capability to use a large number of insolation data formats for numerous sites throughout the United States. The simulations are conducted on a time-step basis, performing steady-state computations at a number of discrete time steps to attain an approximate estimate of the plant's transient performance over the total analysis period.

Following the thermodynamic simulation, an economic evaluation of each plant design is performed. The costing methodology calculates capital costs for the component subsystems and equipment replacements and determines annual operation and maintenance charges. An economic analysis using a discounted cash flow methodology (Doane et al. 1976) then combines the lifetime plant costs and yearly plant electrical production to determine a levelized busbar energy cost.

An important requirement of the study was to determine plant performance over a range of capacity factors. To achieve this, the code actually analyzes a matrix of collector field sizes and storage capacities for each nominal plant design. The various combinations of field and storage yield an array of plant capacity factors and levelized energy costs. Typical results for an analysis of this type are presented in Figure 5.1. The series of adjacent curves represents the results for each specified field size. Points on each curve correspond to the array of storage capacities (in terms of hours of storage) considered. Each point on the graph depicts an energy production figure, specified in terms of a plant capacity factor, and a levelized energy cost for a particular plant configuration. Note that, at smaller field sizes, only the smaller storage capacities are represented. This is because the analysis considers one field size at a time and calculates the performance at increasing storage capacities. When it is clear that the addition of further storage capacity yields no increase in plant output and, therefore, is not cost-effective, the calculation for that field size is completed and the next field size is considered, again starting at the lowest storage capacity.

The significant portion of the plant in Figure 5.1 is the broad curve across the bottom of the matrix. This envelope represents the locus of field and storage combinations that yields the minimum levelized energy costs over the range of capacity factors. These are the plant designs in which field size and storage capacity are matched to achieve least-cost performance. This curve has a number of uses: it shows how levelized energy cost varies with capacity factor for a concept; it may be used to select the least-cost field and storage combination at a specific capacity factor; or used to select the overall least-cost plant design and the corresponding capacity factor and levelized energy cost.

FIGURE 5.1. Sample Plot of Energy Cost Versus Capacity Factor

In addition to results from the computer simulations, the systems analysis effort produced estimates for the plant availability of each generic concept. This portion of the analysis is discussed in Section 6.2. There were, then, three attributes for which values were determined in the systems analysis: capacity factor, levelized energy cost, and forced outage.

These attributes were used to rank the concepts based on the preference of decision makers in the utility industry. The ranking analysis employed a multiattribute utility methodology. The remainder of this section discusses the parameters used to characterize the performance and economics of the generic concepts and introduces the ranking methodology.

5.1 PERFORMANCE PARAMETERS

The SOLSTEP performance simulation used in this study modeled four major component subsystems: the collector (concentrator and receiver), energy transport, energy storage, and energy conversion subsystems. Each of these subsystems was characterized by several performance parameters, which are briefly described in the rest of this subsection. Values for each parameter were developed for each concept considered in this study.

Every generic concept used the normal direct insolation striking the collector field. In addition, the Low Concentration Nontracking concept used a fraction of the diffuse insolation. A geometric optics efficiency for the concentrator field was used to quantify the shading, blocking, and cosine losses experienced by the field. The geometric optics were considered as a variable function of the solar altitude and azimuth angles. Other parameters used to characterize the concentrator included the surface optical efficiency (reflectivity for mirrors) and an average surface degradation factor. The energy transfer efficiency from the concentrator to the receiver was quantified by two parameters. The concentrator-receiver interception factor accounted for tracking and spillage errors and was treated as a variable function of wind speed. The second parameter was an average value for the atmospheric attenuation in the collector field. Receiver thermal performance was modeled by three parameters: absorptivity, average thermal efficiency, and a receiver thermal loss term. The thermal loss parameter was treated as a variable function of receiver power, ambient air temperature, and wind speed. The final parameter describing the collector field was a field efficiency correction ratio that accounted for variations in the collector performance with changing field sizes.

The energy transport subsystem was characterized by an efficiency factor that varied with field size. It was considered as a thermal or electrical efficiency, depending on the type of transport used in a particular concept.

The energy storage subsystem was modeled by several parameters. The first two were a storage input efficiency and a storage output efficiency. A third term specified a storage energy loss with time. Also, the maximum storage drawdown was limited by setting a minimum allowable storage charge. Like the

parameters used to describe the transport subsystem, the storage parameters were expressed in thermal or electrical terms, depending on the type of storage used by a concept. For electric storage systems, a maximum storage charge rate was specified. In concepts using thermal storage, the maximum charge rate was set by the storage input pump power.

Several parameters were used to model the performance of the heat engines used in each of the generic concept designs. A nominal heat engine efficiency specified the thermal to electric conversion efficiency of the heat engine/generator unit. This parameter was a net value that included auxiliary loads inherent to the engine plant, such as condensate pumps and cooling tower fans. The nominal figure represented conversion efficiency at full load and standard ambient air temperature. It was corrected for partial load conditions and variations in ambient air temperature. For concepts using thermal storage, thermal transport, and large central heat engines, the standby and startup energy requirements and plant auxiliary loads were also characterized. Standby loads included warming requirements for storage heat exchangers and heat engine standby requirements for seal steam and maintenance of condensor vacuum. Two parameters were used to characterize engine startup: a bulk amount of energy required to warm up the heat engine and a minimum time allowed to ramp the turbine to full power. Four auxiliary loads were considered: feedwater pump, field recirculating pump, storage input pump, and storage output pump. In each case the installed capacity for the auxiliary load was varied with plant size, field size, and storage size, as appropriate. Actual energy requirements accounted for part-load operation whenever applicable.

The preceeding discussion has briefly explained the parameters used to characterize the performance of the generic concepts. It is not practical to include all of the input data used in the analysis in this report; however, Table 5.1 summarizes some of the major variables. A range of values indicates a variation with plant size, field size, or storage size. For parameters that were treated as variable functions, a nominal value is given.

TABLE 5.1. Summary of Performance Parameters

Performance Parameters	Concept				
	PFCR/R	PFCR/R Barstow	PFCR/B-EES	PFCR/B-TES	PFDR/R
Input Parameters					
Fraction of direct isolation	1.0	1.0	1.0	1.0	1.0
Fraction of diffuse insolation	0.0	0.0	0.0	0.0	0.0
Peak geometric optics efficiency ^(a)	0.75-0.80	0.77	0.75-0.80	0.75-0.80	1.0
Surface optical efficiency	0.92	0.92	0.92	0.92	0.92
Surface degradation factor	0.95	0.95	0.95	0.95	0.95
Concentrator-receiver intercept factor	1.0 ^(b)	1.0 ^(b)	1.0 ^(b)	1.0 ^(b)	0.90
Atmospheric attenuation factor	1.0 ^(b)	1.0 ^(b)	1.0 ^(b)	1.0 ^(b)	1.0
Receiver absorptivity	0.95	0.85	0.94	0.94	0.96
Receiver thermal efficiency	1.0	1.0	1.0	1.0	1.0
Receiver thermal loss (kW/m ²)	0.021	0.035	0.027	0.027	0.017
Field sizes (10 ³ m ²)	150-6000	300-3000	150-6000	150-6000	150-5000
Storage sizes (hr)	0-18	0-18	0-18	0-18	0-18
Field efficiency correction factor	0.84-1.0	0.90-1.0	0.84-1.0	0.84-1.0	1.0
Transport thermal/electrical efficiency	0.99	1.0	0.96-0.99	0.96-0.99	0.89-0.91
Nominal heat engine efficiency	0.382-0.391	0.350	0.418-0.419	0.418-0.420	0.358-0.360
Storage throughput efficiency	0.99	0.99	0.72	1.0	0.99
Storage energy loss factor (%/hr)	0.055-0.086	0.083	0.0075-0.03	0.12	0.16-0.18
Engine standby energy requirement (kW)	200-800	400	--	0.0	200-800
Storage standby energy requirement (kW)	22-110	200	--	0.0	22-110
Engine warmup energy requirement (MW/hr)	50-200	100	(c)	1.6-6.2	50-200
Engine ramp rate (hr)	0.50	0.50	(c)	1.0	0.20
Feedwater pump power rating (kW)	240-16200	540-5400	--	--	--
Field recirculation pump power rating (kW)	--	--	--	--	450-14000
Storage output pump power rating (kW)	180-880	120	--	--	700-2800
Storage input pump power rating (kW)	--	1200	--	1700-9800	--
Calculated Parameters					
Peak field efficiency	0.59-0.63	0.53	0.58-0.62	0.58-0.62	0.74
Annual average field efficiency	0.46-0.49	0.38	0.45-0.48	0.45-0.48	0.64
Annual average transport efficiency	0.98-0.99	0.99	0.98-0.99	0.98-0.99	0.89-0.90
Annual average storage efficiency	0.98-0.99	0.95	0.69-0.72	0.72-0.85	0.96-0.97
Annual average heat engine efficiency	0.38-0.39	0.34	0.37-0.38	0.41	0.35-0.36
Annual average system efficiency	0.16-0.17	0.11	0.17	0.17-0.18	0.19

(a) Peak efficiency values may occur at different times for each concept.

(b) Intercept and attenuation factors are accounted for in the geometric optics efficiency.

(c) Transient requirements were accounted for by adjusting the nominal heat engine efficiency.

TABLE 5.1. (contd)

PFDR/B	PFDR/S	Concept				
		FMOF	LFCR	LFDR-TC	LFDR-TR	LCNT
1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.0	0.0	0.0	0.0	0.0	0.0	0.25
1.0	1.0	0.97	0.86-0.89	1.0	0.82	1.0
0.92	0.92	0.92	0.92	0.85	0.81	0.79
0.95	0.95	0.95	0.95	0.94	0.92	0.98
0.90	0.90	0.93	1.0	0.98	0.98	1.0
1.0	1.0	0.99	0.99	1.0	1.0	1.0
0.94	0.94	0.86	0.96	0.92	0.90	0.93
1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.035	0.038	0.038	0.029	0.075	0.062	0.082
150-5000	75-5000	200-8000	200-8000	250-12000	250-10000	400-12000
0-18	0-18	0-18	0-18	0-18	0-18	0-18
1.0	1.0	1.0	0.94-1.0	1.0	1.0	1.0
0.96	0.95	0.97	0.98	0.97-0.98	0.97-0.98	0.84-0.87
0.321	0.370	0.358-0.360	0.358-0.360	0.267-0.271	0.358-0.360	0.209-0.213
0.72	0.72	0.99	0.99	0.99	0.99	0.99
0.0075-0.03	0.0075-0.03	0.16-0.17	0.16-0.17	0.11	0.16-0.17	0.16-0.17
--	--	200-800	200-800	200-800	200-800	200-800
--	--	22-110	22-110	77-300	22-110	77-300
--	--	50-200	50-200	50-200	50-200	50-200
--	--	0.20	0.20	0.10	0.20	0.10
--	--	--	--	--	--	--
--	--	320-13000	280-11000	300-17000	100-4000	560-17000
--	--	700-2800	700-2800	700-2800	700-2800	1200-6300
--	--	--	--	--	--	--
0.73	0.72	0.64	0.68-0.70	0.61	0.46	0.63
0.65	0.64	0.37	0.36	0.38	0.28	0.39
0.96	0.96	0.95-0.96	0.98	0.95-0.96	0.97	0.84-0.85
0.70-0.72	0.71-0.72	0.96-0.97	0.97	0.96-0.97	0.97	0.94-0.95
0.28-0.30	0.32-0.33	0.36	0.36	0.26-0.27	0.36	0.21
0.18-0.19	0.20-0.21	0.12	0.12	0.09	0.09	0.06

5.2 ECONOMIC PARAMETERS

Cost estimate scaling relationships (CESRs) were developed for each capital investment cost account and were implemented in the plant simulation code SOLSTEP. The CESRs are mathematical relationships that relate subsystem costs to system physical parameters, such as field size or power rating. The advantage of CESRs is that they allow simulation of many plant configurations without developing detailed cost estimates for each. These relationships facilitate detailed analyses of plant cost variations with design changes.

Developing CESRs involved determining which physical parameters can best be related to component costs, estimating costs for components at several values of the physical parameters, and then using regression analysis to determine the form and coefficients of the CESR. Cost estimate scaling relationships used in this study generally have the form

$$\text{Cost} = A + B(X)^S + C(Y)^T$$

Here, X and Y are the physical parameters used to scale component costs. Fixed costs, which are costs not related to the physical scaling parameters, are represented by A. Variable cost coefficients, represented by B, C, S and T, represent scaling factors. These scaling factors are unique to each plant concept and are subject to the constraints under which the systems were modeled.

Functional forms of the CESR for each capital investment cost account are given in Table 5.2. These functions yield the cost results shown in Appendix B. Costs predicted by these functions are not necessarily the same as the point estimates given in Appendix A. Differences between costs predicted by the CESRs and the point estimates for a given design are due to the approximate nature of curve fits.

5.3 RANKING METHODOLOGY

This section discusses the multiattribute utility method used to rank solar thermal electric power concepts under consideration in the DOE Solar

TABLE 5.2. Cost Estimate Scaling Relationships for Capital Investment Cost Accounts

Subsystem	Relationship	Term Definition
Concentrator	$\text{Cost} = A + B(X)^S$	$X = \text{Collector field size, m}^2$
Receiver	$\text{Cost} = A + B(X)^S + C(X)^T$	$X = \text{Collector field size, m}^2$
Thermal Transport	$\text{Cost} = A + B(X)^S + \frac{C + D(X)^T}{Y^V}$ $\text{Cost} = A + \left(\frac{X - B}{C} \right)^S$	$X = \text{Number of collectors}$ $Y = \text{Ground cover ratio}$
Electric Transport	$\text{Cost} = A(X) + \left(\frac{B + C(X)}{Y^V} \right)$	$X = \text{Number of collectors}$ $Y = \text{Ground cover ratio}$
Energy Conversion	$\text{Cost} = A + B(X)$	$X = \text{Plant generating capacity}$
Power Conditioning	$\text{Cost} = A + B(X)^S$	$X = \text{Nameplate plant rating, MWe}$
Thermal/Electric Storage	$\text{Cost} = A + B(X)^S + C(Y)^T$	$X = \text{Nameplate plant rating, MWe}$ $Y = \text{Storage capacity, kWh}$
Structures	$\text{Cost} = A(X)^S$	$X = \text{Nameplate plant rating, MWe}$
Land	$\text{Cost} = A(X)^S \left(\frac{Y}{Z} \right)$	$X = \text{Nameplate plant rating, MWe}$ $Y = \text{Collector field size, m}^2$ $Z = \text{Ground cover ratio}$
Instrumentation and Control	$\text{Cost} = A + B(X) + C(Y)$	$X = \text{Concentrator cost}$ $Y = \text{Cost of receiver, structures, thermal transport, power conditioning, energy conversion, thermal/electric storage}$
Spare Parts	$\text{Cost} = A(X)^S + B(Y)^T$	$X = \text{Cost of concentrator, receiver}$ $Y = \text{Thermal transport, electric transport, energy conversion, power conditioning, thermal/electric storage, structures, and instrumentation and control}$
Service Facilities	$\text{Cost} = A(X)^S + B(Y)^T$	$X = \text{Cost of concentrator, receiver}$ $Y = \text{Thermal transport, electric transport, energy conversion, power conditioning, thermal/electric storage, structures and instrumentation and control}$

Thermal Program. The multiattribute utility method (MAUM) used in this study is similar to that developed by Edwards (1977) and implemented by Currie and Jannol (1980) to rank 1- to 10-MWe solar power concepts.

The objectives of the ranking task were 1) to use MAUM to rank generic 50-, 100-, and 200-MWe solar thermal electric power concepts based upon their potential for commercial acceptability, and 2) to statistically check whether or not the ranks generated from MAUM are consistent with ranks generated by a holistic ranking method.

5.3.1 Methodology

Multiattribute utility methodology analysis assumes that, if a decision maker is offered a choice among several alternative power systems, all of which perform the same functions, he will choose the system that provides him the highest level of utility or satisfaction. Further, MAUM assumes that decision makers derive satisfaction from the attainment of goals. For example, a decision maker considering the purchase of a new electric power system might desire a system with 1) minimum operating costs, 2) maximum availability, and 3) maximum reliability. These three criteria represent his general goals, but are not directly measurable. However, certain attributes or characteristics of electric power systems are measurable and may be used to indicate the degree to which the decision maker's goals are attained. Levelized energy costs (LEC), capacity factor (CF), and forced outage (FO) may be used as respective measures of system operating costs, availability, and reliability. Given the goals of the decision maker, it is clear that lower levels of LEC and FO are preferred to higher levels, and higher levels of CF are preferred to lower levels. The relationship among goals, attributes, and utility is expressed in Figure 5.2.

Rarely does a single electric power system simultaneously satisfy all of the goals of a decision maker. This is particularly true in cases where the achievement of one goal conflicts with the achievement of another. For example, a decision maker may wish to increase system reliability. However, to do so might require an increase in operating costs. He is then forced to trade off the goal of minimizing system operating costs to achieve his goal of maximizing system reliability.

FIGURE 5.2. Relationship Among Attributes, Goals, and Utility

Ultimately, the decision to trade off the attainment of one goal for attainment of a conflicting goal depends upon two factors: 1) the value attached by the decision maker to achieving one goal relative to another, and 2) the incremental values associated with changes in the level of attainment of both goals. A utility-maximizing decision maker would be willing to trade off attainment of one goal for the attainment of another, so long as the additional utility gained from attainment of the second goal is greater than the amount of utility lost by nonattainment of the first.

Multiattribute utility methodology provided a formal framework within which the preferences of decision makers for specified attributes common to all electric power systems were combined with the operating characteristics of solar power concepts to indicate which of several alternative concepts had the greatest potential for commercial acceptance. Decision makers were interviewed to elicit their relative preferences for different attributes of solar concepts and their preferences for values that each attribute may assume over its relevant range. This information was used to construct a utility index, or function of specified attributes. Alternative solar concepts were ranked on the basis of their utility scores.

Using MAUM to rank solar power concepts rather than simply asking electric utility officials directly to rank-order several candidate solar power concepts has two advantages. First, MAUM explicitly indicates which attributes of solar

power concepts have an impact on concept ranking and how important various attributes are, both relative to one another and over the range of values they may assume. Second, MAUM rankings are generalizable, whereas direct (holistic) rankings of concepts are not. For example, MAUM can rank any concept whose attributes are known and fall within the attribute range over which preferences were elicited. A holistic ranking of concepts, on the other hand, is able to rank only those concepts presented to decision makers. If a new concept is introduced or attributes of an existing concept modified, the direct concept ranking method would have to be repeated to rank those concepts.

The procedure used to rank large solar power concepts in this study is similar to that used by Currie and Jannol (1980) to rank small solar concepts. One notable difference between the two studies is that, in this study, attribute importance weights are normalized so that each decision maker is given equal weight when group concept scores are calculated.

5.3.2 Decision Maker Selection

Because the major objective of the ranking task was to identify which of several alternative 50- to 200-MWe solar electric power concepts have the greatest commercial potential, it was necessary to interview decision makers who were most likely to use those solar concepts. The small power systems study identified utility executives in the far West, Southwest, and Southeast as the decision makers who had the highest probability of using solar power concepts (Currie and Jannol 1980). This previous study also identified DOE program managers as another group with interest in solar power concepts.

For this study, utility officials in the far West and Southwest were interviewed. Unlike the earlier study, DOE program managers were not contacted for two reasons: 1) they would not be the ultimate purchasers of commercial solar power concepts, and 2) their preferences tended to be highly similar to those of utility executives for small solar concepts (Currie and Jannol 1980). Table 5.3 shows the numbers of persons interviewed and questionnaires completed in the decision maker selection task.

TABLE 5.3. Summary of Decision Maker Contacts

	<u>No. Interviewed</u>	<u>No. of Completed Questionnaires</u>
<u>Arizona</u>	<u>6</u>	<u>6</u>
Arizona Public Service Company	3	3
Salt River Project	3	3
<u>California</u>	<u>14</u>	<u>13</u>
City of Burbank Public Service Department	2	2
Department of Water and Power, Los Angeles	3	3
Pacific Gas and Electric	2	2
Electric Power Research Institute	3	2
San Diego Gas and Electric Company	2	2
Southern California Edison	2	2
<u>Colorado</u>	<u>3</u>	<u>3</u>
Public Service Company of Colorado	3	3
<u>Nevada</u>	<u>2</u>	<u>1</u>
Sierra Pacific Power Company	2	1
<u>New Mexico</u>	<u>2</u>	<u>2</u>
Public Service Company of New Mexico	1	1
Plains Electric Generation and Transmission Cooperative	1	1
<u>Oregon</u>	<u>5</u>	<u>3</u>
Pacific Power	3	1
Portland General Electric	2	2

TABLE 5.3. (contd)

	<u>No. Interviewed</u>	<u>No. of Completed Questionnaires</u>
<u>Texas</u>	<u>15</u>	<u>13</u>
West Texas Utilities Company	2	1
El Paso Electric Company	2	2
Dallas Power and Light Company	3	2
Southwestern Public Service Company	1	1
City Public Service (San Antonio)	2	2
Texas Power and Light Company	1	1
Houston Lighting and Power Company	1	1
Central Power and Light Company	1	1
Gulf States Utilities Company	1	1
Texas Electric Service Company	1	1
<u>Washington</u>	<u>1</u>	<u>1</u>
Washington Public Power Supply System	1	1
TOTAL	48	42

5.3.3 Attribute Selection

The technical characteristics or attributes of alternative power systems play an important role in decision makers' choices of which system to purchase. For this reason, it is critical that attributes selected for use in MAUM be those attributes having the greatest impact on decision makers' choices. According to Feinberg, Kuehn, and Miles (1979), five properties of attributes are desirable:

- differentiation – The attributes should reflect actual differences between the alternative technologies being considered.
- importance – Each attribute should represent a significant factor in the value model of decision makers.

- familiarity – Each attribute should be recognizable and understandable to the decision maker.
- measurability – The criteria or attribute can be subjectively or objectively measured with data that can be attained with the time and resources available for the decision analysis.
- independence – Changes within certain limits in the value of one attribute should not affect preferences or tradeoffs between other attributes.

Based on the above properties and information contained in Currie and Jannol (1980), three attributes were selected for use in the MAUM analysis: levelized energy costs (LEC), capacity factor (CF), and forced outage (FO). Table 5.4 lists important components and ranges of these attributes.

The LEC and CF attributes were selected because they had statistically significantly higher importance weights assigned to them by both utility and DOE decision makers than any of the other five attributes used in the small solar concept ranking. Other attributes included in the small solar concept ranking were forced outage (FO), fixed costs as a percentage of variable cost (FIX), plant flexibility (FLEX), environmental and safety effects (ENV), and public investment in research and development necessary for commercialization (R&D).

The R&D attribute was eliminated as a variable in MAUM on the basis of importance. The importance weight attached to R&D by utility decision makers was statistically significantly lower than that for any other attribute.

The FLEX and ENV attributes were eliminated from MAUM on the basis of differentiation, familiarity, and measurability. In the small solar study, both these attributes were based on subjective scales, difficult to quantify and, no doubt, difficult for decision makers to understand. In addition, ENV did not vary substantially among alternative solar concepts. Although FLEX did vary among solar concepts in the small solar study, it is irrelevant to this study because components of FLEX such as rooftop applications and hybrid systems are either not applicable to large solar power concepts or not considered.

TABLE 5.4. Important Components and Ranges of Attributes

<u>Attribute</u>	<u>Important Components</u>	<u>Range</u>
Levelized Energy Cost (LEC)	Capital cost Operation and maintenance costs Actual and rated capacity factors Construction time (interest during construction) Fixed charge rate Costs of environmental regulations	50 mills/kWh - 200 mills/kWh (1978 \$)
Capacity Factor (CF)	Annual scheduled outage rate Maintenance schedule Plant startup ramp rate Minimum load and part-load efficiency Startup power required	0.20 - 0.90
Forced Outage (FO)	Annual forced outage not including scheduled maintenance	2% - 12%

Finally, FIX was dropped from MAUM on the basis of differentiability. All solar concepts have high fixed costs relative to variable costs, so the range on this variable was too narrow to have a major impact on concept rankings.

5.3.4 Questionnaire Development

The questionnaire developed in this study consisted of three distinct parts. The first part elicited preferences of decision makers for the attributes LEC, CF, and FO. The preference information generated in this part of the questionnaire was used to calculate importance weights and preference functions for each decision maker. The second part of the questionnaire allowed decision makers to directly rank 13 hypothetical solar power cases on the basis of LEC, CF, and FO. This information was used to check whether the ranks generated by MAUM were consistent with those generated by a direct (holistic) method. The third part of the questionnaire was designed to determine attributes other than LEC, CF, and FO that might potentially have an impact on the commercial acceptance of solar power concepts.

5.3.5 Importance Weights

To determine importance weights, complete descriptions of all attributes, along with their ranges, were assembled on 5 x 7 cards. Decision makers were asked to read all of the cards and then order the attributes in terms of importance. Decision makers were then asked to assign an importance weight of 100 to the most important attribute and importance weights between 0 and 100 to other attributes to represent how important those attributes were relative to the most important attribute.

5.3.6 Preference Functions

To determine preference functions, three grids were developed, one for each attribute. The vertical axis of each grid was a preference scale ranging from a low score of 0 to a high score of 10. The horizontal axis of the grid represented the range of values that could be assumed by each attribute. Decision makers assigned a preference score to each possible attribute value. The locus of preference scores assigned to each attribute level defined the preference function.

5.3.7 Holistic Ranks for Hypothetical Solar Cases

The attributes of 13 hypothetical solar power cases were described on white 3 x 5 cards. Decision makers were instructed to order the solar cases on the cards from the most preferred case to the least preferred cases. After ordinally ranking the 13 hypothetical solar cases, each decision maker was asked to place a yellow 3 x 5 card marked "unacceptable" in front of the first card in the ordered deck that he would never consider purchasing under any circumstances. The ordinal concept ranking for the hypothetical solar cases using the holistic method was compared with that from MAUM to check whether or not the two ranking methods generated similar results. A description of the checks for consistency between methods and the results of those checks are presented in Appendix C.

5.3.8 Other Important Attributes

A set of questions was developed to find out what other attributes might influence the commercial viability of solar power concepts. Figure C.1 in Appendix C shows the questions asked and summarizes decision maker responses.

6.0 RESULTS

This section presents the major results from the analysis of large solar thermal concepts for electric power generating systems. Seven generic collector concepts were analyzed with various heat engine cycles and energy storage subsystems. Altogether, eleven specific solar thermal concepts were evaluated:

1. Point Focus Central Receiver/Rankine heat engine (PFCR/R)
2. Point Focus Central Receiver/Brayton heat engine - electric energy storage (PFCR/B-EES)
3. Point Focus Central Receiver/Brayton heat engine - thermal energy storage (PFCR/B-TES)
4. Point Focus Distributed Receiver/Rankine heat engine (PFDR/R)
5. Point Focus Distributed Receiver/Brayton heat engine (PFDR/B)
6. Point Focus Distributed Receiver/Stirling heat engine (PFDR/S)
7. Fixed Mirror Distributed Focus/Rankine heat engine (FMDF)
8. Line Focus Central Receiver/Rankine heat engine (LFCR)
9. Line Focus Distributed Receiver - Tracking Collector/Rankine heat engine (LFDR-TC)
10. Line Focus Distributed Receiver - Tracking Receiver/Rankine heat engine (LFDR-TR)
11. Low Concentration Nontracking/Rankine heat engine (LCNT).

In each case the concepts were analyzed at three nominal power plant ratings: 50, 100, and 200 MWe. In addition to the eleven major systems, a single-point analysis was performed for a 100-MWe Point Focus Central Receiver system with an open receiver, Rankine heat engine, and a 6-hour oil/rock thermal energy storage subsystem. This plant configuration would be typical of a commercialized plant using technology from the Barstow 10-MWe pilot project. It is included for comparison purposes.

The remainder of this section contains specific results for each of these concepts. The systems analysis yielded three primary attributes that were used to characterize the performance of each plant. Values of these attributes are presented in Subsection 6.1. The second subsection presents the preferences of the utility decision makers obtained from the multiattribute ranking analysis. Finally, Subsection 6.3 describes variations in system performance that could be expected for variations in several key component cost estimates.

6.1 ATTRIBUTES

The generic solar thermal concepts investigated in this study were evaluated on the basis of three primary attributes: capacity factor, levelized energy cost, and forced outage. Values for capacity factor and levelized energy cost were arrived at after an extensive analysis and detailed computer simulations. Less emphasis was placed on developing estimates for forced outage. However, the forced outage rates provide a reasonable qualitative assessment of the relative reliability of the generic concepts.

6.1.1 Plant Capacity Factor and Levelized Energy Cost

Capacity factor was defined as

$$CF = \frac{\text{Net energy generated annually (kWh)}}{\text{Rated capacity (kW) x number of hours in year}}$$

The net energy generated, used to calculate capacity factor, does not include forced outages.

Levelized energy costs provide a useful index for comparing technologies with different operating characteristics but with the same end use. The LEC represents an average of the increasing busbar cost of energy over the life of the system. That is, if the system were to produce exactly its expected output, and if the output were sold at a price equal to the LEC, the resultant revenues would exactly recover the full costs of the system over its lifetime, including a return on investment.

To calculate the LEC, the fixed and variable costs of a solar plant concept are estimated over the expected lifetime of the system. Fixed costs refer to the initial capital investment; variable costs are those that recur annually or intermittently, such as O&M and replacement costs. The present value of these costs in 1978 dollars is aggregated to obtain the total life-cycle cost. Then, the life-cycle cost is annualized over the operating life of the plant to produce a stream of equivalent annual payments. The LEC, in mills/kWh, is simply this annualized cost divided by the expected yearly output of the specific system.

Figure 6.1 illustrates the relationship between levelized energy cost and the distribution of increasing annual charges. The horizontal line represents the levelized busbar energy cost in mills/kWh. The curved line represents a hypothetical series of increasing charges. The LEC is representative of these increasing costs if the two streams of payments have the same present value.

FIGURE 6.1. Relationship of Levelized Energy Costs to Increasing Annual Costs

Plant capacity factor and levelized energy cost were the primary results obtained in this study. As previously mentioned, each of the eleven major concepts was analyzed at three power levels. At each power level several collector field sizes and storage capacities were considered. This matrix analysis approach made it possible to estimate the levelized energy costs that could be expected over a range of capacity factor. The result of the matrix approach is a plot depicting levelized energy cost versus capacity factor, as shown in Figure 5.1, for each concept at each power level. The design envelope across the bottom of the figure represents the costs for the most economical plant configurations over a range of capacity factor. Design envelopes for all the concepts at 100 MWe are plotted together in Figures 6.2 through 6.5.

Figure 6.2 shows the lowest possible energy cost for each concept in a configuration without an energy storage subsystem. In all cases the least-cost zero storage plant yielded a capacity factor in the approximate range of 0.2 to 0.3. Note that most of the curves exhibit a discontinuity just after the least-cost zero storage point. This behavior occurs because most storage subsystems have a power-dependent cost (\$/kW) as well as a capacity-dependent cost (\$/kWh). The power-dependent fixed cost causes the first increment of storage capacity to be much more expensive than successive increments. Therefore, the design envelope locus is actually two curves, one for zero storage points and one for greater than zero storage points.

The minimum energy cost for each concept at a capacity factor of 0.4 is shown in Figure 6.3. Two distinctly different types of behavior can be observed as the design envelopes move toward the 0.4 capacity factor. Levelized energy costs for systems with electric storage and the high-temperature air/brick Brayton storage systems increase while costs for other thermal energy storage concepts decrease. This behavior is caused by two factors. Electric storage subsystems are located after the heat engine/ generator, that is, between the generator and the grid. Therefore, to take advantage of increased storage, these concepts must add additional generating capacity. Second, the electric and air/brick storage subsystems themselves are significantly more expensive than other storage concepts.

FIGURE 6.2. Levelized Energy Costs for Zero Storage Plants, 100 MWe

The results in Figure 6.4 show the greatest separation of concepts. Thermal storage concepts (except air/brick) are near their minimum cost capacity factors while energy costs for electric and air/brick storage concepts are still rising. At this point the concepts fall into four main groups: the PFCR/R at the low end; the FMDF and PFDR/R; the PFCR/Bs, the LFCR, the LFDRs, and the PFDR Stirling and Brayton; and the LCNT at the high end of the energy cost band. This classification can be viewed in another manner. The two-axis tracking central receiver concept with thermal storage performed best, followed

by the two-axis tracking, distributed receiver concepts with thermal storage, then electric storage, air/brick storage, and line focus concepts, and finally, the nontracking concept.

FIGURE 6.3. Levelized Energy Costs for 0.4 Capacity Factor Plants, 100 MWe

FIGURE 6.4. Levelized Energy Cost for 0.7 Capacity Factor Plants, 100 MWe

Figure 6.5 shows the least-cost plant configurations for each concept. Concepts that would require electric storage or air/brick storage optimized at configurations with no energy storage and, therefore, low capacity factors. Most thermal energy storage concepts optimized at higher capacity factors, in the range of 0.6 to 0.8, with substantial energy storage subsystems. The Line Focus Distributed Receiver - Tracking Collector optimized at a moderately low capacity factor because of the high replacement costs for its high-temperature oil storage subsystem. Figure 6.5 also includes the result of the Barstow-type

100-MWe central receiver point analysis. This plant optimized at a somewhat low capacity factor, approximately 0.44, because only a 6-hour storage system was considered. Nevertheless, the oil/rock storage system used in this concept operates at a significantly lower temperature than the solar receiver. Therefore, electric energy conversion using energy from storage takes place at a lower efficiency and this concept would be expected to optimize at lower storage capacities and, hence, lower capacity factors than other thermal storage concepts.

FIGURE 6.5. Levelized Energy Cost for Least-Cost Plants, 100 MWe

Figures 6.2 through 6.5 presented capacity factor and levelized energy cost results for 100-MWe plants. A brief summary of cost results for all plant sizes appears in Table 6.1. Complete results may be found in Appendix B. Figure 6.6 depicts the variation in levelized energy cost with plant size for three concepts. In all cases the variation is extremely slight; there appear to be no significant economies or diseconomies of scale in this size range. However, some comments can be made about the very slight tendencies. The PFCR/R, a concept with a central receiver and a central heat engine, increases slightly in cost from 100 to 200 MWe. The LFDR-TC, which is representative of concepts with distributed receivers and central heat engines, decreases in cost less from 100 to 200 MWe than it did from 50 to 100 MWe. This indicates that it, too, would not benefit from larger plant sizes. Finally, the PFDR/S, which is typical of distributed receiver, distributed generation concepts, decreases slightly, but more uniformly, over the plant size range. Its modular nature leads less to diseconomies of scale than other concepts.

6.1.2 Forced Outage Analysis

The equivalent annual availability (EAA) for each plant was calculated as the product of the EAAs of the plant subsystems. For this analysis each subsystem component was considered to have only two states of availability (0% or 100%); thus, partial outages were not considered.

A data base consisting of outage rates for large commercial solar thermal power plants is virtually nonexistent. This necessitated formulating several basic assumptions and extrapolating or interpolating the limited amount of data available for PFCR/R configurations (Honeywell 1977; Hallet and Gervais 1977) and PFCR/B configurations (Davidson et al. 1978) to the distributed, line focus, and nontracking concepts. The basic data extracted from these sources for use in the current study consisted of estimates for mean time to repair (MTTR), mean time between failures (MTBF), and expected outage hours (POH) for each component or subsystem in the plant. These numbers, combined with the proposed yearly operating hours for each plant, provided values for calculation.

TABLE 6.1. Summary of Levelized Energy Cost

Concept	Plant Size (MWe)	Capacity Factor					
		No Storage (CF)		Least Cost (CF)		0.4	0.7
PFCR/R	50	92	(0.30)	70	(0.67)	79	70
	100	86	(0.26)	68	(0.68)	76	69
	200	83	(0.26)	70	(0.66)	74	70
PFCR/R Barstow	100			102	(0.44)		
PFCR/B-EES	50	95	(0.30)	95	(0.30)	112	118
	100	88	(0.30)	88	(0.30)	106	116
	200	86	(0.24)	86	(0.29)	106	120
PFCR/B-TES	50	95	(0.30)	95	(0.30)	99	108
	100	88	(0.30)	88	(0.30)	94	106
	200	86	(0.29)	86	(0.29)	93	108
PFDR/R	50	114	(0.32)	93	(0.74)	100	93
	100	108	(0.24)	90	(0.64)	95	93
	200	100	(0.30)	90	(0.63)	94	92
PFDR/B	50	103	(0.32)	103	(0.32)	122	131
	100	99	(0.32)	99	(0.32)	115	126
	200	97	(0.32)	97	(0.32)	114	126
PFDR/S	50	94	(0.31)	94	(0.31)	110	118
	100	90	(0.31)	90	(0.31)	108	117
	200	88	(0.31)	88	(0.31)	106	116
FMDF	50	117	(0.21)	87	(0.62)	95	87
	100	109	(0.21)	85	(0.75)	90	85
	200	106	(0.24)	84	(0.58)	88	84
LFCR	50	156	(0.20)	113	(0.77)	123	114
	100	146	(0.20)	108	(0.79)	116	108
	200	139	(0.18)	107	(0.80)	113	107
LFDR-TC	50	125	(0.27)	115	(0.43)	116	122
	100	119	(0.23)	111	(0.43)	111	121
	200	119	(0.26)	110	(0.43)	110	120
LFDR-TR	50	145	(0.25)	108	(0.75)	118	109
	100	138	(0.25)	106	(0.76)	113	106
	200	135	(0.25)	105	(0.76)	111	105
LCNT	50	245	(0.20)	205	(0.77)	212	205
	100	240	(0.20)	208	(0.65)	212	209
	200	238	(0.20)	209	(0.55)	211	210

FIGURE 6.6. Levelized Energy Cost Versus Plant Size

The range of plant availabilities (EAA) calculated for the generic concepts corresponded to a range of $88\% \leq \text{EAA} \leq 98\%$. This corresponds to forced outages of between 2% and 12%. Equivalent annual availabilities are presented in Table 6.2.

6.2 COMPARATIVE RANKING OF CONCEPTS

The results from implementing the ranking methodology are presented and interpreted in this section.

6.2.1 Decision Maker Preferences

The preferences of decision makers for attributes of solar electric power systems were elicited in face-to-face interviews. Although only three

attributes were used in the MAUM analysis, care was taken to identify other attributes that might have an impact on both solar concept ranks and market acceptance.

TABLE 6.2. Equivalent Annual Availabilities (%)
for Solar Thermal Generic Concepts

<u>Generic Concept</u>	<u>Plant Rating (MWe)</u>		
	<u>50</u>	<u>100</u>	<u>200</u>
PFCR/R	92.2	90.2	88.0
PFCR/R Barstow	92.2	90.2	88.0
PFCR/B	94.2	92.7	92.0
PFDR/R	93.2	91.9	90.1
PFDR/S	97.2	97.1	97.0
PFDR/B	97.3	97.1	97.1
F MDF	93.2	91.9	90.1
LFDR/R	92.2	90.2	88.0
LFDR-TR	93.2	91.9	90.1
LFDR-TC	93.2	91.9	90.1
LCNT	95.1	93.6	91.7

Note: Forced Outage (FO) = 1 - EAA where EAA
is equivalent annual availability

Decision makers tended to regard LEC as the most important attribute, giving it an average importance weight of 98. Capacity factor was considered by most to be the second most important attribute, with an average importance weight of 61. Forced outage was the least important of the attributes, with an average importance weight of 41. The mean importance weights assigned to the attributes are all statistically different at the 0.05 level of significance.

Decision makers were asked open-ended questions about what other factors might influence their decision to purchase a solar power system. A more detailed discussion of other important attributes is contained in Appendix C.

The most common concern mentioned by decision makers was the cost of solar systems. Other important factors mentioned were reliability, availability,

dependability, and land use. Decision makers were also interested in proven and demonstrated performance of solar electric power systems before they would consider purchase.

Another factor that could potentially have a major impact on the decision to purchase a solar electric power system was the ability to burn fossil fuels to keep the capacity factor of a solar electric power system up. In general, decision makers indicated that being allowed to burn fossil fuels would have a favorable impact on their decision to purchase a solar power system.

6.2.2 Concept Ranks

This section discusses the results of the MAUM analysis on several generic 50-, 100-, and 200-MWe solar electric power concepts. Information generated by MAUM includes 1) concept unacceptability scores, 2) concept preference scores, and 3) concept ranks. This information was calculated for all solar concepts at several different capacity factor levels.

6.2.2.1 Concept Unacceptability Scores

Table 6.3 shows the number of people assigning unacceptable scores to solar concepts at different capacity factor levels. In general, the number of people unwilling to accept a particular solar concept falls as the capacity factor increases, up to a point. After a certain capacity factor level is reached, the unacceptability of a solar concept begins to increase due to high levelized energy costs. For most solar concepts, the highest level of acceptability lies between capacity factors of 0.6 and 0.8.

6.2.2.2 Solar Concept Scores

Table 6.4 shows solar concept scores for five capacity factor levels. A higher concept score for a solar concept indicates a higher level of preference. In general, concept scores increase as capacity factors rise, up to a certain point. Past about an 0.8 capacity factor, levelized energy cost rises so much that concept scores drop in spite of the higher capacity factor. The optimal capacity factor is that capacity factor at which the concept score of a solar concept is maximized. For most solar concepts, optimal capacity factor occurs between 0.6 and 0.8.

TABLE 6.3. Number of Decision Makers Giving Each Solar Concept an Unacceptable Score

Solar Concept	Rating (MWe)	No Storage	Minimum LEC CF	Capacity Factor							
				0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
PFCR/R	50	17	5	24	17	12	10	6	5	5	7
PFCR/B-Electric	50	17	17	24	17	14	12	10	9	9	18
PFCR/B-Thermal	50	17	17	24	17	12	10	10	9	9	18
PFDR/R	50	14	7	26	18	14	10	8	7	7	9
PFDR/B	50	14	14	24	18	14	20	19	18	18	19
PFDR/S	50	12	12	--	17	14	12	10	9	18	18
F MDF	50	18	7	--	18	12	10	8	7	7	9
LFCR	50	27	9	--	23	14	12	10	9	9	18
LFDR-TR	50	23	9	26	23	14	12	10	9	9	19
LFDR-TC	50	23	12	--	18	14	12	10	9	18	--
LCNT	50	--	--	--	--	--	--	--	--	--	--
PFCR/R	100	18	6	24	18	13	9	7	6	6	8
PFCR/R-Barstow	100	12	12	26	18	14	12	--	--	--	--
PFCR/B-Electric	100	17	17	24	17	14	12	10	9	18	18
PFCR/B-Thermal	100	17	17	24	17	12	10	10	9	9	18
PFDR/R	100	18	8	24	18	13	11	9	8	8	9
PFDR/B	100	12	12	24	17	14	12	10	18	18	19
PFDR/S	100	12	12	--	17	14	12	10	9	18	18
F MDF	100	--	--	--	--	--	--	--	--	--	--
LFCR	100	26	9	--	18	14	12	10	9	9	18
LFDR-TR	100	23	9	26	18	14	12	10	9	9	18
LFDR-TC	100	18	12	--	18	14	12	10	9	18	19
LCNT	100	--	--	--	--	--	--	--	--	--	--
PFCR/R	200	18	6	24	18	11	9	7	6	6	8
PFCR/B-Electric	200	18	18	24	18	14	12	10	9	18	19
PFCR/B-Thermal	200	18	18	24	17	12	11	10	9	9	18
PFDR/R	200	18	8	24	18	13	11	9	8	8	9
PFDR/B	200	12	12	24	17	14	12	10	18	18	19
PFDR/S	200	12	12	--	17	14	12	10	9	9	18
F MDF	200	18	9	24	18	13	11	9	8	8	9
LFCR	200	--	9	26	18	14	12	10	9	9	18
LFDR-TR	200	23	9	26	18	14	12	10	9	9	18
LFDR-TC	200	18	12	--	18	14	12	10	9	8	24
LCNT	200	--	--	--	--	--	--	--	--	--	--

TABLE 6.4. Solar Concept Scores^(a)

Power Level	Solar Concept	Optimal CF	No Storage	Min LEC	0.40 CF	0.70 CF
50 MWe	PFCR/R	6.5	2.7	6.2	4.0	6.3
	PFCR/B-Electric	4.6	2.9	2.9	3.1	4.5
	PFCR/B-Thermal	4.9	2.9	2.9	3.5	4.8
	PFDR/R	5.4	2.6	5.4	3.3	5.3
	PFDR/B	3.7	3.2	3.2	3.1	3.7
	PFDR/S	4.8	3.5	3.5	3.4	4.8
	FMDF	5.7	2.0	5.3	3.5	5.6
	LFCR	4.6	1.1	4.6	2.6	4.4
	LFDR-TR	4.8	1.6	4.8	2.8	4.7
	LFDR-TC	4.3	1.8	3.3	2.9	4.3
	LCNT	NA ^(b)	NA	NA	NA	NA
100 MWe	PFCR/R	6.1	2.6	5.989	3.818	6.00
	PFCR/R-Barstow	NA	NA	NA	2.91	NA
	PFCR/B-Electric	4.4	2.9	2.9	3.09	4.41
	PFCR/B-Thermal	4.697	2.9	2.9	3.48	4.697
	PFDR/R	5.2	2.18	5.0	3.346	5.115
	PFDR/B	4.27	3.39	3.39	3.24	3.705
	PFDR/S	4.8	3.675	3.675	3.41	4.838
	FMDF	5.5	2.09	5.535	3.519	5.42
	LFCR	4.5	1.13	4.53	2.596	4.34
	LFDR-TR	4.7	1.53	4.737	2.849	4.609
	LFDR-TC	4.185	1.905	3.238	2.898	4.185
	LCNT	NA	NA	NA	NA	NA
	PFCR/R	5.65	2.458	5.499	3.69	5.637
	PFCR/B-Electric	4.226	2.855	2.855	3.03	4.226
	PFCR/B-Thermal	4.565	2.855	2.855	3.426	4.565
	PFDR/R	5.00	2.30	4.767	3.187	4.927
	PFDR/B	4.299	3.46	3.46	3.265	3.705
200 MWe	PFDR/S	4.856	3.74	3.74	3.45	4.857
	FMDF	5.308	2.04	4.75	3.39	5.23
	LFCR	4.29	NA	4.29	2.417	4.08
	LFDR-TR	4.54	1.43	4.54	2.707	4.41
	LFDR-TC	3.99	1.848	3.06	2.73	3.99
	LCNT	NA	NA	NA	NA	NA

(a) Higher concept scores indicate higher levels of preference.

(b) NA = not applicable

Another point of interest is that concept scores for solar concepts at lower power levels are slightly higher than those for higher power levels. This occurs because forced outage for larger solar concepts is higher than forced outage for smaller solar concepts.

Concept ranks are computed from concept scores and presented in Figures 6.7 through 6.9. Ranks are presented for the optimal, no storage, minimum LEC, 0.4 and 0.7 capacity factors. Dark lines drawn through the columns of these figures represent boundaries of significant statistical differences between mean concept scores for different concepts. For example, a dark line marked "1st" indicates that the highest ranked concept is statistically significantly different from concepts below the line. A dark line marked "2nd" indicates that the second-ranked concept is significantly different from concepts below the line, and so on.

For the 50-MWe solar concepts, the PFCR/R, FMDF, and PFDR/R rank higher than other concepts at optimal, minimum LEC, and 0.7 capacity factors. The LCNT ranks lowest at all capacity factors because its LEC is so high that it is beyond the upper range in the MAUM analysis (this is true at all power levels).

For the 100-MWe solar concepts, the PFCR/R, FMDF, and PFDR/R again rank higher than other concepts at optimal, minimum LEC, and 0.7 capacity factors.

For the 200-MWe solar concepts, the PFCR/R, FMDF, and PFDR/R rank the highest at the optimal, minimum LEC, and 0.7 capacity factors.

For all power levels, the PFCR/R ranks highest at optimal, minimum LEC, and 0.7 capacity factors. The FMDF and PFDR/R share second and third places at these capacity factors. There is, however, no statistically significant difference between the PFCR/R, FMDF, and PFDR/R at these capacity factors.

6.3 SENSITIVITY ANALYSIS

Sensitivity analysis is a means of identifying variables that, if changed, could considerably affect the economics of a solar thermal power concept. Costs for solar components were estimated in this study based on technological advancements and increased production scenarios. The sensitivity analyses,

NA - NOT APPLICABLE

Lines indicate boundaries for statistically significant differences at the 0.05 level. Optimal capacity factors are enclosed in parentheses.

FIGURE 6.7. 50-MWe Solar Concept Ranks

LINES INDICATE BOUNDARIES FOR STATISTICALLY SIGNIFICANT DIFFERENCES AT THE 0.5 LEVEL. OPTIMAL CAPACITY FACTORS ARE ENCLOSED IN PARENTHESES.

FIGURE 6.8. 100-MWe Solar Concept Ranks

NA - NOT APPLICABLE

LINES INDICATE BOUNDARIES FOR STATISTICALLY SIGNIFICANT DIFFERENCES AT THE 0.05 LEVEL. OPTIMAL CAPACITY FACTORS ARE ENCLOSED IN PARENTHESES.

FIGURE 6.9. 200-MWe Solar Concept Ranks

then, are simply offered as a "what if" case; what if cost reductions are more or less than those predicted. In carrying out a sensitivity analysis, individual parameters are changed and the effect of such a change on the levelized energy cost is computed.

Sensitivity analyses performed for one plant concept and power level are expected to generalize to other concepts and power levels. Each of the following subsections discusses the results of varying an individual parameter.

To clarify the effect of changing individual parameters, a graph of normalized LEC versus capacity factor is shown for each analysis. The reference LEC is represented by a straight line at a normalized LEC of 1.0. The magnitude of the change in LEC with changes in individual parameters is shown as the deviation from this baseline at each capacity factor.

6.3.1 Wet Cooling Versus Dry Cooling

Rankine and large Brayton energy conversion systems in this study utilize dry cooling towers in their heat rejection systems. Whether to employ wet or dry cooling is not so much a question of economics (wet cooling is invariably cheaper than dry cooling), but a question of water availability in arid climates where solar thermal power plants are often proposed. A presumption of this study was that dry cooling would be required due to climatic considerations. This sensitivity analysis, then, is offered to show the cost if wet cooling is feasible.

Comparative costs of cooling, as calculated by the PNL team, are \$82 and \$34 per kW_e installed generating capacity for dry and wet cooling, respectively. The effect of this difference on concept LEC was estimated for the PFCR/R concept at a 100-MWe power plant rating. Implementation of wet cooling reduced LEC by 3 to 6%, depending on capacity factor, with the optimal LEC decreasing 3%. A comparison of LEC for the PFCR/R concept at 100 MWe as a function of capacity factor for wet and dry cooling is shown in Figure 6.10.

6.3.2 Transport Costs

Costs for thermal energy transport can make up major fractions of the total initial capital investment cost, particularly for distributed receiver concepts, and, as such, can have significant impacts on levelized energy cost.

FIGURE 6.10. Wet Cooling Versus Dry Cooling

The PFDR/R concept was chosen to illustrate potential effects of variations in thermal energy transport costs because of its substantial cost for thermal energy transport. The effects of halving and doubling the reference case transport costs for the 100-MWe plant are shown in Figure 6.11. The high-cost case results in an increase in levelized energy cost over the reference case of between 10 and 12%, while the low-cost case decreases costs from 5 to 6%. The greatest impact from variations in transport costs occurs at higher capacity factors, where large collector field sizes require the most extensive, and expensive, transport subsystems.

FIGURE 6.11. Variation of LEC with Different Transport System Costs

6.3.3 Thermal Storage Costs

Thermal storage subsystem components are all conventional items; however, thermal storage is considered a relatively new technology. It is likely that cost reductions could be forthcoming through improvements in the design and efficiency of these systems. Thermal storage costs are not a major contributor to levelized energy costs. Therefore, the LEC is expected to be relatively insensitive to changes or uncertainties in the cost of thermal storage.

Draw salt storage costs for the 100-MWe PFDR/R plant were varied to determine the sensitivity of the LEC to changes in thermal storage costs. Draw salt storage costs estimated by PNL are comparable to the DOE cost goals. To demonstrate the impact of storage costs well above these goals, PNL costs were doubled for this concept. This 100% increase in draw salt storage costs increases the LEC for the PFDR/R plant from 1 to 6% over the range of capacity factors.

A 50% decrease in PNL draw salt storage costs was also analyzed. This decrease leads to a corresponding decrease in the LEC of only 0.5 to 2.5% shown graphically in Figure 6.12.

FIGURE 6.12. Variation of LEC with Different Thermal Storage Costs

Results of this sensitivity analysis indicate that failure to achieve thermal storage cost reductions through technology improvements, or achievement of cost reductions beyond DOE cost goals, will have little impact on the LEC. This is because storage costs are only a small part of the overall cost of a solar thermal plant.

6.3.4 Electric Storage Costs

Redox battery electric storage systems offer promise of low-cost electric energy storage using advanced technology. Cost estimates used for Redox batteries were estimated assuming expected technology breakthroughs have occurred.

Given this uncertainty in the future cost, it is important to assess the impact of different Redox battery cost scenarios on the LEC.

Electric storage costs for the 100-MWe PFDR/S plant were doubled to represent costs if little technological improvement were achieved. Doubling electric storage costs increases the LEC from 8 to 11% across the range of capacity factors. Electric storage costs were decreased 50% to represent a case where technological improvements were achieved beyond those assumed in the reference costs. This decrease results in a 4 to 5.5% decrease in LEC. This change is shown in Figure 6.13.

Improvements in Redox battery technology have the potential of moderately improving the economics of solar thermal concepts utilizing electric storage.

FIGURE 6.13. Variation of LEC with Different Electric Storage Costs

6.3.5 Operating and Maintenance Costs

Uncertainty in O&M costs arises due to lack of actual operating experience. Different recommended frequencies for collector cleaning to prevent optical degradation are available in the literature. Using the PNL reference assumption of monthly cleaning, collector cleaning costs dominate the costs of scheduled maintenance. Because collector cleaning costs are a component of O&M costs, and because uncertainty exists as to how often cleaning should occur, the collector cleaning assumption was varied to assess its impact on the LEC. For the 100-MWe PFCR/R plant, no collector cleaning was assumed. (Collector field performance was not varied for this analysis.) The no-cleaning assumption reduced O&M costs 7 to 10%. This decrease in O&M costs results in a decrease of less than 1% in the LEC. If collector field performance had been reduced to correspond to the no-cleaning assumption, the impact on the LEC would have been much more significant.

To assess the effect of large O&M costs on the LEC, annual O&M costs were assumed to be 2% of the initial capital investment for the 100-MWe PFCR/R plant. This represents a 150 to 200% increase in O&M costs above the reference case. This increase leads to an increase in the LEC of 16 to 18%. The effects of these changes are shown in Figure 6.14.

Operation and maintenance costs could have a significant impact on the economics of solar thermal plants. Large changes in annual O&M costs with respect to the reference costs result in significant changes in the LEC.

6.3.6 Financing Assumptions

Solar thermal power plants as a class are a capital intensive energy source and, as such, are very sensitive to economic assumptions regarding the value of money, such as the cost of capital, the capital recovery factor, and the fixed charge rate. To investigate this sensitivity, these parameters were varied from the reference case, and the effects on levelized energy cost analyzed for the PFCR/R concept at 100 MWe.

Values of the economic parameters used in both the reference cases and in the sensitivity analysis are shown in Table 6.5. The reference parameters were

FIGURE 6.14. Variation of LEC with Different O&M Costs

TABLE 6.5. Financing Assumptions for Reference Case and Sensitivity Analysis

	Reference Case (%)	High Cost Case (%)	Tax Credit Case (%)
Cost of Capital	8.6	10.0	10.0
Capital Recovery Factor	9.4	10.6	10.6
Fixed Charge Rate	15.7	18.0	14.0

established as a study ground rule, and were chosen to be consistent with the previous small power systems analysis. Economic parameters for the "high cost" case are based on recommendations in the EPRI Technical Assessment Guide (Esselman, Colburn, and Cronin 1979, pp. 7-6 through 7-10) for comparison of alternative power plants when investment tax credits are not assumed. The tax credit case is also based upon EPRI recommendations, and reflects the impact of a 10% investment tax credit.

Effects of the variation in financing assumptions do not significantly vary over the range of capacity factors analyzed, because they do not affect individual plant costs but only the contribution of costs to the levelized energy cost. Results of the sensitivity analysis are shown in Figure 6.15. For the high-cost case, levelized energy cost has been increased over the reference case by 15%. The tax credit case results in a reduction of levelized energy costs over the reference case by 8%.

FIGURE 6.15. Variation in LEC with Financial Assumptions

6.3.7 Receiver/Engine Costs

Estimates of levelized energy cost for concepts using a distributed receiver-distributed engine combination can be greatly affected by the estimated cost or performance of the engine/receiver. Because a very large percentage of total cost is due to identical, distributed units (concentrators, receivers, and energy conversion equipment), these concepts exhibit only limited benefits from economies of scale and, hence, require a reduction in component costs to achieve lower energy costs.

Preliminary cost goals for the PFDR/S concept, as reported by JPL, were used in the sensitivity analysis, and are shown in Table 6.6. Results from the sensitivity analysis are shown in Figure 6.16, and indicate very dramatic cost

TABLE 6.6. Receiver/Engine Costs

	Reference Case	JPL Cost Goals	Sensitivity Analysis Value
Receiver Cost	\$178	\$20-40/kWe	\$30/kWe
Engine Cost	\$205/kWe	\$50-200/kWe	\$125/kWe

FIGURE 6.16. Variation in LEC with Receiver/Engine Costs

reductions over the reference case. By far the majority of the cost reductions result from the change in receiver costs, which were roughly 8 times lower in the sensitivity analysis than for the reference case. Results from this analysis indicate that, if current cost goals can be achieved, the levelized energy costs estimated in this analysis for the PFDR/B and PFDR/S concepts could be significantly improved.

6.3.8 Tower Costs

For all concepts analyzed, the collector field is the highest cost item for the power plant. For the central receiver concepts, the collector field can be conveniently divided into three elements: concentrator, receiver, and tower. In this sensitivity analysis, tower costs for the PFCR/R concept at 100 MW were varied from the reference case, using double the reference tower costs for the high-cost case, and half the reference tower costs for the low-cost case. As can be seen in Figure 6.17, the impact of the various tower costs had a relatively minor effect upon levelized energy cost. The high-cost case increase resulted in LEC increases of from 3 to 5%, with corresponding decreases for the low-cost case. The impact of tower costs was greatest at high capacity factors, where large concentrator field sizes required very tall, expensive towers for the receiver.

FIGURE 6.17. Variation in LEC with Tower Cost

6.3.9 Receiver Cost

In this sensitivity analysis, the receiver cost for the PFCR/R concept at 100 MW was doubled and halved from the reference case receiver cost to determine the effect of different receiver costs on the levelized energy cost. Results of the analysis appear in Figure 6.18, and show that the impact of changes in receiver costs are of approximately the same magnitude as changes in tower costs. The receiver high-cost case increases levelized energy cost by approximately 5 to 6%, while the low-cost case decreases levelized energy cost from the reference case by about 3%. Changes in levelized energy cost due to variations in receiver cost are fairly uniform over the range of capacity factors considered, but have a somewhat greater effect at low capacity factors and smaller field sizes, where the cost for the receiver subsystem is dominated by receiver costs rather than tower costs. At higher capacity factors, costs for

FIGURE 6.18. Variation in LEC with Receiver Cost

the tower make up an overall larger percentage of the total cost for the receiver subsystem, somewhat mitigating the effect of variations in receiver cost.

6.3.10 Concentrator Costs

Concentrator costs make up the largest percentage of overall collector cost for all concepts and, as such, could be expected to have the largest impact on levelized energy cost. In this sensitivity analysis, concentrator costs were reduced by 15%, and increased by 25% for the PFCR/R concept at 100 MW. A much smaller range of variation was used in this analysis than for the previous sensitivities because it was felt that doubling and halving of the concentrator costs would suggest an unrealistic case. The unit costs used in the analysis were $\$80/\text{m}^2$ for the reference case, $\$68/\text{m}^2$ for the low cost case, and $\$100/\text{m}^2$ for the high cost case.

Although concentrator costs were varied over a smaller range than tower or receiver costs, they had a much larger impact on levelized energy cost, as can be seen in Figure 6.19. The high-cost case increased costs by approximately 12%, while the low-cost case reduced the levelized energy cost by about 7% over the reference case. The impact of changes in concentrator cost tended to be the greatest at moderate capacity factors, dropping off slightly at very high or low capacity factors, reflecting a reduced importance of concentrator cost at those conditions.

FIGURE 6.19. Variation in LEC with Concentrator Costs

7.0 COMMENTS, CONCLUSIONS, AND RECOMMENDATIONS

7.1 COMMENTS

The objective of this study was to rank solar thermal concepts with the potential for commercialization in the 1990s. However, some of the concepts analyzed represent inherently nearer-term technologies than others. For example, parabolic trough collectors are currently more fully developed than central receiver or parabolic dish designs; Rankine heat engines are more fully developed than Stirling engines. The study did not include costs associated with bringing all concepts to a similar level of development.

The levelized energy cost values estimated in this study are based on solar insolation data from Barstow, California. This location has significantly higher levels of insolation than most other sites in the United States. Although the results of this study are largely valid at other locations in a relative sense (that is, comparing one concept to another), actual levelized energy costs at other sites are potentially much higher than those reported in this analysis.

Although the sensitivity analyses give some information on the effect of subsystem cost changes on the levelized energy cost (LEC), they do not yield information on the effect of a cost change on the relative ranking of a concept.

Central receiver tower costs can vary widely, depending on such parameters as design wind speed, design seismic loading, receiver weight, and receiver dimensions. These design parameters become increasingly important as tower height increases.

7.2 GENERAL CONCLUSIONS

Three general conclusions were drawn from this study.

First, concepts employing electric storage exhibit large increases in levelized energy cost with increasing capacity factor. This behavior is caused by two factors: 1) additional generating capacity must be provided to take

advantage of the additional storage capacity required at high capacity factors, and 2) electric storage subsystems are significantly more expensive than most types of thermal storage.

Second, concept LEC and MAUM scores generally improved as capacity factors rose, up to a certain point. Beyond a capacity factor of approximately 0.8, levelized energy cost increased so much that concept scores dropped despite the higher capacity factor. For most solar concepts, a maximum concept score occurred with a capacity factor of between 0.6 and 0.8.

Third, results based on a breakdown of operation and maintenance expense into individual tasks show that operation and maintenance cost is between 0.5 and 1.5% of capital cost for the concepts considered in this study. The detailed systems analysis approach for estimating O&M costs yielded more accurate costs than assuming an overall percentage of capital cost.

7.3 CONCLUSIONS ON CONCEPT RANKING

When concept comparisons were based on levelized energy cost only,

- the PFCR/R, a two-axis tracking concept with a central receiver and thermal storage, was the least-cost system over the entire range of capacity factor.
- The LCNT, a nontracking concept, was at least 60% more expensive than any other concept over the entire range of capacity factor.
- At low capacity factors where no storage is employed, energy costs for four concepts (PFCR/R, PFCR/B, PFDR/B, and PFDR/S) were significantly lower than for the others, while energy costs for two (LFDR-TR and LFCR) were significantly higher.
- At higher capacity factors (0.4 to 0.7), the energy cost of one concept (PFCR/R) was significantly lower, while for six concepts (LFDR-TR, PFCR/B-EES, LFCR, PFDR/S, LFDR-TC, and PFDR/B) it was significantly higher.

- Comparing the concepts on the basis of lowest energy cost, regardless of capacity factor, one (PFCR) was significantly lower than the others, while three (LFDR-TR, LFDR-TC, and LFCR) were significantly higher.
- Over the range of capacity factors, two-axis tracking systems with thermal storage outperformed one-axis tracking systems. The non-tracking concept was not competitive at any capacity factor.
- Two-axis tracking systems with electric storage were competitive at low capacity factors when little storage was necessary but not at high capacity factors.
- The cost advantages of two-axis tracking concepts and their high-temperature working fluids are due primarily to increased energy collection and conversion efficiencies.

Second, when comparisons are made on the basis of levelized energy cost (LEC), capacity factor (CF), and forced outage rate (FO),

- for the 50-MWe solar concepts, the PFCR/R, FMDF, and PFDR/R rank higher than other concepts at optimal, minimum LEC, and 0.7 capacity factors. The LCNT ranks lowest at all capacity factors because its LEC is so high.
- For the 100-MWe solar concepts, the PFCR/R, FMDF, and PFDR/R rank higher than other concepts at optimal, minimum LEC, and 0.7 capacity factors.
- For the 200-MWe solar concepts, the PFCR/R, FMDF, and PFDR/R rank the highest at the optimal, minimum LEC, and 0.7 capacity factors.
- For all power levels, the PFCR/R ranks highest at optimal, minimum LEC, and 0.7 capacity factors. The FMDF and PFDR/R share second and third places at these capacity factors. There is, however, no statistically significant difference among PFCR/R, FMDF/R, and PFDR/R at these capacity factors.
- For the zero storage case, the PFDR/S and PFDR/B rank highest.

Finally, neither the relative ranking nor the relative cost performance of the concepts changes significantly over the range of 50 to 200 MWe.

7.4 CONCLUSIONS BASED ON INTERVIEWS WITH DECISION MAKERS

Decision maker interviews led to four conclusions.

First, utility decision makers tended to regard levelized energy cost as the most important attribute, giving it an average weight of 98. Capacity factor was considered by most to be the second most important attribute, with an average weight of 61. Forced outage was the least important of the attributes, with an average weight of 41.

Second, the most common concern mentioned by decision makers was the cost of solar systems. Other important factors mentioned were reliability, availability, dependability, and land use. Decision makers were also interested in proven and demonstrated performance of solar electric power systems before they would consider purchase.

Third, on collateral issues, the utility decision makers expressed:

- little interest in lowering startup times for 50- to 200-MWe solar power systems
- moderate interest in the concept's potential for process heat generation.
- strong interest in ease of adding capacity, potential for grid power storage, and ability to burn fossil fuels to provide for makeup capacity factor.

Finally, the multiattribute ranks agreed with those obtained using a holistic approach.

7.5 SENSITIVITY ANALYSIS CONCLUSIONS

Six conclusions are based on the results of the sensitivity analyses.

First, for all concepts, LEC is most sensitive to changes in the cost of the concentrators. Therefore, the ability to achieve concentrator cost reductions through the establishment of a mature solar concentrator manufacturing industry will have a significant impact on the economics of solar thermal power concepts.

Second, solar thermal plants are capital-intensive energy systems and, as such, are very sensitive to financial assumptions used for analysis. In addition, tax credits can significantly reduce the LEC of solar concepts.

Third, the PFCR/R concept is moderately sensitive to variations in energy conversion costs and O&M costs. The use of wet cooling in place of dry cooling will decrease the LEC of power generated from the PFCR/R by 2 to 8% depending on capacity factor. The LEC of the solar concepts shows little change when collector cleaning is eliminated. The effect of degrading collector performance would outweigh any benefit derived from the elimination of collector cleaning. Increases in annual O&M costs with respect to the reference costs result in moderate increases in the LEC.

Next, the LEC of the PFCR/R concept is relatively insensitive to changes in thermal transport, thermal storage, and tower and receiver costs. However, the cumulative effect of changes in each of these parameters can have a significant effect on the LEC.

Fifth, the effect of the cost of the Redox battery on the LEC of concepts using electric storage shows that improvements in Redox battery technology have the potential of moderately improving the economics of solar thermal concepts utilizing electric storage.

Finally, the PFDR/S and PFDR/B concepts are very sensitive to the cost of the distributed heat engine and receiver. Results indicate that, if the optimistic cost goals can be achieved, then the levelized energy costs estimated in this analysis for the PFDR/B and PFDR/S concepts can be significantly improved.

7.6 RECOMMENDATIONS

Four recommendations are offered:

1. The Point Focus Central Receiver/Rankine concept with molten salt as the transport and storage fluid should receive highest priority for commercial development as a large electric power plant.
2. The line focus systems (distributed and central receiver) should receive reduced priority for development as large electric power plants.
3. The LCNT should not be developed as a large electric power plant.
4. Predictions of performance for solar thermal concepts should be reported on the basis of a standard day, standard site (for example, Middletown, U.S.A.). Energy cost estimates should be based on annual performance.

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APPENDIX A

COMPONENT COST ESTIMATES

APPENDIX A

COMPONENT COST ESTIMATES

Many component cost estimates were generated as part of the economic analysis task. As discussed in Section 5.2, these estimates were used to derive generalized cost estimate scaling relationships (CESRs), which were then used to estimate costs during computer simulation runs. This appendix contains a number of the component cost estimates that served as inputs in developing the CESRs. The component cost estimates are presented to fill in the information gap that would exist if only results were presented.

For the most part, component cost estimates shown in this appendix are presented as an aggregation of subcomponent costs. For example, costs for the thermal transport subsystems are shown for the overall piping run, although costs were estimated on the subcomponent basis, i.e., for each type and size of pipe.

A.1 COLLECTOR COST ESTIMATES

Costs for concentrators and receivers, which jointly compose the collector subsystem, were estimated as described in Section 4.1. With the exception of receivers used in Point Focus Central Receiver concepts, all collector fields were modeled with a constant unit cost, in $\$/\text{m}^2$. Concentrator and receiver costs used in this study for all concepts except the Point Focus Central Receiver are shown in Table A.1.

Unlike other concepts, Point Focus Central Receiver concepts were analyzed using receiver configurations that were varied for different collector field sizes. In general, as collector field area increases, receiver size and tower height must also increase. Because no single receiver configuration was used, receiver costs vary with heliostat field size.

TABLE A.1. Collector Costs (1978 \$/m²)

<u>Concept</u>	<u>Concentrator Cost</u>	<u>Receiver Cost</u>
PFCR/R	80	15-26 ^(a)
PFCR/B	80	28-38 ^(a)
PFCR Barstow	80	13-15 ^(a)
PFDR/R	116	25
PFDR/B	116	40
PFDR/S	116	40
F MDF	65	25
LFCR	72	57
LFDR-TC	67	8
LFDR-TR	70	28
LCNT	62	29

(a) Receiver costs for PFCR concepts varied with concentrator field size.

Absorber units for PFCR/B (thermal and electric), PFCR/R, and PFCR/R-Barstow concepts and towers for Brayton and Rankine systems are the components of central receivers. Subcomponents include support structure, circulation and flow equipment, heat exchangers, and installation and checkout for the absorber units and the foundation, as well as the tower itself, for the tower subcomponents.

Cost differences among absorber units were based on the relative design requirements of absorber subcomponents for the cavity-gas (PFCR/B), cavity-molten salt (PFCR/R), and external-steam (PFCR/R-Barstow) absorbers. Absolute costs were based largely on information from Boeing (Davidson et al. 1978) concerning the Brayton receiver. Cost scaling relationships for each of the absorbers were developed based on estimated scaling coefficients for each of the subcomponents.

Many variables affect the cost of central receiver towers, not all of which could possibly be included in this study. Estimated tower costs reflect a survival wind velocity of 90 mph and horizontal and vertical acceleration

limits of 0.25 g. Absorber height and weight were also considered in this analysis, leading to separate cost estimating relationships for Brayton and Rankine systems. Differences in tower design for the PFCR/R and PFCR/R-Barstow concepts were minimal, and as a result, separate estimating relationships for these two Rankine concepts were not necessary.

Component costs for central receiver absorbers and central receiver towers are shown in Figures A.1 and A.2, respectively.

A.2 ENERGY TRANSPORT COSTS

A summary of the costs estimated for thermal energy transport equipment is shown in Table A.2. Costs shown for the piping account are a summation of individual costs for pipe, pipe supports, pipe fittings, and valves. The

FIGURE A.1. Component Costs for Central Receiver Absorbers

FIGURE A.2. Component Costs for Central Receiver Towers

insulation account contains costs for insulating the various diameters and lengths of pipe. Pumps, compressors, and other equipment relating to the circulating receiver fluid are included under circulation equipment. Costs for the receiver working fluid itself (draw salt or oil) are reported in the media account, and costs for tanks used to store the working fluid during draindown are listed under storage tank costs.

As discussed in Section 4.2.2, most of the thermal energy transport costs were based upon detailed cost estimates for specific field sizes. The exception to this is the PFCR/B concept, where cost estimates were based upon designs and estimated costs presented by Boeing (Davidson et al. 1978). These cost estimates were reviewed by PNL, then scaled to estimate costs at other

TABLE A.2. Thermal Energy Transport Costs (1978 \$)

Concept	Field Size (m ²)	Piping	Insulation	Circulation Equipment	Media	Storage Tank	Total
PFCR/R	500,000	1,235,000	40,000	1,920,000	17,000	18,000	3,230,000
PFCR/R	2,500,000	5,851,000	142,000	16,700,000	163,000	77,000	22,933,000
PFCR/R	4,500,000	7,699,000	171,000	38,400,000	359,000	128,000	46,757,000
PFCR Barstow	500,000	973,000	49,000	204,000	--	--	1,226,000
PFCR Barstow	2,500,000	3,261,000	146,000	446,000	--	--	3,853,000
PFCR Barstow	4,500,000	7,398,000	237,000	707,000	--	--	8,342,000
PFCR/B	500,000	--	--	--	--	--	5,660,000
PFCR/B	2,500,000	--	--	--	--	--	14,510,000
PFCR/B	4,500,000	--	--	--	--	--	20,470,000
PFDR/R	400,000	8,958,000	2,303,000	286,000	220,000	94,000	11,861,000
PFDR/R	2,160,000	49,193,000	14,032,000	1,605,000	2,573,000	449,000	67,852,000
PFDR/R	4,320,000	93,086,000	25,767,000	3,465,000	10,986,000	1,136,000	134,440,000
F MDF	876,000	3,959,000	2,229,000	430,000	429,000	143,000	7,190,000
F MDF	3,504,000	16,097,000	9,052,000	1,702,000	2,043,000	388,000	29,282,000
F MDF	7,008,000	33,174,000	18,636,000	3,459,000	5,290,000	713,000	61,272,000
LFCR	743,000	3,251,000	1,486,000	355,000	565,000	171,000	5,828,000
LFCR	2,973,000	14,049,000	6,624,000	1,439,000	4,212,000	616,000	26,940,000
LFCR	5,946,000	35,118,000	13,962,000	3,068,000	10,848,000	1,127,000	64,123,000
LFDR-TC	1,017,000	5,817,000	2,639,000	301,000	1,326,000	348,000	10,431,000
LFDR-TC	4,067,000	27,648,000	13,001,000	1,409,000	7,612,000	1,061,000	50,731,000
LFDR-TC	8,133,000	57,698,000	27,256,000	2,879,000	17,665,000	1,816,000	107,314,000
LFDR-TR	1,383,000	4,150,000	2,056,000	174,000	840,000	223,000	7,443,000
LFDR-TR	5,535,000	18,936,000	10,346,000	771,000	4,809,000	670,000	35,532,000
LFDR-TR	11,070,000	36,635,000	25,849,000	1,615,000	10,940,000	1,133,000	76,172,000
LCNT	501,000	18,277,000	3,794,000	307,000	694,000	230,000	23,302,000
LCNT	4,006,000	153,399,000	40,429,000	2,624,000	8,277,000	1,119,000	205,848,000
LCNT	7,512,000	305,841,000	81,262,000	5,411,000	33,280,000	2,668,000	428,462,000

field sizes. It should be noted that there is no difference in thermal transport requirements between the PFCR/B-EES and the PFCR/B-TES; thus, they are presented as one system in Table A.2.

The overall cost of thermal energy transport varies widely among the concepts, with highest costs overall (on a unit cost, $\$/m^2$ basis) being for distributed receiver concepts, such as the LCNT, and PFDR/R, which have extensive piping systems. Lowest overall costs were obtained by the Point Focus Central Receiver concepts, which require minimal piping systems.

The costs for piping components normally dominate the cost for thermal energy transport, except in the case of the PFCR/R, where costs for circulation equipment are larger than costs for piping. This arises due to the very large pumps required in the PFCR/R to pump large volumes of draw salt many hundreds of feet vertically to the receiver, and also from the inclusion of a hydraulic pressure recovery turbine following the downcomer. Cost estimates for the draw salt hydraulic turbine are subject to much more uncertainty than the other components for energy transport subsystems, but are felt to be conservative.

Electric transport subsystem costs, obtained from cost estimating manuals (Kolstad 1974; R. S. Means 1976), are shown in Table A.3. Component costs, as well as overall subsystem costs, scale linearly with field size because of the modularity of the electric transport design. The cost of the transformers dominates electric transport subsystem costs.

TABLE A.3. Electric Transport Subsystem Costs (1978 \$)

Component	Number of Dish Receivers		
	5,000	30,000	50,000
Transmission Cable	1,126,000	6,767,000	11,189,000
Transformers	1,430,000	8,580,000	14,300,000
Switchgear	456,000	2,732,000	4,554,000
Total	3,012,000	18,079,000	30,143,000

A.3 ENERGY CONVERSION COMPONENT/SUBCOMPONENT COSTS

Component and/or subcomponent costs for energy conversion are given in Tables A.4, A.5, and A.6 for Rankine, central Brayton, and distributed system concepts. Variation in costs with power level is shown where applicable.

Rankine energy conversion subcomponents include turbogenerator, steam generator, condenser, piping, cooling tower, and turbine building as shown in Table A.4. Cost differences between Rankine concepts are the result of different operating conditions at the turbogenerator. Turbine operating conditions affect all Rankine subcomponents except for the turbine building. Costs for the steam generator are also directly related to each concept's storage design, whether it be high- or intermediate-temperature draw salt, or intermediate- or low-temperature oil/rock storage. Steam generator costs for the PFCR/R concept are significantly higher than for other Rankine concepts due to a design that calls for stainless steel as opposed to carbon steel material. Condenser, piping, and cooling tower costs were estimated by the BNW-I dry cooling optimization code (Braun et al. 1977). The code trades off capital costs of heat rejection with Rankine cycle performance to arrive at its predicted cost. The costs listed in Table A.4 for the PFCR/R concept are for steam conditions of 950°F, 1450 psi. A late design change to the steam conditions of 950°F, 1800 psi necessitated a cost adjustment for this concept. Rather than reestimate individual subcomponents of the PFCR/R concept, the total energy conversion system cost was adjusted to reflect this change. For the 950°F, 1800 psi conditions, an overall cost increase of 1.3 percent was implemented based on information in Oganowski and Muller (1980).

Central Brayton energy conversion subcomponents include turbomachinery, recuperator, generator, precooler, intercooler, cooling tower, and turbine building. Except for the cooling tower and turbine building, cost estimates for the 1500°F closed-cycle system (see Table A.5) were based mostly on information from Boeing (Davidson et al. 1978). Costs for central Brayton energy conversion were based on the premise that, even with technological advances, systems greater than 100 MWe would require multiple units. A further assumption was that costs per kWe generating capacity installed would be constant for units between 50 and 100 MWe.

TABLE A.4. Rankine Energy Conversion Component/Subcomponent Costs
(Millions of 1978 Dollars)

Concept	Power Rating (MWe)	Turbo- Generator	Steam Generator	Condenser	Piping	Cooling Tower	Turbine Building	Total
PFCR	50	4.75	2.38	0.45	0.77	3.00	1.35	12.70
	100	8.40	5.95	0.88	1.50	5.82	2.00	24.55
	200	15.40	11.90	1.71	2.91	11.30	2.90	46.12
PFDR	50	4.75	1.77	0.49	0.81	3.29	1.35	12.46
	100	8.40	3.53	0.96	1.58	6.39	2.00	22.86
	200	15.40	7.06	1.86	3.07	12.41	2.90	42.70
FMDF	50	4.75	1.77	0.49	0.81	3.29	1.35	12.46
	100	8.40	3.53	0.96	1.58	6.39	2.00	22.86
	200	15.40	7.06	1.86	3.07	12.41	2.90	42.70
LFCR	50	4.75	1.77	0.49	0.81	3.29	1.35	12.46
	100	8.40	3.53	0.96	1.58	6.39	2.00	22.86
	200	15.40	7.06	1.86	3.07	12.41	2.90	42.70
LFDR-TR	50	4.75	1.77	0.49	0.81	3.29	1.35	12.46
	100	8.40	3.53	0.96	1.58	6.39	2.00	22.86
	200	15.40	7.06	1.86	3.07	12.41	2.90	42.70
LFDR-TC	50	5.15	1.28	0.77	1.28	5.18	1.35	15.01
	100	9.20	2.56	1.49	2.48	10.06	2.00	27.79
	200	17.20	5.12	2.89	4.82	19.53	2.90	52.46
LCNT	50	5.55	1.42	1.06	1.79	6.99	1.35	18.16
	100	10.20	2.85	2.06	3.48	13.57	2.00	34.16
	200	19.20	5.70	4.00	6.76	26.35	2.90	64.91
Barstow	100	8.40	2.56	0.88	1.50	5.82	2.00	21.16

TABLE A.5. Central Brayton Energy Conversion Component/Subcomponent Costs (1978 \$/kWe Installed Generating Capacity)

<u>Concept</u>	<u>Turbomachinery, Recuperator, Generator, Precooler, Intercooler</u>	<u>Cooling Tower</u>	<u>Turbine Building</u>	<u>Total</u>
PFCR/B	206	41.3	20	267.3

TABLE A.6. Distributed Brayton and Stirling Energy Conversion Component/Subcomponent Costs

<u>Concept</u>	<u>Total Cost for Integrated Heat Engine- Generator - Heat Rejection Unit - 1978 \$/kWe Installed Generating Capacity</u>
PFDR/S	205.5
PFDR/B	246.5

Both distributed Brayton and Stirling energy conversion systems consist of an integrated heat engine-generator-heat rejection unit. Design and cost for these units is identical with that reported in the small power systems study. Costs are constant \$/kWe installed generating capacity due to the large number of units required for even small plant sizes.

A.4 THERMAL STORAGE COSTS

Component cost estimates for oil/rock thermal storage systems are presented in Tables A.7 and A.8. Component costs for the low-temperature (450°F) system are higher than the corresponding component costs for the intermediate-temperature system. The lower the temperature, the larger the storage volume (and, therefore, the more equipment) required to achieve a given storage capacity. The cost of the oil/rock storage medium dominates the other component costs.

Component cost estimates for draw salt thermal storage systems are presented in Tables A.9 and A.10. The storage medium dominates the costs of draw salt storage. The cost of the recirculation component is higher for the

TABLE A.7. Low-Temperature (450°F) Oil/Rock Storage
Subsystem Component Costs (1977 \$)

Plant Size	Component	Storage Subsystem Capacity		
		~3 Hours	~6 Hours	~18 Hours
50 MWe	Containment	912,000	1,767,000	4,210,000
	Medium	1,910,000	3,640,000	10,590,000
	Recirculation	1,198,000	1,333,000	2,400,000
	<u>TOTAL</u>	<u>4,020,000</u>	<u>6,740,000</u>	<u>17,200,000</u>
100 MWe	Containment	1,808,000	3,040,000	8,440,000
	Medium	3,800,000	7,280,000	21,160,000
	Recirculation	2,292,000	2,590,000	3,940,000
	<u>TOTAL</u>	<u>7,900,000</u>	<u>12,910,000</u>	<u>33,540,000</u>
200 MWe	Containment	3,080,000	5,820,000	16,910,000
	Medium	7,590,000	14,540,000	42,340,000
	Recirculation	5,240,000	6,210,000	10,010,000
	<u>TOTAL</u>	<u>15,910,000</u>	<u>26,570,000</u>	<u>69,260,000</u>

TABLE A.8. Intermediate-Temperature (580°F) Oil/Rock Storage
Subsystem Component Costs (1977 \$)

Plant Size	Component	Storage Subsystem Capacity		
		~3 Hours	~6 Hours	~18 Hours
50 MWe	Containment	616,000	800,000	1,973,000
	Medium	856,000	1,650,000	4,770,000
	Recirculation	478,000	550,000	827,000
	<u>TOTAL</u>	<u>1,950,000</u>	<u>3,000,000</u>	<u>7,570,000</u>
100 MWe	Containment	850,000	1,676,000	3,820,000
	Medium	1,720,000	3,280,000	9,520,000
	Recirculation	1,030,000	1,164,000	1,800,000
	<u>TOTAL</u>	<u>3,600,000</u>	<u>6,120,000</u>	<u>15,140,000</u>
200 MWe	Containment	1,747,000	2,702,000	7,530,000
	Medium	3,440,000	6,560,000	19,000,000
	Recirculation	1,983,000	2,268,000	3,380,000
	<u>TOTAL</u>	<u>7,170,000</u>	<u>11,530,000</u>	<u>29,910,000</u>

high-temperature system because of the use of stainless steel. Although stainless steel must also be used for containment vessels at the high temperature,

TABLE A.9. Intermediate-Temperature (850°F) Draw Salt Storage Subsystem Component Costs (1977 \$)

Plant Size	Component	Storage Subsystem Capacity		
		~ 3 Hours	~ 6 Hours	~ 18 Hours
50 MWe	Containment	730,000	1,096,000	2,076,000
	Medium	1,392,000	2,635,000	7,614,000
	Recirculation	208,000	209,000	230,000
	<u>TOTAL</u>	<u>2,330,000</u>	<u>3,940,000</u>	<u>9,920,000</u>
100 MWe	Containment	1,169,000	1,640,000	5,306,000
	Medium	2,777,000	5,263,000	15,201,000
	Recirculation	440,000	587,000	733,000
	<u>TOTAL</u>	<u>4,390,000</u>	<u>7,490,000</u>	<u>21,240,000</u>
200 MWe	Containment	1,715,000	2,331,000	7,104,000
	Medium	5,540,000	9,944,000	30,400,000
	Recirculation	2,295,000	2,575,000	3,576,000
	<u>TOTAL</u>	<u>9,550,000</u>	<u>14,850,000</u>	<u>41,080,000</u>

TABLE A.10. High-Temperature (1000°F) Draw Salt Storage Subsystem Component Costs (1977 \$)

Plant Size	Component	Storage Subsystem Capacity		
		~ 3 Hours	~ 6 Hours	~ 18 Hours
50 MWe	Containment	553,000	768,000	1,561,000
	Medium	886,000	1,667,000	4,823,000
	Recirculation	221,000	225,000	226,000
	<u>TOTAL</u>	<u>1,660,000</u>	<u>2,660,000</u>	<u>6,610,000</u>
100 MWe	Containment	861,000	1,241,000	2,289,000
	Medium	1,763,000	3,320,000	9,564,000
	Recirculation	756,000	759,000	787,000
	<u>TOTAL</u>	<u>3,380,000</u>	<u>5,320,000</u>	<u>12,640,000</u>
200 MWe	Containment	1,289,000	1,879,000	4,577,000
	Medium	3,515,000	6,610,000	19,078,000
	Recirculation	3,006,000	3,551,000	5,125,000
	<u>TOTAL</u>	<u>7,810,000</u>	<u>12,040,000</u>	<u>28,780,000</u>

the overall cost of containment at the higher temperature is less because the medium volume required for a given storage capacity is less than at the low temperature.

A.5 OTHER PLANT COMPONENT COSTS

Other plant components are structures, land and site improvements, power conditioning, instrumentation and control, spare parts, and service facilities. Although other plant components are poor cost differentiators among concepts, as discussed in Section 4.2.5, they do contribute a significant part of the levelized energy cost. Estimated costs for each of the components are shown in Tables A.11 through A.14. Cost variations among concepts and/or power levels are noted under the component headings.

TABLE A.11. Other Plant Component Costs

<u>Component</u>	<u>Plant Power Rating (MWe)</u>	<u>Total Cost (1978 \$)</u>
Structures	50	753,000
	100	967,000
	200	1,238,000
Land and Site Improvements	N.A.	
• Purchase		5,000/acre
• Development		2,770/acre
Power Conditioning	50	1,033,000
	100	1,478,000
	200	2,115,000
Instrumentation and Control		
• Master Control	N.A.	1,100,000(a)
• Nonconcentrator-related Control	N.A.	3% of receiver, storage, transport, structures, power conditioning, and energy conversion capital cost
• Concentrator-related Control	N.A.	Varies with concept; see Table A.12.
Spare Parts		Varies with power plant rating; see Table A.13.
Service Facilities		Varies with power plant rating and engine type; see Table A.14.

(a) LCNT master control cost = \$733,000.

TABLE A.12. Concentrator-Related Control Costs

<u>Concept</u>	<u>Percentage of Concentrator Cost</u>
PFCR/R, PFCR/R - Barstow	1.00
PFCR/B - Thermal and Electric	1.00
PFDR/R, PFDR/B, PFDR/S	0.34
F MDF	0.33
LFCR	0.10
LFDR-TC	0.20
LFDR-TR	0.20
LCNT	0.05

TABLE A.13. Spare Parts Cost

<u>Plant Power Rating (MWe)</u>	<u>Percentage of Collector Capital Cost</u>	<u>Percentage of Noncollector Capital Cost</u>
50	0.095	0.165
100	0.065	0.135
200	0.045	0.110

TABLE A.14. Service Facilities Costs

<u>Engine Type</u>	<u>Plant Power Rating (MWe)</u>	<u>Percentage of Collector Capital Cost</u>	<u>Percentage of Noncollector Capital Cost</u>
Rankine	50	0.235	1.625
	100	0.185	1.535
	200	0.155	1.475
Stirling, Brayton	50	0.235	1.475
	100	0.185	1.395
	200	0.155	1.345

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APPENDIX B
COMPUTER RUNS

PFCR RANKINE 50MW
50 MW
08-08-80 18:02:45

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	300.	600.	191.	273.	356.	443.	533.	636.	773.	1000.
STORAGE SIZE (HRS)	.00	12.00	.00	2.19	4.69	7.30	10.00	12.53	14.59	18.00
STORAGE CAPACITY (1000 KWH)	0.	1854.	0.	335.	720.	1124.	1543.	1937.	2259.	2795.
GENERATING CAPACITY (MW)	50.66	51.14	50.49	50.62	50.75	50.89	51.03	51.20	51.42	51.78
FIELD EFFICIENCY	.485	.475	.491	.486	.485	.483	.478	.474	.471	.465
TRANSPORT EFFICIENCY	.989	.989	.989	.989	.989	.989	.989	.989	.989	.988
STORAGE EFFICIENCY	*****	.983	*****	.719	.985	.985	.984	.983	.982	.979
ENERGY CONV. EFF. (FIELD)	.374	.380	.361	.373	.378	.379	.380	.380	.382	.383
ENERGY CONV. EFF. (STORAGE)	*****	.381	*****	.273	.376	.379	.380	.381	.382	.382
SYSTEM EFFICIENCY	.153	.173	.161	.169	.173	.174	.173	.170	.160	.139
CAPACITY FACTOR	.30	.67	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.323	.377	.265	.305	.332	.352	.368	.382	.399	.419
RECEIVER (\$/M**2)	23.	18.	26.	23.	22.	20.	19.	18.	17.	16.
FRACTION OF LEC	.092	.087	.087	.089	.090	.089	.088	.086	.085	.082
TRANSPORT (\$/M**2)	5.8	6.7	5.2	5.7	6.0	6.3	6.6	6.8	7.1	7.5
FRACTION OF LEC	.023	.032	.017	.022	.025	.028	.030	.033	.035	.039
STORAGE (\$/KWH)	.0	2.5	.0	2.2	2.4	2.5	2.5	2.5	2.5	2.5
FRACTION OF LEC	.000	.036	.000	.011	.020	.028	.033	.037	.037	.037
ENERGY CONV. (\$/KW)	267.	269.	266.	266.	267.	268.	268.	269.	270.	272.
FRACTION OF LEC	.179	.106	.230	.186	.156	.133	.116	.101	.087	.071
BALANCE OF PLANT (\$/KW)	134.	199.	112.	129.	147.	165.	185.	206.	234.	281.
FRACTION OF LEC	.090	.078	.097	.090	.086	.082	.080	.077	.076	.073
INDIRECT/CONT. (\$/KW)	263.	455.	201.	252.	304.	358.	414.	476.	557.	690.
FRACTION OF LEC	.177	.179	.174	.176	.177	.178	.179	.179	.180	.180
TOTAL INITIAL CAP. (\$/KW)	1315.	2277.	1005.	1258.	1519.	1791.	2071.	2382.	2784.	3449.
FRACTION OF LEC	.884	.894	.871	.880	.885	.890	.893	.895	.899	.902
REPLACEMENT CAPITAL (\$/KW)	0.	3.	0.	1.	1.	2.	3.	4.	4.	5.
FRACTION OF LEC	.000	.002	.000	.000	.001	.001	.001	.002	.002	.002
OPER. AND MAINT. (1000 \$/YR)	584.	894.	502.	578.	658.	742.	829.	924.	1043.	1241.
FRACTION OF LEC	.116	.104	.129	.120	.114	.109	.106	.103	.100	.096
LEC (MILLS/KWH)	92.	70.	107.	88.	79.	75.	72.	70.	72.	79.

PFCR RANKINE 100MW
100 MW
08-08-80 17:49:01

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	500.	1250.	386.	566.	743.	917.	1097.	1296.	1592.	2153.
STORAGE SIZE (HRS)	.00	12.00	.00	.79	2.91	7.00	10.16	12.55	15.55	18.00
STORAGE CAPACITY (1000 KWH)	0.	3673.	0.	240.	887.	2137.	3108.	3844.	4772.	5533.
GENERATING CAPACITY (MW)	101.62	103.39	101.35	101.77	102.19	102.60	103.03	103.50	104.20	105.52
FIELD EFFICIENCY	.480	.461	.485	.477	.470	.467	.463	.460	.454	.444
TRANSPORT EFFICIENCY	.984	.984	.984	.984	.984	.984	.984	.984	.984	.983
STORAGE EFFICIENCY	*****	.985	*****	.993	.989	.986	.985	.985	.984	.982
ENERGY CONV. EFF. (FIELD)	.371	.383	.365	.374	.382	.383	.383	.383	.384	.386
ENERGY CONV. EFF. (STORAGE)	*****	.384	*****	.384	.380	.382	.383	.384	.385	.385
SYSTEM EFFICIENCY	.163	.168	.159	.164	.166	.168	.169	.167	.156	.130
CAPACITY FACTOR	.26	.68	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.328	.397	.295	.338	.364	.376	.388	.399	.412	.433
RECEIVER (\$/M**2)	18.	16.	19.	18.	17.	17.	16.	16.	15.	14.
FRACTION OF LEC	.075	.078	.071	.076	.078	.078	.078	.078	.078	.078
TRANSPORT (\$/M**2)	6.5	7.9	6.1	6.6	7.0	7.4	7.7	7.9	8.3	8.9
FRACTION OF LEC	.026	.039	.023	.028	.032	.035	.037	.040	.043	.048
STORAGE (\$/KWH)	.0	2.7	.0	4.8	3.2	2.8	2.7	2.7	2.7	2.7
FRACTION OF LEC	.000	.039	.000	.009	.017	.031	.038	.040	.041	.037
ENERGY CONV. (\$/KW)	248.	252.	247.	248.	249.	250.	251.	252.	254.	256.
FRACTION OF LEC	.203	.100	.236	.185	.152	.128	.111	.097	.082	.064
BALANCE OF PLANT (\$/KW)	99.	180.	88.	107.	125.	144.	164.	185.	216.	274.
FRACTION OF LEC	.081	.071	.084	.080	.077	.074	.072	.071	.070	.069
INDIRECT/CONT. (\$/KW)	218.	456.	185.	239.	294.	352.	409.	471.	561.	725.
FRACTION OF LEC	.178	.181	.177	.179	.180	.180	.181	.181	.182	.182
TOTAL INITIAL CAP. (\$/KW)	1089.	2282.	927.	1197.	1470.	1759.	2047.	2353.	2804.	3626.
FRACTION OF LEC	.892	.905	.887	.895	.899	.902	.904	.906	.908	.911
REPLACEMENT CAPITAL (\$/KW)	0.	3.	0.	0.	1.	2.	3.	4.	4.	5.
FRACTION OF LEC	.000	.002	.000	.000	.001	.001	.001	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	887.	1582.	800.	948.	1104.	1276.	1445.	1623.	1884.	2350.
FRACTION OF LEC	.108	.093	.113	.105	.100	.097	.095	.093	.090	.087
LEC (MILLS/KWH)	86.	68.	97.	83.	76.	72.	70.	69.	71.	82.

PFCR RANKINE 200MW
200 MW
08-08-80 17:48:00

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1000.	2500.	789.	1145.	1507.	1881.	2260.	2680.	3309.	4571.
STORAGE SIZE (HRS)	.00	12.00	.00	.87	3.09	7.57	10.56	13.08	15.93	18.00
STORAGE CAPACITY (1000 KWH)	0.	7224.	0.	521.	1851.	4546.	6351.	7878.	9609.	10871.
GENERATING CAPACITY (MW)	203.61	207.70	203.03	204.01	205.00	206.01	207.05	208.20	209.91	213.36
FIELD EFFICIENCY	.465	.441	.469	.462	.456	.448	.443	.439	.432	.416
TRANSPORT EFFICIENCY	.981	.982	.981	.981	.982	.982	.982	.982	.981	.980
STORAGE EFFICIENCY	*****	.987	*****	.993	.989	.987	.987	.987	.986	.985
ENERGY CONV. EFF. (FIELD)	.378	.389	.371	.381	.388	.389	.389	.389	.390	.392
ENERGY CONV. EFF. (STORAGE)	*****	.390	*****	.390	.386	.388	.390	.390	.391	.391
SYSTEM EFFICIENCY	.160	.164	.157	.161	.164	.164	.164	.162	.151	.122
CAPACITY FACTOR	.26	.66	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.343	.402	.315	.352	.375	.386	.396	.405	.417	.434
RECEIVER (\$/M**2)	16.	15.	16.	15.	15.	15.	15.	15.	15.	15.
FRACTION OF LEC	.067	.075	.062	.068	.071	.072	.074	.075	.077	.081
TRANSPORT (\$/M**2)	7.5	9.2	7.1	7.7	8.2	8.6	9.0	9.3	9.7	10.4
FRACTION OF LEC	.032	.046	.028	.034	.038	.041	.044	.047	.051	.057
STORAGE (\$/KWH)	.0	2.8	.0	6.0	3.5	3.0	2.8	2.8	2.8	2.7
FRACTION OF LEC	.000	.041	.000	.012	.020	.035	.040	.042	.042	.035
ENERGY CONV. (\$/KW)	238.	243.	238.	239.	240.	241.	242.	244.	246.	249.
FRACTION OF LEC	.204	.098	.237	.184	.149	.124	.106	.092	.077	.059
BALANCE OF PLANT (\$/KW)	86.	169.	75.	94.	114.	135.	156.	179.	213.	280.
FRACTION OF LEC	.074	.068	.075	.072	.071	.069	.068	.068	.067	.067
INDIRECT/CONT. (\$/KW)	210.	453.	180.	235.	291.	354.	415.	482.	580.	771.
FRACTION OF LEC	.180	.182	.179	.180	.181	.182	.182	.182	.183	.183
TOTAL INITIAL CAP. (\$/KW)	1049.	2267.	899.	1174.	1457.	1772.	2077.	2409.	2901.	3857.
FRACTION OF LEC	.900	.911	.896	.902	.906	.908	.910	.911	.913	.916
REPLACEMENT CAPITAL (\$/KW)	0.	3.	0.	0.	1.	2.	3.	4.	4.	5.
FRACTION OF LEC	.000	.002	.000	.000	.001	.001	.001	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	1575.	2944.	1411.	1711.	2026.	2384.	2730.	3105.	3657.	4727.
FRACTION OF LEC	.100	.088	.104	.097	.093	.091	.089	.087	.085	.083
LEC (MILLS/KWH)	83.	70.	93.	80.	74.	72.	70.	70.	74.	87.

PFCR RANKINE-BARSTOW 100MW
100 MW
08-08-80 17:53:14

DESIGN POINT CAPACITY FACTORS

	6 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1250.	1250.	522.	777.	1094.	1883.	*****	*****	*****	*****
STORAGE SIZE (HRS)	6.00	6.00	6.00	6.00	6.00	6.00	*****	*****	*****	*****
STORAGE CAPACITY (1000 KWH)	1992.	1992.	1992.	1992.	1992.	1992.	*****	*****	*****	*****
GENERATING CAPACITY (MW)	103.49	103.49	102.18	102.64	103.21	104.63	*****	*****	*****	*****
FIELD EFFICIENCY	.375	.375	.390	.383	.377	.365	*****	*****	*****	*****
TRANSPORT EFFICIENCY	.987	.987	.986	.987	.987	.985	*****	*****	*****	*****
STORAGE EFFICIENCY	.959	.959	.079	.886	.953	.961	*****	*****	*****	*****
ENERGY CONV. EFF. (FIELD)	.346	.346	.336	.343	.345	.347	*****	*****	*****	*****
ENERGY CONV. EFF. (STORAGE)	.247	.247	.021	.231	.246	.249	*****	*****	*****	*****
SYSTEM EFFICIENCY	.109	.109	.118	.119	.113	.083	*****	*****	*****	*****
CAPACITY FACTOR	.44	.44	.20	.30	.40	.50	*****	*****	*****	*****
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	*****	*****	*****	*****
FRACTION OF LEC	.408	.408	.292	.347	.392	.453	*****	*****	*****	*****
RECEIVER (\$/M**2)	13.	13.	15.	14.	14.	13.	*****	*****	*****	*****
FRACTION OF LEC	.069	.069	.056	.063	.067	.072	*****	*****	*****	*****
TRANSPORT (\$/M**2)	2.0	2.0	2.3	2.2	2.1	1.9	*****	*****	*****	*****
FRACTION OF LEC	.010	.010	.009	.009	.010	.011	*****	*****	*****	*****
STORAGE (\$/KWH)	5.3	5.3	5.3	5.3	5.3	5.3	*****	*****	*****	*****
FRACTION OF LEC	.043	.043	.073	.059	.047	.032	*****	*****	*****	*****
ENERGY CONV. (\$/KW)	219.	219.	216.	217.	218.	221.	*****	*****	*****	*****
FRACTION OF LEC	.089	.089	.151	.121	.098	.067	*****	*****	*****	*****
BALANCE OF PLANT (\$/KW)	174.	174.	103.	128.	159.	235.	*****	*****	*****	*****
FRACTION OF LEC	.071	.071	.072	.072	.071	.071	*****	*****	*****	*****
INDIRECT/CONT. (\$/KW)	423.	423.	234.	300.	383.	586.	*****	*****	*****	*****
FRACTION OF LEC	.173	.173	.163	.168	.171	.176	*****	*****	*****	*****
TOTAL INITIAL CAP. (\$/KW)	2115.	2115.	1169.	1502.	1914.	2930.	*****	*****	*****	*****
FRACTION OF LEC	.863	.863	.817	.839	.857	.880	*****	*****	*****	*****
REPLACEMENT CAPITAL (\$/KW)	109.	109.	109.	109.	109.	109.	*****	*****	*****	*****
FRACTION OF LEC	.051	.051	.087	.070	.056	.037	*****	*****	*****	*****
OPER. AND MAINT. (1000 \$/YR)	1421.	1421.	925.	1099.	1315.	1848.	*****	*****	*****	*****
FRACTION OF LEC	.086	.086	.096	.091	.087	.082	*****	*****	*****	*****
LEC (MILLS/KWH)	102.	102.	132.	110.	103.	123.	*****	*****	*****	*****

PECR BRAYTON-ELECTRIC STORAGE 50 MW
08-21-90 08:19:20

DESIGN POINT CAPACITY FACTORS

	0.50	0.60	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	250.	250.	164.	248.	363.	466.	582.	713.	879.	1182.
STORAGE SIZE (HRS)	.00	.00	.00	.00	1.88	4.98	8.45	10.69	13.18	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	117.	309.	525.	665.	820.	1122.
GENERATING CAPACITY (MW)	50.00	50.00	32.86	49.66	72.52	93.18	116.30	142.55	175.73	236.36
FIELD EFFICIENCY	.480	.480	.484	.480	.475	.472	.467	.463	.459	.452
TRANSPORT EFFICIENCY	.989	.989	.991	.989	.987	.986	.984	.983	.981	.979
STORAGE EFFICIENCY	*****	*****	*****	*****	.450	.719	.719	.718	.718	.716
ENERGY CONV. EFF. (FIELD)	.483	.483	.484	.483	.369	.363	.350	.336	.313	.264
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.187	.187	.188	.187	.170	.167	.159	.152	.141	.118
CAPACITY FACTOR	.30	.30	.20	.30	.40	.50	.60	.70	.80	.90

ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF IEC	.258	.258	.239	.258	.239	.244	.249	.255	.262	.269
RECEIVER (\$/M**2)	34.	34.	37.	34.	32.	31.	30.	29.	28.	26.
FRACTION OF IEC	.111	.111	.112	.111	.096	.094	.092	.091	.090	.088
TRANSPORT (\$/M**2)	15.1	15.1	18.9	15.1	12.9	11.7	10.6	9.8	9.0	7.9
FRACTION OF IEC	.043	.043	.054	.043	.039	.036	.033	.031	.029	.027
STORAGE (\$/KWH)	.0	.0	.0	.0	87.6	42.3	31.0	27.6	25.2	22.4
FRACTION OF IEC	.000	.000	.000	.000	.084	.086	.087	.082	.077	.072
ENERGY CONV. (\$/KWH)	267.	267.	176.	266.	382.	498.	622.	762.	939.	1264.
FRACTION OF IEC	.172	.172	.160	.172	.160	.163	.166	.171	.175	.180
BALANCE OF PLANT (\$/KWH)	127.	127.	105.	127.	166.	195.	228.	263.	308.	389.
FRACTION OF IEC	.082	.082	.096	.082	.068	.064	.061	.059	.057	.055
INDIRECT/COST. (\$/KWH)	261.	261.	181.	259.	416.	524.	643.	770.	927.	1213.
FRACTION OF IEC	.165	.168	.165	.168	.171	.172	.172	.172	.173	.173
TOTAL INITIAL CAP. (\$/KWH)	1303.	1303.	906.	1295.	2081.	2619.	3216.	3848.	4634.	6066.
FRACTION OF IEC	.840	.840	.825	.840	.857	.859	.860	.861	.863	.864
REPLACEMENT CAPITAL (\$/KWH)	50.	50.	33.	50.	77.	103.	133.	164.	202.	273.
FRACTION OF IEC	.037	.037	.034	.037	.036	.039	.041	.042	.043	.044
OPER. AND MAINT. (1000 \$/YR)	644.	644.	519.	642.	876.	1054.	1251.	1457.	1712.	2178.
FRACTION OF IEC	.123	.123	.140	.123	.107	.102	.099	.097	.094	.092
IEC (MILLS/KWH)	95.	95.	102.	95.	112.	113.	115.	118.	124.	144.

PECR BRAYTON-ELECTRIC STORAGE 100 MW
 100 MW
 08-19-80 18:46:04

DESIGN POINT CAPACITY FACTORS

	STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	500.	500.	332.	502.	718.	949.	1191.	1444.	1828.	2435.
STORAGE SIZE (HPS)	.00	.00	.00	.03	2.61	5.38	8.29	11.33	13.97	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	3.	324.	668.	1030.	1407.	1735.	2238.
GENERATING CAPACITY (MW)	100.00	100.00	66.33	100.43	143.53	189.72	238.24	288.78	365.55	487.10
FIELD EFFICIENCY	.470	.470	.475	.470	.462	.457	.452	.448	.440	.433
TRANSPORT EFFICIENCY	.945	.985	.988	.985	.982	.980	.978	.976	.974	.970
STORAGE EFFICIENCY	*****	*****	*****	.006	.627	.720	.720	.720	.719	.719
ENERGY CONV. EFF. (FIELD)	.403	.403	.404	.403	.381	.363	.349	.338	.311	.265
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	.000	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.184	.184	.184	.184	.173	.163	.156	.149	.136	.114
CAPACITY FACTOR	.30	.30	.20	.30	.40	.50	.60	.70	.80	.90

ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	89.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.281	.281	.268	.241	.251	.256	.260	.263	.269	.275
RECEIVER (\$/M**2)	29.	29.	30.	29.	28.	28.	28.	27.	27.	28.
FRACTION OF LEC	.102	.102	.101	.087	.088	.089	.090	.090	.092	.094
TRANSPORT (\$/M**2)	11.3	11.3	13.4	11.3	9.7	8.7	7.9	7.3	6.6	5.9
FRACTION OF LEC	.040	.040	.045	.034	.031	.028	.026	.024	.022	.020
STORAGE (\$/KWH)	.0	.0	.0	5301.7	67.2	40.2	31.3	26.9	24.6	22.4
FRACTION OF LEC	.000	.000	.000	.102	.095	.091	.088	.086	.079	.071
ENERGY CONV. (\$/KW)	267.	267.	177.	268.	384.	507.	637.	772.	977.	1302.
FRACTION OF LEC	.188	.188	.179	.161	.167	.171	.174	.176	.180	.183
BALANCE OF PLANT (\$/KW)	102.	102.	81.	110.	140.	172.	205.	240.	291.	372.
FRACTION OF LEC	.072	.072	.082	.066	.061	.058	.056	.055	.054	.052
INDIRECT/CONT. (\$/KW)	243.	243.	167.	288.	397.	513.	635.	762.	945.	1234.
FRACTION OF LEC	.171	.171	.169	.173	.173	.173	.174	.174	.174	.174
TOTAL INITIAL CAP. (\$/KW)	1214.	1214.	835.	1441.	1985.	2566.	3175.	3809.	4725.	6171.
FRACTION OF LEC	.854	.854	.845	.865	.867	.867	.868	.868	.869	.870
REPLACEMENT CAPITAL (\$/KW)	50.	50.	33.	51.	77.	106.	136.	167.	211.	280.
FRACTION OF LEC	.041	.041	.039	.035	.039	.041	.042	.044	.044	.045
OPER. AND MAINT. (1000 \$/YR)	1017.	1017.	778.	1124.	1468.	1834.	2218.	2616.	3190.	4093.
FRACTION OF LEC	.106	.106	.117	.100	.095	.092	.090	.088	.087	.085
LEC (MILLS/KWH)	88.	88.	92.	103.	106.	110.	113.	116.	126.	146.

PEER BRAYTON-ELECTRIC STORAGE 200MW
 200 MW
 08-19-80 19:43:26

DESIGN POINT CAPACITY FACTORS

	STR	DPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1000.	1000.	680.	1039.	1478.	1975.	2485.	3025.	3851.	5333.
STORAGE SIZE (HRS)	.00	.00	.00	.24	2.87	5.85	8.91	12.07	14.55	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	59.	711.	1451.	2210.	2997.	3613.	4469.
GENERATING CAPACITY (MW)	200.00	200.00	135.92	207.89	295.61	395.00	496.94	604.96	770.25	*****
FIELD EFFICIENCY	.456	.456	.464	.455	.447	.438	.432	.428	.415	.402
TRANSPORT EFFICIENCY	.980	.980	.983	.980	.976	.973	.970	.968	.964	.958
STORAGE EFFICIENCY	*****	*****	*****	.057	.688	.720	.720	.720	.720	.720
ENERGY CONV. EFF. (FIELD)	.400	.400	.402	.398	.378	.360	.346	.335	.310	.260
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	.000	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.180	.180	.182	.179	.168	.157	.149	.143	.129	.105
CAPACITY FACTOR	.29	.29	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.295	.295	.288	.252	.259	.263	.265	.267	.271	.276
RECEIVER (\$/M**2)	27.	27.	27.	27.	27.	28.	28.	29.	30.	31.
FRACTION OF LEC	.100	.100	.098	.085	.088	.091	.093	.096	.100	.107
TRANSPORT (\$/M**2)	8.5	8.5	10.0	8.4	7.2	6.4	5.8	5.4	4.9	4.2
FRACTION OF LEC	.031	.031	.036	.026	.023	.021	.019	.018	.016	.015
STORAGE (\$/KWH)	0.	0.	0.	592.3	62.5	38.2	30.2	26.2	24.2	22.4
FRACTION OF LEC	.000	.000	.000	.106	.097	.092	.089	.086	.077	.065
ENERGY CONV. (\$/KW)	267.	267.	182.	278.	395.	529.	664.	809.	1029.	1426.
FRACTION OF LEC	.197	.197	.192	.169	.173	.176	.177	.178	.181	.185
BALANCE OF PLANT (\$/KW)	88.	88.	68.	99.	129.	164.	200.	237.	293.	393.
FRACTION OF LEC	.065	.065	.072	.060	.057	.055	.053	.052	.052	.051
INDIRECT/CONT. (\$/KW)	233.	233.	162.	288.	398.	524.	653.	791.	991.	1348.
FRACTION OF LEC	.172	.172	.171	.174	.174	.174	.174	.174	.175	.175
TOTAL INITIAL CAP. (\$/KW)	1165.	1165.	809.	1438.	1990.	2619.	3266.	3954.	4955.	6742.
FRACTION OF LEC	.861	.861	.856	.872	.872	.872	.872	.872	.873	.874
REPLACEMENT CAPITAL (\$/KW)	50.	50.	34.	53.	80.	111.	142.	175.	222.	303.
FRACTION OF LEC	.043	.043	.041	.037	.040	.042	.043	.044	.045	.045
OPER. AND MAINT. (1000 \$/YR)	1754.	1754.	1306.	2023.	2704.	3475.	4265.	5102.	6320.	8485.
FRACTION OF LEC	.096	.096	.102	.091	.088	.086	.084	.083	.082	.081
LEC (MILLS/KWH)	86.	86.	88.	102.	106.	111.	116.	120.	131.	159.

PECR BRAYTON-THERMAL STORAGE 50 MW
08-20-80 12:28:07

DESIGN POINT CAPACITY FACTORS

	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90		
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	250.	250.	160.	248.	360.	449.	544.	662.	818.	1194.
STORAGE SIZE (HRS)	.00	.00	.00	.00	1.79	4.46	7.33	9.93	12.28	17.32
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	294.	738.	1216.	1651.	2046.	2907.
GENERATING CAPACITY (MW)	50.00	50.00	50.00	50.00	51.70	54.26	57.02	59.53	61.81	66.77
FIELD EFFICIENCY	.430	.480	.485	.480	.475	.473	.468	.464	.461	.452
TRANSPORT EFFICIENCY	.989	.989	.991	.989	.987	.986	.985	.983	.982	.978
STORAGE EFFICIENCY	*****	*****	*****	*****	.505	.845	.839	.835	.833	.810
ENERGY CONV. EFF. (FIELD)	.408	.408	.407	.408	.409	.409	.409	.409	.409	.410
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.244	.411	.414	.416	.417	.419
SYSTEM EFFICIENCY	.186	.186	.194	.186	.171	.172	.170	.164	.151	.117
CAPACITY FACTOR	.30	.30	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.258	.258	.206	.257	.270	.262	.257	.260	.269	.287
RECEIVER (\$/M**2)	34.	34.	30.	34.	32.	31.	30.	29.	28.	26.
FRACTION OF LEC	.111	.111	.097	.111	.109	.101	.096	.094	.094	.094
TRANSPORT (\$/M**2)	15.1	15.1	18.2	15.1	13.0	11.8	10.9	10.1	9.2	7.9
FRACTION OF LEC	.049	.049	.047	.049	.044	.039	.035	.033	.031	.028
STORAGE (\$/KWH)	.0	.0	.0	.0	23.1	23.1	23.1	23.1	23.1	23.1
FRACTION OF LEC	.000	.000	.000	.000	.064	.125	.166	.187	.195	.202
ENERGY CONV. (\$/KW)	267.	267.	267.	267.	276.	290.	305.	318.	330.	357.
FRACTION OF LEC	.172	.172	.216	.173	.130	.106	.090	.078	.068	.054
BALANCE OF PLANT (\$/KW)	127.	127.	108.	127.	157.	186.	217.	251.	292.	388.
FRACTION OF LEC	.092	.082	.088	.082	.074	.068	.064	.061	.060	.058
INDIRECT/COST. (\$/KW)	261.	261.	202.	259.	367.	480.	600.	727.	871.	1203.
FRACTION OF LEC	.168	.168	.163	.168	.173	.175	.177	.178	.179	.181
TOTAL INITIAL CAP. (\$/KW)	1303.	1303.	1011.	1297.	1837.	2399.	2999.	3634.	4355.	6014.
FRACTION OF LEC	.840	.840	.817	.839	.863	.876	.884	.891	.896	.904
REPLACEMENT CAPITAL (\$/KW)	50.	50.	50.	50.	52.	55.	58.	60.	62.	67.
FRACTION OF LEC	.037	.037	.047	.037	.028	.023	.019	.017	.015	.012
OPER. AND MAINT. (1000 \$/YR)	644.	644.	570.	643.	787.	939.	1102.	1273.	1464.	1903.
FRACTION OF LEC	.123	.123	.136	.123	.109	.102	.096	.092	.089	.085
LEC (MILLS/KWH)	95.	95.	115.	95.	99.	101.	105.	108.	113.	137.

PECR BRAYTON-THERMAL STORAGE 100MW

100 MW

08-19-80 20:16:02

DESIGN POINT CAPACITY FACTORS

	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
PERFORMANCE RESULTS:								
FIELD SIZE (1000 M**2)	300.	500.	723.	904.	1096.	1316.	1549.	1800.
STORAGE SIZE (HRS)	.00	.00	.00	.05	2.35	4.80	7.39	10.19
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	15.	773.	1590.	2441.	3376.
GENERATING CAPACITY (MW)	100.00	100.00	100.00	100.09	104.46	109.12	114.09	119.48
FIELD EFFICIENCY	.470	.470	.475	.470	.463	.458	.454	.449
TRANSPORT EFFICIENCY	.985	.985	.988	.985	.983	.981	.979	.977
STORAGE EFFICIENCY	*****	*****	*****	.013	.662	.842	.839	.835
ENERGY CONV. EFF. (FIELD)	.409	.409	.409	.409	.410	.410	.410	.410
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	.006	.322	.413	.415	.417
SYSTEM EFFICIENCY	.184	.184	.191	.184	.178	.172	.166	.161
CAPACITY FACTOR	.30	.30	.20	.30	.40	.50	.60	.70
ECONOMIC RESULTS:								
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.281	.281	.229	.281	.276	.273	.271	.270
RECEIVER (\$/M**2)	29.	29.	30.	29.	28.	28.	28.	27.
FRACTION OF LEC	.102	.102	.097	.102	.097	.095	.094	.093
TRANSPORT (\$/M**2)	11.3	11.3	13.6	11.3	9.9	8.9	8.1	7.5
FRACTION OF LEC	.040	.040	.039	.040	.034	.030	.027	.025
STORAGE (\$/KWH)	.0	.0	.0	23.1	23.1	23.1	23.1	23.1
FRACTION OF LEC	.000	.000	.000	.002	.088	.138	.171	.195
ENERGY CONV. (\$/KW)	267.	267.	267.	268.	279.	292.	305.	319.
FRACTION OF LEC	.188	.188	.237	.186	.138	.111	.093	.080
BALANCE OF PLANT (\$/KW)	164.	164.	85.	164.	133.	164.	196.	231.
FRACTION OF LEC	.073	.073	.075	.073	.066	.062	.060	.058
INDIRECT/CONT. (\$/KW)	243.	243.	188.	245.	353.	468.	589.	720.
FRACTION OF LEC	.171	.171	.167	.171	.175	.177	.179	.180
TOTAL INITIAL CAP. (\$/KW)	1215.	1215.	939.	1226.	1767.	2339.	2946.	3602.
FRACTION OF LEC	.854	.854	.834	.854	.875	.886	.894	.900
REPLACEMENT CAPITAL (\$/KW)	50.	50.	50.	50.	53.	55.	58.	60.
FRACTION OF LEC	.040	.040	.051	.040	.030	.024	.020	.017
OPER. AND MAINT. (1000 \$/YR)	1017.	1017.	877.	1023.	1303.	1598.	1911.	2248.
FRACTION OF LEC	.106	.106	.115	.106	.096	.090	.086	.083
LEC (MILLS/KWH)	88.	88.	104.	89.	94.	98.	102.	106.

PECR BRAYTON-THERMAL STORAGE 200-MW
 200 MW
 08-19-80 19:59:23

DESIGN POINT CAPACITY FACTORS

	0 STR	0 PT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1000.	1000.	667.	1035.	1429.	1910.	2333.	2798.	3588.	5333.
STORAGE SIZE (HRS)	.00	.00	.00	.21	2.57	4.64	7.67	10.79	13.76	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	140.	1691.	3053.	5066.	7155.	9163.	12045.
GENERATING CAPACITY (MW)	200.00	200.00	200.00	200.81	209.75	217.62	229.23	241.28	252.87	269.50
FIELD EFFICIENCY	.456	.456	.464	.455	.448	.439	.434	.430	.419	.402
TRANSPORT EFFICIENCY	.980	.980	.983	.980	.977	.974	.971	.969	.965	.958
STORAGE EFFICIENCY	*****	*****	*****	.060	.721	.842	.837	.832	.825	.807
ENERGY CONV. EFF. (FIELD)	.409	.409	.408	.409	.410	.410	.410	.410	.411	.411
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	.029	.353	.413	.415	.417	.419	.421
SYSTEM EFFICIENCY	.179	.179	.185	.179	.173	.162	.159	.154	.139	.105
CAPACITY FACTOR	.29	.29	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	80.	80.	80.	80.	80.	80.	80.	80.	80.	80.
FRACTION OF LEC	.295	.295	.247	.294	.285	.289	.279	.273	.280	.300
RECEIVER (\$/M**2)	27.	27.	27.	27.	27.	28.	28.	28.	29.	31.
FRACTION OF LEC	.100	.100	.084	.099	.097	.100	.098	.097	.103	.116
TRANSPORT (\$/M**2)	8.5	8.5	10.0	8.4	7.3	6.5	6.0	5.5	5.0	4.2
FRACTION OF LEC	.031	.031	.031	.031	.026	.023	.021	.019	.018	.016
STORAGE (\$/KWH)	.0	.0	.0	23.1	23.1	23.1	23.1	23.1	23.1	23.1
FRACTION OF LEC	.000	.000	.000	.011	.097	.134	.175	.202	.207	.196
ENERGY CONV. (\$/KW)	267.	267.	267.	268.	280.	291.	306.	322.	338.	360.
FRACTION OF LEC	.197	.197	.247	.191	.140	.110	.092	.079	.066	.051
BALANCE OF PLANT (\$/KW)	89.	89.	71.	92.	121.	154.	188.	224.	278.	387.
FRACTION OF LEC	.066	.066	.066	.065	.060	.058	.056	.055	.054	.054
INDIRECT/CONT. (\$/KW)	233.	233.	182.	243.	354.	472.	602.	742.	931.	1303.
FRACTION OF LEC	.172	.172	.169	.173	.177	.179	.180	.181	.182	.183
TOTAL INITIAL CAP. (\$/KW)	1167.	1167.	912.	1216.	1768.	2359.	3012.	3711.	4656.	6516.
FRACTION OF LEC	.862	.862	.844	.864	.883	.893	.900	.905	.910	.916
REPLACEMENT CAPITAL (\$/KW)	50.	50.	50.	51.	53.	55.	58.	61.	64.	68.
FRACTION OF LEC	.043	.043	.053	.041	.030	.024	.020	.017	.014	.011
OPER. AND MAINT. (1000 \$/YR)	1754.	1754.	1499.	1805.	2361.	2952.	3606.	4305.	5239.	7050.
FRACTION OF LEC	.096	.096	.103	.095	.087	.083	.080	.078	.076	.073
LEC (MILLS/KWH)	86.	86.	100.	87.	93.	98.	103.	108.	118.	146.

PFDR RANKINE 50MW
50 MW
08-11-80 08:54:05

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	300.	600.	172.	244.	319.	398.	482.	566.	691.	910.
STORAGE SIZE (HRS)	.00	12.00	.00	1.32	3.57	5.95	8.47	10.99	14.73	18.00
STORAGE CAPACITY (1000 KWH)	0.	2020.	0.	219.	593.	991.	1420.	1849.	2494.	3063.
GENERATING CAPACITY (MW)	51.61	52.52	51.22	51.44	51.67	51.91	52.16	52.42	52.80	53.46
FIELD EFFICIENCY	.637	.637	.637	.637	.637	.637	.637	.637	.637	.637
TRANSPORT EFFICIENCY	.900	.900	.900	.901	.901	.900	.900	.900	.900	.898
STORAGE EFFICIENCY	*****	.963	*****	.427	.967	.967	.965	.964	.958	.954
ENERGY CONV. EFF. (FIELD)	.352	.357	.338	.349	.354	.355	.356	.357	.357	.359
ENERGY CONV. EFF. (STORAGE)	*****	.357	*****	.155	.352	.355	.356	.357	.357	.358
SYSTEM EFFICIENCY	.165	.190	.178	.189	.193	.194	.192	.191	.180	.154
CAPACITY FACTOR	.32	.74	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.350	.375	.293	.324	.343	.357	.366	.373	.380	.392
RECEIVER (\$/M**2)	25.	25.	25.	25.	25.	25.	25.	25.	25.	25.
FRACTION OF LEC	.075	.081	.063	.070	.074	.077	.079	.080	.082	.085
TRANSPORT (\$/M**2)	29.6	30.1	29.2	29.4	29.6	29.8	29.9	30.0	30.2	30.3
FRACTION OF LEC	.089	.097	.074	.082	.088	.092	.094	.096	.099	.103
STORAGE (\$/KWH)	.0	3.5	.0	4.4	3.8	3.6	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.038	.000	.011	.021	.028	.033	.037	.041	.040
ENERGY CONV. (\$/KW)	258.	262.	257.	258.	259.	260.	261.	262.	263.	266.
FRACTION OF LEC	.130	.071	.188	.148	.120	.100	.085	.074	.062	.049
BALANCE OF PLANT (\$/KW)	118.	171.	98.	110.	123.	137.	151.	165.	187.	222.
FRACTION OF LEC	.059	.046	.072	.063	.057	.053	.049	.047	.044	.041
INDIRECT/CONT. (\$/KW)	350.	657.	235.	305.	379.	457.	540.	624.	747.	955.
FRACTION OF LEC	.176	.177	.172	.175	.176	.176	.177	.177	.177	.177
TOTAL INITIAL CAP. (\$/KW)	1750.	3285.	1175.	1524.	1894.	2286.	2702.	3119.	3737.	4775.
FRACTION OF LEC	.879	.885	.862	.873	.879	.882	.884	.885	.886	.887
REPLACEMENT CAPITAL (\$/KW)	0.	5.	0.	1.	2.	3.	4.	5.	7.	8.
FRACTION OF LEC	.000	.002	.000	.000	.001	.001	.001	.002	.002	.002
OPER. AND MAINT. (1000 \$/YR)	811.	1420.	633.	746.	875.	1019.	1180.	1350.	1600.	2014.
FRACTION OF LEC	.121	.113	.138	.127	.120	.117	.114	.113	.112	.111
LEC (MILLS/KWH)	114.	93.	126.	108.	100.	96.	94.	93.	98.	111.

PFDR RANKINE 100MW
100 MW
08-08-80 18:06:55

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	400.	1000.	345.	488.	636.	794.	943.	1152.	1397.	1847.
STORAGE SIZE (HRS)	.00	12.00	.00	1.33	3.54	5.91	10.30	12.91	14.38	18.00
STORAGE CAPACITY (1000 KWH)	0.	3991.	0.	434.	1162.	1943.	3419.	4302.	4804.	6051.
GENERATING CAPACITY (MW)	101.75	103.33	101.61	101.98	102.37	102.79	103.18	103.73	104.37	105.55
FIELD EFFICIENCY	.637	.637	.637	.637	.637	.637	.637	.637	.637	.637
TRANSPORT EFFICIENCY	.897	.896	.898	.897	.898	.898	.897	.895	.894	.891
STORAGE EFFICIENCY	*****	.962	*****	.428	.969	.969	.964	.962	.961	.956
ENERGY CONV. EFF. (FIELD)	.346	.358	.338	.350	.356	.357	.358	.359	.360	.361
ENERGY CONV. EFF. (STORAGE)	*****	.359	*****	.156	.354	.357	.358	.359	.360	.360
SYSTEM EFFICIENCY	.184	.197	.178	.188	.194	.194	.196	.190	.178	.152
CAPACITY FACTOR	.24	.64	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.332	.374	.317	.344	.360	.371	.374	.382	.391	.401
RECEIVER (\$/M**2)	25.	25.	25.	25.	25.	25.	25.	25.	25.	25.
FRACTION OF LEC	.071	.080	.068	.074	.077	.079	.080	.082	.084	.086
TRANSPORT (\$/M**2)	29.8	30.4	29.7	29.9	30.1	30.3	30.4	30.5	30.6	30.8
FRACTION OF LEC	.085	.098	.081	.089	.094	.097	.098	.100	.103	.107
STORAGE (\$/KWH)	.0	3.6	.0	4.6	3.9	3.7	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.046	.000	.012	.022	.029	.042	.044	.041	.040
ENERGY CONV. (\$/KW)	230.	233.	230.	231.	231.	232.	233.	234.	235.	238.
FRACTION OF LEC	.165	.075	.182	.140	.113	.094	.080	.067	.057	.045
BALANCE OF PLANT (\$/KW)	78.	130.	74.	85.	98.	111.	125.	142.	162.	198.
FRACTION OF LEC	.056	.042	.058	.052	.048	.045	.043	.041	.039	.037
INDIRECT/CONT. (\$/KW)	248.	554.	223.	292.	365.	443.	524.	626.	740.	954.
FRACTION OF LEC	.177	.179	.176	.178	.178	.179	.179	.179	.179	.179
TOTAL INITIAL CAP. (\$/KW)	1238.	2772.	1115.	1462.	1827.	2216.	2618.	3128.	3702.	4772.
FRACTION OF LEC	.885	.894	.882	.889	.892	.894	.894	.894	.894	.894
REPLACEMENT CAPITAL (\$/KW)	0.	5.	0.	1.	2.	3.	4.	6.	6.	8.
FRACTION OF LEC	.000	.002	.000	.000	.001	.001	.002	.002	.002	.002
OPER. AND MAINT. (1000 \$/YR)	1085.	2182.	1009.	1229.	1477.	1756.	2062.	2455.	2914.	3755.
FRACTION OF LEC	.115	.104	.118	.111	.107	.105	.104	.104	.104	.104
LEC (MILLS/KWH)	108.	90.	117.	102.	95.	92.	90.	93.	96.	110.

PFDR RANKINE 200MW
200 MW
08-11-80 08:59:44

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1000.	2000.	689.	1000.	1279.	1587.	1898.	2325.	2811.	3714.
STORAGE SIZE (HRS)	.00	12.00	.00	.92	4.67	7.04	10.77	12.98	14.43	18.00
STORAGE CAPACITY (1000 KWH)	0.	8023.	0.	608.	3091.	4677.	7193.	8692.	9690.	12155.
GENERATING CAPACITY (MW)	205.64	208.48	204.76	205.64	206.43	207.31	208.19	209.41	210.79	213.35
FIELD EFFICIENCY	.637	.637	.637	.637	.637	.637	.637	.637	.637	.637
TRANSPORT EFFICIENCY	.894	.890	.896	.894	.893	.892	.891	.889	.888	.885
STORAGE EFFICIENCY	*****	.962	*****	.976	.959	.965	.963	.962	.961	.957
ENERGY CONV. EFF. (FIELD)	.347	.358	.339	.349	.355	.357	.358	.359	.360	.361
ENERGY CONV. EFF. (STORAGE)	*****	.359	*****	.356	.353	.357	.359	.359	.360	.360
SYSTEM EFFICIENCY	.182	.195	.178	.184	.192	.194	.195	.188	.177	.151
CAPACITY FACTOR	.30	.63	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.362	.378	.328	.357	.364	.374	.377	.386	.394	.403
RECEIVER (\$/M**2)	25.	25.	25.	25.	25.	25.	25.	25.	25.	25.
FRACTION OF LEC	.077	.081	.070	.076	.078	.080	.081	.083	.084	.086
TRANSPORT (\$/M**2)	30.4	30.9	30.2	30.4	30.6	30.7	30.9	31.0	31.1	31.3
FRACTION OF LEC	.095	.101	.085	.094	.096	.099	.100	.103	.106	.109
STORAGE (\$/KWH)	.0	3.6	.0	5.3	3.8	3.7	3.6	3.6	3.5	3.5
FRACTION OF LEC	.000	.047	.000	.010	.029	.035	.044	.044	.041	.040
ENERGY CONV. (\$/KW)	220.	222.	219.	220.	220.	221.	222.	223.	225.	227.
FRACTION OF LEC	.137	.073	.180	.135	.108	.090	.076	.064	.054	.043
BALANCE OF PLANT (\$/KW)	75.	125.	62.	76.	90.	104.	120.	139.	160.	201.
FRACTION OF LEC	.047	.041	.051	.047	.044	.042	.041	.040	.039	.038
INDIRECT/CONT. (\$/KW)	288.	552.	217.	292.	366.	443.	525.	629.	743.	960.
FRACTION OF LEC	.180	.180	.179	.180	.180	.180	.180	.180	.180	.180
TOTAL INITIAL CAP. (\$/KW)	1439.	2759.	1087.	1460.	1832.	2216.	2624.	3143.	3717.	4799.
FRACTION OF LEC	.898	.900	.893	.898	.900	.900	.900	.899	.898	.898
REPLACEMENT CAPITAL (\$/KW)	0.	5.	0.	0.	2.	3.	5.	6.	6.	8.
FRACTION OF LEC	.000	.002	.000	.000	.001	.001	.002	.002	.002	.002
OPER. AND MAINT. (1000 \$/YR)	2204.	4077.	1765.	2229.	2725.	3267.	3871.	4659.	5570.	7252.
FRACTION OF LEC	.102	.098	.107	.102	.099	.098	.098	.099	.100	.101
LEC (MILLS/KWH)	100.	90.	113.	100.	94.	91.	90.	92.	96.	110.

PEDR BRAYTON 50
 50 MW
 08-19-80 20:48:07

DESIGN POINT CAPACITY FACTORS

	0 STR	0PT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	250.	250.	156.	234.	344.	436.	542.	666.	800.	1079.
STORAGE SIZE (HRS)	.00	.00	.00	.00	1.31	4.07	7.27	9.99	14.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	82.	256.	461.	639.	906.	1180.
GENERATING CAPACITY (MW)	50.00	50.00	31.25	46.88	68.72	87.16	108.48	133.15	160.00	215.79
FIELD EFFICIENCY	.647	.647	.647	.647	.647	.647	.647	.647	.647	.647
TRANSPORT EFFICIENCY	.962	.962	.962	.962	.962	.962	.962	.962	.962	.962
STORAGE EFFICIENCY	*****	*****	*****	*****	.306	.702	.700	.696	.690	.676
ENERGY CONV. EFF. (FIELD)	.309	.309	.309	.309	.281	.277	.268	.255	.241	.203
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.198	.198	.198	.198	.180	.177	.171	.163	.154	.130
CAPACITY FACTOR	.32	.32	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.327	.327	.310	.325	.302	.305	.307	.311	.312	.318
RECEIVER (\$/M**2)	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.
FRACTION OF LEC	.113	.113	.107	.112	.104	.105	.106	.107	.107	.110
TRANSPORT (\$/M**2)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
FRACTION OF LEC	.017	.017	.016	.017	.016	.016	.016	.016	.016	.016
STORAGE (\$/KWH)	.0	.0	.0	.0	111.8	45.2	31.3	26.5	22.8	20.8
FRACTION OF LEC	.000	.000	.000	.000	.069	.070	.071	.068	.069	.062
ENERGY CONV. (\$/KW)	246.	246.	154.	231.	339.	430.	535.	656.	789.	1064.
FRACTION OF LEC	.139	.139	.132	.138	.128	.130	.131	.132	.132	.135
BALANCE OF PLANT (\$/KW)	128.	128.	102.	124.	163.	191.	223.	260.	300.	380.
FRACTION OF LEC	.072	.072	.088	.074	.062	.058	.055	.052	.050	.048
INDIRECT/CONT. (\$/KW)	272.	272.	175.	256.	414.	521.	645.	785.	942.	1249.
FRACTION OF LEC	.153	.153	.150	.153	.157	.157	.158	.158	.158	.159
TOTAL INITIAL CAP. (\$/KW)	1457.	1457.	938.	1371.	2212.	2786.	3450.	4197.	5037.	6680.
FRACTION OF LEC	.821	.821	.803	.819	.838	.841	.843	.845	.846	.848
REPLACEMENT CAPITAL (\$/KW)	58.	58.	36.	55.	82.	109.	140.	174.	214.	287.
FRACTION OF LEC	.037	.037	.036	.037	.036	.038	.039	.040	.041	.042
OPER. AND MAINT. (1000 \$/YR)	850.	850.	639.	815.	1123.	1357.	1629.	1934.	2277.	2946.
FRACTION OF LEC	.142	.142	.162	.144	.126	.121	.118	.115	.113	.111
LEC (MILLS/KWH)	103.	103.	109.	103.	122.	123.	126.	131.	138.	162.

PEDR BRAYTON 100-
 100 MW
 08-19-80 20:47:29

DESIGN POINT CAPACITY FACTORS

	STP	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	500.	500.	312.	469.	655.	861.	1073.	1286.	1583.	2076.
STORAGE SIZE (HRS)	.00	.00	.00	.00	1.86	4.33	7.76	12.00	13.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	231.	537.	963.	1491.	1615.	2238.
GENERATING CAPACITY (MW)	100.00	100.00	62.50	93.75	131.01	172.17	214.63	257.14	316.67	415.15
FIELD EFFICIENCY	.647	.647	.647	.647	.647	.647	.647	.647	.647	.647
TRANSPORT EFFICIENCY	.962	.962	.962	.962	.962	.962	.962	.962	.962	.961
STORAGE EFFICIENCY	*****	*****	*****	*****	.447	.720	.720	.720	.719	.719
ENERGY CONV. EFF. (FIELD)	.309	.309	.309	.309	.297	.281	.270	.263	.244	.210
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.198	.198	.198	.198	.189	.180	.173	.169	.156	.134
CAPACITY FACTOR	.32	.32	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.339	.339	.328	.338	.307	.311	.313	.312	.319	.322
RECEIVER (\$/M**2)	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.
FRACTION OF LEC	.117	.117	.113	.117	.106	.107	.108	.108	.110	.111
TRANSPORT (\$/M**2)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
FRACTION OF LEC	.018	.018	.017	.018	.016	.016	.016	.016	.017	.017
STORAGE (\$/KWH)	0.	0.	0.	0.	83.3	43.8	30.6	24.7	23.9	21.1
FRACTION OF LEC	.000	.000	.000	.000	.078	.073	.074	.077	.067	.063
ENERGY CONV. (\$/KW)	246.	246.	154.	231.	323.	424.	529.	634.	781.	1023.
FRACTION OF LEC	.144	.144	.139	.144	.130	.132	.133	.133	.135	.137
BALANCE OF PLANT (\$/KW)	107.	107.	83.	103.	135.	163.	193.	224.	262.	329.
FRACTION OF LEC	.062	.062	.075	.064	.055	.051	.048	.047	.045	.044
INDIRECT/CONT. (\$/KW)	268.	268.	171.	251.	394.	510.	634.	761.	919.	1193.
FRACTION OF LEC	.157	.157	.155	.156	.159	.159	.159	.159	.159	.159
TOTAL INITIAL CAP. (\$/KW)	1431.	1431.	914.	1345.	2105.	2728.	3390.	4070.	4913.	6382.
FRACTION OF LEC	.837	.837	.827	.836	.850	.851	.851	.851	.852	.853
REPLACEMENT CAPITAL (\$/KW)	58.	58.	36.	55.	80.	108.	139.	172.	209.	276.
FRACTION OF LEC	.039	.039	.038	.039	.037	.039	.040	.041	.041	.042
OPER. AND MAINT. (1000 \$/YR)	1428.	1428.	1007.	1358.	1901.	2399.	2926.	3466.	4148.	5327.
FRACTION OF LEC	.124	.124	.135	.125	.114	.111	.109	.107	.107	.105
LEC (MILLS/KWH)	99.	99.	102.	99.	115.	119.	123.	126.	133.	154.

PEDR BRAYTON 2000
 200 MW
 08-20-80 07:50:27

DESIGN POINT CAPACITY FACTORS

	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90
PERFORMANCE RESULTS:																
FIELD SIZE (1000 M**2)	1000.	1000.	625.	938.	1303.	1724.	2146.	2571.	3188.	4156.						
STORAGE SIZE (HRS)	.00	.00	.00	.00	3.00	4.34	7.76	12.00	13.13	18.00						
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	744.	1078.	1925.	2978.	3259.	4469.						
GENERATING CAPACITY (MW)	200.00	200.00	125.00	187.50	260.66	344.83	429.27	514.29	637.61	831.25						
FIELD EFFICIENCY	.647	.647	.647	.647	.647	.647	.647	.647	.647	.647						
TRANSPORT EFFICIENCY	.962	.962	.962	.962	.962	.962	.962	.961	.961	.961						
STORAGE EFFICIENCY	*****	*****	*****	*****	.720	.720	.720	.720	.720	.720						
ENERGY CONV. EFF. (FIELD)	.309	.309	.309	.309	.297	.281	.270	.263	.244	.210						
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.000	.000	.000	.000	.000	.000						
SYSTEM EFFICIENCY	.197	.197	.197	.197	.190	.180	.173	.168	.156	.134						
CAPACITY FACTOR	.32	.32	.20	.30	.40	.50	.60	.70	.80	.90						
ECONOMIC RESULTS:																
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.						
FRACTION OF LEC	.146	.146	.138	.145	.1307	.1314	.1315	.1314	.1320	.1323						
RECEIVER (\$/M**2)	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.						
FRACTION OF LEC	.119	.119	.116	.119	.106	.108	.109	.108	.111	.111						
TRANSPORT (\$/M**2)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0						
FRACTION OF LEC	.018	.018	.018	.018	.016	.016	.016	.016	.017	.017						
STORAGE (\$/KWH)	.0	.0	.0	.0	57.0	43.7	30.6	24.7	23.8	21.2						
FRACTION OF LEC	.010	.010	.010	.010	.086	.074	.075	.078	.067	.063						
ENERGY CONV. (\$/KWH)	246.	246.	154.	231.	321.	425.	529.	634.	786.	1025.						
FRACTION OF LEC	.147	.147	.143	.146	.130	.134	.134	.134	.136	.137						
BALANCE OF PLANT (\$/KWH)	98.	98.	74.	94.	127.	155.	185.	216.	256.	322.						
FRACTION OF LEC	.058	.058	.069	.060	.051	.049	.047	.045	.044	.043						
INDIRECT/CONT. (\$/KWH)	266.	266.	169.	249.	395.	509.	632.	759.	923.	1193.						
FRACTION OF LEC	.158	.158	.157	.158	.160	.160	.160	.160	.160	.160						
TOTAL INITIAL CAP. (\$/KWH)	1420.	1420.	903.	1334.	2111.	2721.	3379.	4060.	4936.	6380.						
FRACTION OF LEC	.846	.846	.841	.846	.856	.856	.856	.855	.855	.855						
REPLACEMENT CAPITAL (\$/KWH)	58.	58.	36.	55.	81.	108.	139.	172.	210.	276.						
FRACTION OF LEC	.040	.040	.039	.039	.038	.039	.040	.041	.042	.042						
OPER. AND MAINT. (1000 \$/YR)	2588.	2588.	1747.	2448.	3539.	4517.	5551.	6612.	8023.	10318.						
FRACTION OF LEC	.114	.114	.121	.115	.106	.105	.104	.103	.103	.102						
LEC (MILLS/KWH)	97.	97.	99.	97.	114.	118.	122.	126.	134.	153.						

PFDR STIRLING 50MW
50 MW
09-02-80 09:14:52

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	222.	222.	142.	214.	299.	393.	490.	589.	741.	990.
STORAGE SIZE (HRS)	.00	.00	.00	.00	2.97	5.80	8.71	11.67	14.12	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	184.	360.	541.	726.	879.	1122.
GENERATING CAPACITY (MW)	50.00	50.00	32.00	48.07	67.30	88.51	110.32	132.55	166.79	222.79
FIELD EFFICIENCY	.642	.642	.642	.642	.642	.642	.642	.642	.642	.642
TRANSPORT EFFICIENCY	.958	.958	.958	.958	.958	.958	.958	.958	.958	.958
STORAGE EFFICIENCY	*****	*****	*****	*****	.711	.719	.719	.718	.717	.716
ENERGY CONV. EFF. (FIELD)	.343	.343	.343	.343	.327	.311	.299	.290	.266	.223
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.217	.217	.217	.217	.206	.196	.189	.184	.167	.140
CAPACITY FACTOR	.31	.31	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.327	.327	.309	.325	.293	.299	.303	.306	.312	.319
RECEIVER (\$/M**2)	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.
FRACTION OF LEC	.113	.113	.107	.112	.101	.103	.105	.106	.108	.110
TRANSPORT (\$/M**2)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
FRACTION OF LEC	.017	.017	.016	.017	.015	.016	.016	.016	.016	.017
STORAGE (\$/KWH)	.0	.0	.0	.0	57.5	36.2	28.8	25.0	23.1	21.1
FRACTION OF LEC	.000	.000	.000	.000	.089	.085	.083	.081	.074	.066
ENERGY CONV. (\$/KW)	205.	205.	132.	198.	277.	364.	453.	545.	685.	916.
FRACTION OF LEC	.130	.130	.123	.130	.117	.119	.121	.122	.125	.127
BALANCE OF PLANT (\$/KW)	116.	116.	96.	114.	145.	172.	199.	226.	267.	333.
FRACTION OF LEC	.074	.074	.090	.075	.061	.056	.053	.051	.048	.046
INDIRECT/CONT. (\$/KW)	240.	240.	158.	231.	369.	476.	587.	700.	865.	1134.
FRACTION OF LEC	.152	.152	.148	.151	.155	.156	.156	.157	.157	.157
TOTAL INITIAL CAP. (\$/KW)	1281.	1281.	846.	1235.	1972.	2547.	3139.	3743.	4625.	6065.
FRACTION OF LEC	.812	.812	.793	.810	.831	.835	.837	.838	.840	.842
REPLACEMENT CAPITAL (\$/KW)	59.	59.	38.	57.	85.	115.	146.	178.	223.	296.
FRACTION OF LEC	.043	.043	.040	.042	.041	.043	.045	.046	.046	.047
OPER. AND MAINT. (1000 \$/YR)	777.	777.	601.	758.	1024.	1260.	1501.	1748.	2107.	2694.
FRACTION OF LEC	.146	.146	.167	.147	.128	.122	.119	.116	.113	.111
LEC (MILLS/KWH)	94.	94.	99.	94.	110.	113.	116.	118.	127.	148.

PFDR STIRLING 100MW
100 MW
09-02-80 09:06:08

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	444.	444.	285.	427.	598.	787.	979.	1185.	1458.	1974.
STORAGE SIZE (HRS)	.00	.00	.00	.00	2.97	6.44	8.75	11.23	14.49	18.00
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	368.	799.	1086.	1394.	1801.	2238.
GENERATING CAPACITY (MW)	100.00	100.00	64.01	96.14	134.61	176.97	220.24	266.72	328.01	444.18
FIELD EFFICIENCY	.642	.642	.642	.642	.642	.642	.642	.642	.642	.642
TRANSPORT EFFICIENCY	.958	.958	.958	.958	.958	.958	.958	.958	.958	.957
STORAGE EFFICIENCY	*****	*****	*****	*****	.712	.720	.720	.719	.719	.718
ENERGY CONV. EFF. (FIELD)	.343	.343	.343	.343	.327	.311	.299	.289	.269	.223
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.217	.217	.217	.217	.206	.197	.189	.182	.169	.141
CAPACITY FACTOR	.31	.31	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.340	.340	.328	.339	.298	.302	.306	.310	.313	.320
RECEIVER (\$/M**2)	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.
FRACTION OF LEC	.117	.117	.113	.117	.103	.104	.106	.107	.108	.111
TRANSPORT (\$/M**2)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
FRACTION OF LEC	.018	.018	.017	.018	.015	.016	.016	.016	.016	.017
STORAGE (\$/KWH)	.0	.0	.0	.0	60.9	36.1	30.5	27.0	24.3	22.4
FRACTION OF LEC	.000	.000	.000	.000	.096	.095	.089	.085	.081	.070
ENERGY CONV. (\$/KW)	205.	205.	132.	198.	277.	364.	453.	548.	674.	913.
FRACTION OF LEC	.135	.135	.131	.135	.119	.120	.122	.124	.125	.128
BALANCE OF PLANT (\$/KW)	99.	99.	79.	97.	129.	155.	181.	209.	247.	315.
FRACTION OF LEC	.065	.065	.078	.066	.055	.051	.049	.047	.046	.044
INDIRECT/CONT. (\$/KW)	236.	236.	154.	227.	368.	479.	587.	703.	855.	1133.
FRACTION OF LEC	.155	.155	.153	.155	.158	.158	.158	.158	.158	.159
TOTAL INITIAL CAP. (\$/KW)	1260.	1260.	826.	1213.	1966.	2560.	3137.	3757.	4575.	6061.
FRACTION OF LEC	.830	.830	.820	.829	.845	.846	.847	.847	.848	.848
REPLACEMENT CAPITAL (\$/KW)	59.	59.	38.	57.	85.	116.	146.	178.	221.	296.
FRACTION OF LEC	.044	.044	.043	.044	.042	.044	.045	.046	.047	.047
OPER. AND MAINT. (1000 \$/YR)	1287.	1287.	934.	1249.	1776.	2245.	2705.	3200.	3852.	5045.
FRACTION OF LEC	.126	.126	.137	.126	.113	.110	.108	.107	.106	.105
LEC (MILLS/KWH)	90.	90.	93.	90.	108.	112.	114.	117.	125.	147.

PFDR STIRLING 200MW
200 MW
08-19-80 21:09:13

DESIGN POINT CAPACITY FACTORS

	0 STR	0PT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	539.	889.	569.	855.	1205.	1574.	1961.	2372.	2916.	3966.
STORAGE SIZE (HRS)	.00	.00	.00	.00	2.46	6.44	8.77	11.23	14.49	17.90
STORAGE CAPACITY (1000 KWH)	0.	0.	0.	0.	611.	1598.	2176.	2787.	3598.	4444.
GENERATING CAPACITY (MW)	200.00	200.00	127.94	192.28	271.21	354.07	441.28	533.68	656.02	892.42
FIELD EFFICIENCY	.642	.642	.642	.642	.642	.642	.642	.642	.642	.642
TRANSPORT EFFICIENCY	.958	.958	.958	.958	.958	.958	.957	.957	.957	.955
STORAGE EFFICIENCY	*****	*****	*****	*****	.591	.720	.720	.720	.720	.720
ENERGY CONV. EFF. (FIELD)	.343	.343	.343	.343	.324	.312	.299	.289	.269	.222
ENERGY CONV. EFF. (STORAGE)	*****	*****	*****	*****	.000	.000	.000	.000	.000	.000
SYSTEM EFFICIENCY	.217	.217	.217	.217	.205	.197	.189	.182	.169	.140
CAPACITY FACTOR	.31	.31	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
FRACTION OF LEC	.347	.347	.338	.346	.305	.305	.309	.312	.315	.322
RECEIVER (\$/M**2)	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.
FRACTION OF LEC	.120	.120	.117	.119	.105	.105	.107	.108	.109	.111
TRANSPORT (\$/M**2)	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
FRACTION OF LEC	.018	.018	.018	.018	.016	.016	.016	.016	.016	.017
STORAGE (\$/KWH)	.0	.0	.0	.0	70.3	36.1	30.4	27.0	24.3	22.5
FRACTION OF LEC	.000	.000	.000	.000	.094	.096	.090	.085	.081	.070
ENERGY CONV. (\$/KW)	205.	205.	131.	198.	279.	364.	453.	548.	674.	917.
FRACTION OF LEC	.138	.138	.135	.138	.121	.122	.123	.125	.126	.128
BALANCE OF PLANT (\$/KW)	90.	90.	70.	88.	120.	147.	173.	201.	239.	308.
FRACTION OF LEC	.061	.061	.072	.061	.052	.049	.047	.046	.045	.043
INDIRECT/COST. (\$/KW)	234.	234.	152.	225.	366.	477.	586.	701.	854.	1136.
FRACTION OF LEC	.157	.157	.156	.157	.159	.159	.159	.159	.159	.159
TOTAL INITIAL CAP. (\$/KW)	1249.	1249.	814.	1203.	1956.	2550.	3132.	3749.	4565.	6074.
FRACTION OF LEC	.840	.840	.834	.840	.852	.852	.852	.851	.851	.851
REPLACEMENT CAPITAL (\$/KW)	59.	59.	38.	57.	84.	116.	146.	178.	220.	296.
FRACTION OF LEC	.045	.045	.044	.045	.042	.044	.045	.046	.047	.047
OPER. AND MAINT. (1000 \$/YR)	2307.	2307.	1600.	2231.	3277.	4196.	5113.	6085.	7372.	9780.
FRACTION OF LEC	.115	.115	.121	.115	.106	.104	.103	.102	.102	.102
LEC (MILLS/KWH)	88.	88.	90.	88.	106.	111.	114.	116.	124.	147.

FMDF 50MW
50 MW
09-02-80 09:27:58

DESIGN POINT CAPACITY FACTORS

	0 STR	0PT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	300.	400.	287.	397.	532.	648.	778.	931.	1151.	1614.
STORAGE SIZE (HRS)	.00	12.00	.00	2.90	4.98	9.72	11.67	13.96	16.81	18.00
STORAGE CAPACITY (1000 KWH)	0.	2020.	0.	481.	829.	1630.	1964.	2359.	2854.	3063.
GENERATING CAPACITY (MW)	51.18	51.97	51.16	51.33	51.55	51.73	51.94	52.18	52.53	53.27
FIELD EFFICIENCY	.369	.369	.369	.369	.369	.369	.369	.369	.369	.369
TRANSPORT EFFICIENCY	.954	.955	.954	.955	.955	.955	.955	.954	.954	.954
STORAGE EFFICIENCY	*****	.963	*****	.969	.969	.963	.963	.962	.958	.957
ENERGY CONV. EFF. (FIELD)	.341	.356	.340	.353	.354	.355	.356	.357	.358	.359
ENERGY CONV. EFF. (STORAGE)	*****	.357	*****	.351	.354	.355	.357	.357	.358	.358
SYSTEM EFFICIENCY	.108	.119	.107	.117	.116	.119	.119	.116	.108	.087
CAPACITY FACTOR	.21	.62	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	65.	65.	65.	65.	65.	65.	65.	65.	65.	65.
FRACTION OF LEC	.294	.358	.289	.313	.337	.344	.356	.367	.379	.400
RECEIVER (\$/M**2)	25.	25.	25.	25.	25.	25.	25.	25.	25.	25.
FRACTION OF LEC	.112	.137	.110	.120	.129	.131	.136	.140	.144	.153
TRANSPORT (\$/M**2)	7.9	8.1	7.9	8.0	8.1	8.1	8.1	8.2	8.2	8.3
FRACTION OF LEC	.036	.045	.035	.039	.042	.043	.045	.046	.048	.051
STORAGE (\$/KWH)	.0	3.5	.0	3.8	3.7	3.5	3.5	3.5	3.5	3.5
FRACTION OF LEC	.000	.049	.000	.023	.030	.047	.049	.050	.051	.041
ENERGY CONV. (\$/KW)	257.	260.	257.	257.	258.	259.	260.	261.	262.	265.
FRACTION OF LEC	.193	.089	.199	.156	.126	.106	.091	.079	.066	.051
BALANCE OF PLANT (\$/KW)	106.	171.	105.	119.	136.	152.	168.	187.	214.	267.
FRACTION OF LEC	.080	.059	.081	.073	.066	.062	.059	.057	.054	.051
INDIRECT/CONT. (\$/KW)	228.	514.	221.	286.	359.	431.	502.	585.	703.	939.
FRACTION OF LEC	.172	.177	.171	.173	.175	.176	.177	.177	.178	.179
TOTAL INITIAL CAP. (\$/KW)	1177.	2654.	1143.	1475.	1855.	2226.	2591.	3022.	3634.	4851.
FRACTION OF LEC	.888	.913	.886	.896	.905	.908	.913	.916	.920	.926
REPLACEMENT CAPITAL (\$/KW)	0.	5.	0.	1.	2.	4.	5.	6.	7.	8.
FRACTION OF LEC	.000	.002	.000	.001	.001	.002	.002	.002	.002	.002
OPER. AND MAINT. (1000 \$/YR)	503.	831.	497.	571.	651.	740.	818.	910.	1038.	1276.
FRACTION OF LEC	.112	.085	.114	.103	.094	.090	.085	.082	.078	.072
LEC (MILLS/KWH)	117.	87.	119.	102.	95.	91.	88.	87.	91.	108.

FMDF 100MW
100 MW
09-02-80 09:09:12

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	600.	2000.	573.	791.	1037.	1287.	1547.	1857.	2290.	3205.
STORAGE SIZE (HRS)	.00	15.00	.00	2.87	6.45	9.45	12.28	14.14	16.74	18.00
STORAGE CAPACITY (1000 KWH)	0.	5050.	0.	947.	2140.	3156.	4115.	4756.	5656.	6093.
GENERATING CAPACITY (MW)	102.38	104.66	102.33	102.69	103.09	103.50	103.92	104.43	105.13	106.62
FIELD EFFICIENCY	.369	.369	.369	.369	.369	.369	.369	.369	.369	.369
TRANSPORT EFFICIENCY	.953	.954	.953	.954	.954	.954	.954	.954	.954	.953
STORAGE EFFICIENCY	*****	.961	*****	.969	.965	.963	.962	.961	.958	.957
ENERGY CONV. EFF. (FIELD)	.341	.359	.340	.353	.356	.357	.358	.359	.360	.361
ENERGY CONV. EFF. (STORAGE)	*****	.359	*****	.353	.355	.357	.358	.359	.359	.360
SYSTEM EFFICIENCY	.108	.115	.107	.117	.119	.120	.120	.116	.108	.087
CAPACITY FACTOR	.21	.75	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	65.	65.	65.	65.	65.	65.	65.	65.	65.	65.
FRACTION OF LEC	.315	.381	.311	.331	.346	.357	.366	.377	.388	.407
RECEIVER (\$/M**2)	25.	25.	25.	25.	25.	25.	25.	25.	25.	25.
FRACTION OF LEC	.120	.145	.118	.126	.132	.136	.140	.144	.148	.155
TRANSPORT (\$/M**2)	8.1	8.4	8.1	8.1	8.2	8.3	8.3	8.3	8.4	8.5
FRACTION OF LEC	.039	.049	.039	.042	.044	.045	.047	.048	.050	.053
STORAGE (\$/KWH)	.0	3.5	.0	4.0	3.7	3.6	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.052	.000	.024	.040	.048	.053	.052	.052	.042
ENERGY CONV. (\$/KW)	231.	236.	231.	232.	233.	234.	234.	236.	237.	240.
FRACTION OF LEC	.187	.069	.193	.149	.119	.100	.085	.074	.062	.047
BALANCE OF PLANT (\$/KW)	82.	170.	80.	94.	110.	126.	143.	162.	188.	241.
FRACTION OF LEC	.066	.050	.067	.061	.057	.054	.052	.050	.049	.047
INDIRECT/CONT. (\$/KW)	216.	611.	209.	273.	345.	417.	490.	573.	689.	922.
FRACTION OF LEC	.175	.179	.175	.176	.177	.178	.178	.179	.180	.180
TOTAL INITIAL CAP. (\$/KW)	1117.	3159.	1082.	1413.	1784.	2152.	2530.	2961.	3562.	4766.
FRACTION OF LEC	.903	.926	.902	.910	.915	.919	.922	.925	.928	.932
REPLACEMENT CAPITAL (\$/KW)	0.	7.	0.	1.	3.	4.	5.	6.	7.	8.
FRACTION OF LEC	.000	.002	.000	.001	.002	.002	.002	.002	.002	.002
OPER. AND MAINT. (1000 \$/YR)	809.	1657.	796.	934.	1091.	1245.	1402.	1576.	1819.	2286.
FRACTION OF LEC	.097	.072	.098	.089	.083	.079	.076	.073	.070	.066
LEC (MILLS/KWH)	109.	85.	111.	96.	90.	87.	85.	85.	89.	105.

FMDF 200MW
200 MW
08-11-80 11:38:50

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1500.	3000.	1108.	1585.	2085.	2588.	3111.	3728.	4609.	6500.
STORAGE SIZE (HRS)	.00	12.00	.65	3.51	6.51	9.53	12.33	14.19	16.83	18.00
STORAGE CAPACITY (1000 KWH)	0.	8023.	429.	2316.	4319.	6354.	8252.	9521.	11342.	12155.
GENERATING CAPACITY (MW)	206.13	209.46	205.26	206.32	207.43	208.55	209.71	211.08	213.03	217.23
FIELD EFFICIENCY	.369	.369	.369	.369	.369	.369	.369	.369	.369	.369
TRANSPORT EFFICIENCY	.948	.949	.948	.949	.949	.949	.949	.949	.948	.947
STORAGE EFFICIENCY	*****	.964	.983	.967	.966	.965	.964	.963	.961	.959
ENERGY CONV. EFF. (FIELD)	.341	.358	.344	.354	.356	.357	.358	.359	.360	.361
ENERGY CONV. EFF. (STORAGE)	*****	.358	.357	.353	.355	.357	.358	.359	.360	.360
SYSTEM EFFICIENCY	.100	.120	.111	.116	.118	.119	.119	.116	.108	.086
CAPACITY FACTOR	.24	.58	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	65.	65.	65.	65.	65.	65.	65.	65.	65.	65.
FRACTION OF LEC	.349	.371	.314	.339	.355	.365	.373	.383	.393	.411
RECEIVER (\$/M**2)	25.	25.	25.	25.	25.	25.	25.	25.	25.	25.
FRACTION OF LEC	.133	.141	.120	.129	.135	.139	.142	.146	.150	.157
TRANSPORT (\$/M**2)	8.3	8.5	8.2	8.3	8.4	8.4	8.5	8.5	8.6	8.6
FRACTION OF LEC	.045	.048	.040	.043	.046	.047	.049	.050	.052	.055
STORAGE (\$/KWH)	.0	3.6	6.1	3.9	3.7	3.6	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.054	.011	.030	.042	.050	.054	.053	.052	.042
ENERGY CONV. (\$/KW)	220.	223.	219.	220.	221.	223.	224.	225.	227.	231.
FRACTION OF LEC	.158	.085	.191	.145	.116	.097	.083	.071	.060	.045
BALANCE OF PLANT (\$/KW)	76.	125.	65.	80.	96.	112.	128.	147.	173.	227.
FRACTION OF LEC	.054	.047	.057	.053	.050	.048	.047	.046	.045	.044
INDIRECT/CONT. (\$/KW)	248.	472.	202.	270.	341.	413.	487.	570.	688.	929.
FRACTION OF LEC	.177	.179	.176	.177	.178	.179	.179	.180	.180	.181
TOTAL INITIAL CAP. (\$/KW)	1279.	2437.	1043.	1393.	1762.	2132.	2514.	2943.	3554.	4801.
FRACTION OF LEC	.917	.927	.909	.917	.922	.925	.927	.929	.932	.935
REPLACEMENT CAPITAL (\$/KW)	0.	5.	0.	2.	3.	4.	5.	6.	7.	8.
FRACTION OF LEC	.000	.002	.000	.001	.002	.002	.002	.002	.002	.002
OPER. AND MAINT. (1000 \$/YR)	1568.	2523.	1397.	1678.	1974.	2275.	2584.	2925.	3413.	4379.
FRACTION OF LEC	.083	.071	.090	.082	.077	.073	.071	.068	.066	.063
LEC (MILLS/KWH)	106.	84.	106.	94.	88.	85.	84.	84.	88.	106.

LFCR 50MW
50 MW
09-02-80 09:57:26

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	300.	1000.	281.	405.	527.	652.	781.	908.	1065.	1442.
STORAGE SIZE (HRS)	.00	18.00	2.44	3.15	6.80	9.77	11.71	15.23	18.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	3063.	404.	522.	1138.	1640.	1971.	2581.	3063.	3063.
GENERATING CAPACITY (MW)	51.11	52.05	51.08	51.25	51.41	51.58	51.75	51.93	52.14	52.65
FIELD EFFICIENCY	.350	.362	.349	.353	.356	.358	.360	.361	.363	.366
TRANSPORT EFFICIENCY	.976	.977	.976	.976	.977	.977	.977	.977	.977	.975
STORAGE EFFICIENCY	*****	.959	.775	.972	.968	.965	.964	.961	.959	.959
ENERGY CONV. EFF. (FIELD)	.349	.357	.348	.354	.355	.356	.357	.357	.357	.358
ENERGY CONV. EFF. (STORAGE)	*****	.358	.279	.352	.355	.356	.357	.358	.358	.358
SYSTEM EFFICIENCY	.100	.119	.109	.114	.117	.118	.118	.119	.116	.096
CAPACITY FACTOR	.20	.77	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	72.	72.	72.	72.	72.	72.	72.	72.	72.	72.
FRACTION OF LEC	.263	.306	.250	.276	.286	.294	.301	.305	.309	.322
RECEIVER (\$/M**2)	56.	57.	56.	57.	57.	57.	57.	57.	57.	57.
FRACTION OF LEC	.205	.243	.195	.217	.226	.232	.238	.241	.245	.256
TRANSPORT (\$/M**2)	6.8	8.1	6.7	7.1	7.4	7.6	7.8	8.0	8.1	8.5
FRACTION OF LEC	.025	.034	.023	.027	.029	.031	.033	.034	.035	.038
STORAGE (\$/KWH)	.0	3.5	3.9	3.8	3.6	3.5	3.5	3.5	3.5	3.5
FRACTION OF LEC	.000	.045	.020	.019	.031	.036	.037	.042	.043	.033
ENERGY CONV. (\$/KW)	256.	260.	256.	257.	258.	258.	259.	260.	260.	263.
FRACTION OF LEC	.156	.055	.158	.122	.097	.081	.069	.060	.053	.041
BALANCE OF PLANT (\$/KW)	112.	216.	111.	128.	146.	165.	183.	202.	225.	276.
FRACTION OF LFC	.068	.046	.068	.060	.055	.052	.049	.047	.045	.043
INDIRECT/CONT. (\$/KW)	283.	824.	278.	365.	461.	556.	652.	751.	869.	1134.
FRACTION OF LEC	.172	.175	.172	.173	.174	.174	.175	.175	.175	.176
TOTAL INITIAL CAP. (\$/KW)	1461.	4257.	1435.	1888.	2381.	2874.	3368.	3881.	4492.	5856.
FRACTION OF LEC	.889	.905	.886	.894	.898	.901	.903	.904	.906	.909
REPLACEMENT CAPITAL (\$/KW)	0.	8.	1.	1.	3.	4.	5.	7.	8.	8.
FRACTION OF LEC	.000	.002	.001	.001	.001	.002	.002	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	617.	1481.	618.	749.	902.	1054.	1202.	1362.	1548.	1941.
FRACTION OF LEC	.111	.093	.113	.105	.101	.098	.096	.094	.092	.089
LEC (MILLS/KWH)	156.	113.	150.	130.	123.	118.	115.	114.	115.	133.

LECR 100MW
100 MW
09-02-80 09:49:44

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	600.	2000.	549.	795.	1032.	1274.	1518.	1777.	2073.	2821.
STORAGE SIZE (HRS)	.00	18.00	2.24	3.00	6.38	9.29	12.22	15.33	18.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	6093.	739.	989.	2116.	3102.	4094.	5169.	6093.	6093.
GENERATING CAPACITY (MW)	102.22	104.14	102.15	102.49	102.81	103.15	103.48	103.83	104.24	105.27
FIELD EFFICIENCY	.357	.369	.356	.360	.362	.364	.366	.368	.369	.372
TRANSPORT EFFICIENCY	.976	.975	.976	.976	.976	.975	.975	.975	.975	.974
STORAGE EFFICIENCY	*****	.959	.716	.973	.968	.966	.964	.961	.959	.959
ENERGY CONV. EFF. (FIELD)	.350	.359	.349	.356	.357	.358	.358	.359	.359	.360
ENERGY CONV. EFF. (STORAGE)	*****	.360	.259	.354	.356	.358	.359	.360	.360	.360
SYSTEM EFFICIENCY	.101	.121	.111	.116	.119	.121	.122	.121	.119	.099
CAPACITY FACTOR	.20	.79	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	72.	72.	72.	72.	72.	72.	72.	72.	72.	72.
FRACTION OF LEC	.278	.315	.264	.289	.298	.304	.309	.313	.317	.330
RECEIVER (\$/M**2)	57.	57.	57.	57.	57.	57.	57.	57.	57.	57.
FRACTION OF LEC	.220	.251	.208	.228	.236	.242	.246	.249	.252	.262
TRANSPORT (\$/M**2)	5.8	6.8	5.8	6.0	6.2	6.4	6.5	6.7	6.8	7.0
FRACTION OF LEC	.023	.030	.021	.024	.026	.027	.028	.029	.030	.032
STORAGE (\$/KWH)	.0	3.5	4.1	4.0	3.7	3.6	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.047	.020	.020	.031	.037	.041	.045	.045	.035
ENERGY CONV. (\$/KW)	231.	235.	231.	232.	232.	233.	234.	234.	235.	237.
FRACTION OF LEC	.149	.051	.154	.117	.093	.077	.066	.057	.050	.038
BALANCE OF PLANT (\$/KW)	87.	189.	85.	101.	119.	136.	154.	173.	194.	244.
FRACTION OF LEC	.056	.041	.057	.051	.048	.045	.044	.042	.041	.040
INDIRECT/CONT. (\$/KW)	270.	806.	261.	347.	438.	530.	622.	721.	831.	1090.
FRACTION OF LEC	.174	.176	.174	.175	.175	.176	.176	.176	.176	.177
TOTAL INITIAL CAP. (\$/KW)	1396.	4164.	1346.	1793.	2263.	2738.	3216.	3726.	4294.	5631.
FRACTION OF LEC	.900	.911	.898	.904	.906	.908	.910	.911	.912	.914
REPLACEMENT CAPITAL (\$/KW)	0.	8.	1.	1.	3.	4.	5.	7.	8.	8.
FRACTION OF LEC	.000	.002	.001	.001	.001	.002	.002	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	1049.	2674.	1027.	1281.	1557.	1835.	2116.	2416.	2749.	3513.
FRACTION OF LEC	.100	.087	.101	.096	.092	.090	.089	.087	.086	.084
LEC (MILLS/KWH)	146.	108.	139.	122.	116.	112.	109.	108.	109.	127.

LFCR 200MW
200 MW
08-11-80 11:02:35

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1000.	4000.	1102.	1548.	2024.	2505.	2986.	3497.	4022.	5520.
STORAGE SIZE (HRS)	.00	18.00	.61	3.29	6.14	9.03	11.91	14.98	18.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	12155.	402.	2167.	4070.	6017.	7965.	10078.	12155.	12155.
GENERATING CAPACITY (MW)	204.17	208.28	204.31	204.92	205.57	206.23	206.89	207.59	208.31	210.36
FIELD EFFICIENCY	.362	.377	.363	.366	.369	.371	.373	.375	.377	.380
TRANSPORT EFFICIENCY	.976	.974	.976	.975	.975	.974	.974	.974	.974	.973
STORAGE EFFICIENCY	*****	.961	.984	.972	.969	.967	.966	.964	.961	.962
ENERGY CONV. EFF. (FIELD)	.344	.359	.346	.356	.357	.358	.359	.359	.359	.361
ENERGY CONV. EFF. (STORAGE)	*****	.360	.358	.354	.356	.358	.359	.359	.360	.360
SYSTEM EFFICIENCY	.109	.123	.111	.119	.122	.123	.124	.124	.123	.101
CAPACITY FACTOR	.18	.80	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	72.	72.	72.	72.	72.	72.	72.	72.	72.	72.
FRACTION OF LEC	.270	.312	.273	.288	.297	.303	.307	.310	.312	.324
RECEIVER (\$/M**2)	57.	57.	57.	57.	57.	57.	57.	57.	57.	57.
FRACTION OF LEC	.214	.249	.217	.229	.236	.241	.245	.247	.249	.258
TRANSPORT (\$/M**2)	8.1	9.9	8.2	8.6	9.0	9.2	9.5	9.7	9.9	10.4
FRACTION OF LEC	.030	.043	.031	.034	.037	.039	.040	.042	.043	.047
STORAGE (\$/KWH)	.0	3.5	6.3	4.0	3.7	3.6	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.046	.009	.022	.031	.037	.041	.044	.046	.035
ENERGY CONV. (\$/KW)	218.	222.	218.	219.	220.	220.	221.	222.	222.	224.
FRACTION OF LEC	.164	.048	.150	.113	.090	.074	.053	.055	.048	.037
BALANCE OF PLANT (\$/KW)	67.	178.	71.	87.	105.	123.	141.	160.	179.	231.
FRACTION OF LEC	.050	.039	.049	.045	.043	.041	.040	.039	.039	.038
INDIRECT/CONT. (\$/KW)	233.	816.	254.	340.	432.	525.	618.	718.	820.	1086.
FRACTION OF LEC	.175	.177	.175	.176	.176	.176	.177	.177	.177	.177
TOTAL INITIAL CAP. (\$/KW)	1203.	4215.	1312.	1755.	2230.	2711.	3193.	3709.	4236.	5612.
FRACTION OF LEC	.903	.914	.904	.908	.910	.912	.913	.913	.914	.916
REPLACEMENT CAPITAL (\$/KW)	0.	8.	0.	1.	3.	4.	5.	7.	8.	8.
FRACTION OF LEC	.000	.002	.000	.001	.001	.002	.002	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	1750.	5242.	1872.	2382.	2931.	3488.	4049.	4649.	5265.	6863.
FRACTION OF LEC	.097	.084	.096	.091	.089	.087	.086	.085	.084	.083
LEC (MILLS/KWH)	139.	107.	134.	119.	113.	110.	108.	107.	107.	126.

LFDR-TR 50MW
50 MW
09-24-80 11:52:32

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	400.	1250.	364.	507.	671.	832.	989.	1158.	1378.	2229.
STORAGE SIZE (HRS)	.00	15.00	.00	3.08	5.05	7.96	11.74	13.90	16.53	18.00
STORAGE CAPACITY (1000 KWH)	0.	2539.	0.	510.	841.	1333.	1975.	2348.	2807.	3063.
GENERATING CAPACITY (MW)	50.86	51.20	50.85	50.90	50.97	51.03	51.10	51.16	51.25	51.59
FIELD EFFICIENCY	.283	.283	.283	.283	.283	.283	.283	.283	.283	.283
TRANSPORT EFFICIENCY	.972	.971	.972	.971	.971	.971	.971	.971	.970	.970
STORAGE EFFICIENCY	*****	.961	*****	.966	.967	.966	.962	.961	.958	.957
ENERGY CONV. EFF. (FIELD)	.344	.357	.341	.354	.355	.356	.356	.357	.358	.358
ENERGY CONV. EFF. (STORAGE)	*****	.358	*****	.350	.354	.356	.357	.358	.359	.358
SYSTEM EFFICIENCY	.086	.093	.085	.091	.092	.093	.094	.093	.090	.063
CAPACITY FACTOR	.22	.75	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.
FRACTION OF LEC	.336	.398	.326	.349	.369	.380	.386	.394	.402	.427
RECEIVER (\$/M**2)	29.	28.	28.	28.	28.	28.	28.	28.	28.	28.
FRACTION OF LEC	.134	.159	.130	.139	.148	.152	.155	.158	.161	.171
TRANSPORT (\$/M**2)	4.7	5.3	4.6	4.3	4.9	5.1	5.2	5.3	5.4	5.7
FRACTION OF LEC	.022	.030	.021	.024	.026	.028	.029	.030	.031	.035
STORAGE (\$/KWH)	.0	3.5	.0	3.8	3.7	3.6	3.5	3.5	3.5	3.5
FRACTION OF LEC	.000	.040	.000	.019	.024	.031	.039	.040	.041	.029
ENERGY CONV. (\$/KW)	255.	257.	255.	256.	256.	256.	256.	257.	257.	258.
FRACTION OF LEC	.153	.058	.163	.126	.101	.084	.071	.062	.054	.035
BALANCE OF PLANT (\$/KW)	117.	221.	113.	131.	150.	170.	190.	210.	237.	334.
FRACTION OF LEC	.070	.050	.072	.064	.059	.056	.053	.051	.049	.046
INDIRECT/CONT. (\$/KW)	286.	777.	267.	352.	444.	537.	630.	726.	849.	1303.
FRACTION OF LEC	.172	.177	.171	.173	.174	.175	.176	.176	.177	.178
TOTAL INITIAL CAP. (\$/KW)	1480.	4017.	1382.	1819.	2293.	2773.	3257.	3750.	4388.	6733.
FRACTION OF LEC	.887	.913	.884	.894	.901	.906	.909	.911	.914	.921
REPLACEMENT CAPITAL (\$/KW)	0.	7.	0.	1.	2.	3.	5.	6.	7.	8.
FRACTION OF LEC	.000	.002	.000	.001	.001	.001	.002	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	636.	1273.	614.	725.	841.	961.	1086.	1207.	1364.	1912.
FRACTION OF LEC	.113	.086	.116	.106	.098	.093	.090	.087	.084	.078
LEC (MILLS/KWH)	139.	108.	145.	126.	118.	113.	111.	109.	111.	150.

LEDR-TR 100MW
100 MW
09-24-80 13:54:32

DESIGN POINT CAPACITY FACTORS

	0 STR	0PT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	800.	2500.	727.	1010.	1339.	1659.	1972.	2310.	2747.	4458.
STORAGE SIZE (HRS)	.00	15.00	.00	3.06	5.03	7.91	11.66	13.86	16.48	18.00
STORAGE CAPACITY (1000 KWH)	0.	5050.	0.	1008.	1666.	2635.	3904.	4657.	5566.	6093.
GENERATING CAPACITY (MW)	101.77	102.55	101.73	101.86	102.02	102.16	102.31	102.46	102.66	103.45
FIELD EFFICIENCY	.283	.283	.283	.283	.283	.283	.283	.283	.283	.283
TRANSPORT EFFICIENCY	.970	.969	.970	.970	.969	.969	.969	.969	.969	.967
STORAGE EFFICIENCY	*****	.960	*****	.966	.967	.966	.962	.961	.958	.957
ENERGY CONV. EFF. (FIELD)	.344	.359	.341	.356	.357	.357	.358	.359	.359	.360
ENERGY CONV. EFF. (STORAGE)	*****	.360	*****	.352	.355	.358	.359	.360	.360	.360
SYSTEM EFFICIENCY	.086	.093	.085	.092	.092	.093	.094	.093	.090	.063
CAPACITY FACTOR	.22	.76	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.
FRACTION OF LEC	.355	.406	.346	.364	.382	.392	.396	.403	.409	.431
RECEIVER (\$/M**2)	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.
FRACTION OF LEC	.142	.162	.138	.146	.153	.157	.158	.161	.164	.173
TRANSPORT (\$/M**2)	5.1	5.8	5.0	5.2	5.4	5.5	5.6	5.7	5.9	6.2
FRACTION OF LEC	.026	.034	.025	.027	.029	.031	.032	.033	.034	.038
STORAGE (\$/KWH)	.0	3.5	.0	3.9	3.7	3.6	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.041	.000	.020	.025	.032	.040	.041	.042	.030
ENERGY CONV. (\$/KW)	230.	232.	230.	230.	231.	231.	231.	232.	232.	234.
FRACTION OF LEC	.146	.054	.156	.119	.094	.078	.066	.058	.049	.032
BALANCE OF PLANT (\$/KW)	92.	196.	88.	106.	125.	145.	164.	185.	211.	308.
FRACTION OF LEC	.058	.045	.060	.055	.051	.049	.047	.046	.045	.043
INDIRECT/CONT. (\$/KW)	275.	768.	256.	340.	433.	525.	619.	714.	838.	1296.
FRACTION OF LEC	.174	.178	.174	.175	.176	.177	.178	.178	.178	.179
TOTAL INITIAL CAP. (\$/KW)	1422.	3969.	1324.	1758.	2235.	2714.	3197.	3691.	4329.	6697.
FRACTION OF LEC	.902	.920	.899	.906	.912	.915	.917	.919	.921	.926
REPLACEMENT CAPITAL (\$/KW)	0.	7.	0.	1.	2.	3.	5.	6.	7.	8.
FRACTION OF LEC	.000	.002	.000	.001	.001	.001	.002	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	1048.	2280.	1003.	1214.	1441.	1673.	1910.	2147.	2452.	3560.
FRACTION OF LEC	.093	.078	.101	.093	.087	.084	.081	.079	.077	.073
LEC (MILLS/KWH)	132.	106.	136.	120.	113.	110.	108.	106.	109.	149.

LFDR-TR 200MW
200 MW
09-24-80 11:56:05

DESIGN POINT CAPACITY FACTORS

	STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1600.	5000.	1455.	2020.	2678.	3321.	3950.	4626.	5500.	8957.
STORAGE SIZE (HRS)	.00	15.00	.00	3.06	5.03	7.92	11.70	13.88	16.50	18.00
STORAGE CAPACITY (1000 KWH)	0.	10079.	0.	2016.	3329.	5272.	7820.	9310.	11117.	12155.
GENERATING CAPACITY (MW)	203.58	205.25	203.51	203.79	204.11	204.43	204.74	205.07	205.49	207.19
FIELD EFFICIENCY	.283	.283	.283	.283	.283	.283	.283	.283	.283	.283
TRANSPORT EFFICIENCY	.969	.967	.969	.969	.968	.968	.967	.967	.967	.962
STORAGE EFFICIENCY	*****	.963	*****	.967	.968	.967	.964	.963	.961	.959
ENERGY CONV. EFF. (FIELD)	.345	.359	.342	.356	.357	.358	.358	.359	.359	.360
ENERGY CONV. EFF. (STORAGE)	*****	.360	*****	.352	.355	.358	.359	.360	.360	.361
SYSTEM EFFICIENCY	.086	.093	.085	.092	.092	.093	.094	.093	.090	.063
CAPACITY FACTOR	.22	.76	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.
FRACTION OF LEC	.366	.409	.357	.373	.389	.397	.401	.406	.412	.433
RECEIVER (\$/M**2)	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.
FRACTION OF LEC	.146	.164	.143	.149	.156	.159	.160	.163	.165	.173
TRANSPORT (\$/M**2)	5.5	6.3	5.4	5.6	5.8	6.0	6.1	6.2	6.4	6.7
FRACTION OF LEC	.029	.037	.028	.030	.032	.034	.035	.036	.037	.042
STORAGE (\$/KWH)	0.	3.5	0.	4.0	3.8	3.6	3.6	3.5	3.5	3.5
FRACTION OF LEC	.000	.042	.000	.021	.026	.033	.040	.041	.042	.030
ENERGY CONV. (\$/KW)	218.	219.	217.	218.	218.	218.	219.	219.	219.	221.
FRACTION OF LEC	.142	.051	.152	.115	.091	.075	.063	.055	.047	.031
BALANCE OF PLANT (\$/KW)	78.	181.	74.	91.	111.	130.	150.	170.	196.	294.
FRACTION OF LEC	.051	.042	.052	.048	.046	.044	.043	.043	.042	.041
INDIRECT/CONT. (\$/KW)	270.	765.	250.	335.	428.	521.	615.	712.	836.	1301.
FRACTION OF LEC	.176	.179	.176	.177	.178	.178	.178	.179	.179	.180
TOTAL INITIAL CAP. (\$/KW)	1393.	3951.	1294.	1731.	2209.	2692.	3180.	3677.	4317.	6721.
FRACTION OF LEC	.909	.924	.907	.913	.917	.920	.921	.923	.924	.928
REPLACEMENT CAPITAL (\$/KW)	0.	7.	0.	1.	2.	3.	5.	6.	7.	8.
FRACTION OF LEC	.000	.002	.000	.001	.001	.001	.002	.002	.002	.001
OPER. AND MAINT. (1000 \$/YR)	1876.	4309.	1785.	2201.	2651.	3111.	3578.	4049.	4657.	6911.
FRACTION OF LEC	.091	.075	.093	.086	.082	.079	.077	.075	.074	.071
LEC (MILLIS/KWH)	128.	105.	132.	117.	111.	108.	107.	105.	108.	149.

LFDR-TC 50MW
50 MW
09-02-80 09:46:33

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	500.	750.	358.	505.	687.	854.	1027.	1354.	1801.	2674.
STORAGE SIZE (HRS)	.00	6.00	.00	3.07	5.24	8.48	12.00	13.25	15.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	1343.	0.	684.	1172.	1906.	2703.	2991.	3391.	4082.
GENERATING CAPACITY (MW)	51.29	51.59	51.12	51.30	51.51	51.71	51.91	52.30	52.83	53.86
FIELD EFFICIENCY	.383	.383	.383	.383	.383	.383	.383	.383	.383	.383
TRANSPORT EFFICIENCY	.961	.961	.961	.962	.961	.961	.961	.960	.959	.957
STORAGE EFFICIENCY	*****	.966	*****	.960	.964	.966	.966	.968	.967	.964
ENERGY CONV. EFF. (FIELD)	.260	.265	.252	.261	.264	.265	.266	.267	.268	.269
ENERGY CONV. EFF. (STORAGE)	*****	.264	*****	.258	.262	.265	.266	.266	.267	.267
SYSTEM EFFICIENCY	.082	.089	.086	.091	.090	.090	.090	.080	.069	.052
CAPACITY FACTOR	.27	.43	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	67.	67.	67.	67.	67.	67.	67.	67.	67.	67.
FRACTION OF LEC	.372	.373	.330	.348	.368	.371	.369	.392	.412	.434
RECEIVER (\$/M**2)	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.
FRACTION OF LEC	.043	.043	.038	.040	.043	.043	.043	.046	.048	.050
TRANSPORT (\$/M**2)	9.5	9.9	9.1	9.5	9.8	10.1	10.3	10.7	11.1	11.6
FRACTION OF LEC	.052	.055	.045	.049	.054	.056	.057	.063	.068	.075
STORAGE (\$/KWH)	.0	2.6	.0	3.1	2.7	2.4	2.3	2.3	2.3	2.2
FRACTION OF LEC	.000	.026	.000	.022	.025	.030	.034	.030	.026	.022
ENERGY CONV. (\$/KW)	309.	311.	308.	309.	310.	311.	312.	314.	317.	322.
FRACTION OF LEC	.172	.115	.212	.159	.124	.101	.084	.068	.054	.039
BALANCE OF PLANT (\$/KW)	136.	171.	119.	139.	162.	185.	208.	249.	306.	418.
FRACTION OF LEC	.076	.063	.081	.071	.065	.060	.056	.054	.052	.051
INDIRECT/CONT. (\$/KW)	309.	437.	247.	322.	407.	489.	575.	724.	929.	1331.
FRACTION OF LEC	.171	.162	.169	.165	.163	.158	.154	.157	.159	.161
TOTAL INITIAL CAP. (\$/KW)	1597.	2259.	1275.	1665.	2105.	2527.	2969.	3742.	4801.	6876.
FRACTION OF LEC	.886	.839	.875	.854	.843	.819	.796	.809	.819	.832
REPLACEMENT CAPITAL (\$/KW)	0.	147.	0.	59.	122.	237.	381.	437.	518.	666.
FRACTION OF LEC	.000	.062	.000	.034	.056	.088	.117	.108	.101	.092
OPER. AND MAINT. (1000 \$/YR)	693.	895.	615.	732.	853.	976.	1106.	1305.	1578.	2114.
FRACTION OF LEC	.114	.099	.125	.111	.101	.094	.088	.084	.080	.076
LEC (MILLS/KWH)	125.	115.	135.	120.	116.	114.	115.	122.	136.	170.

LFDR-TC 100MW
100 MW
09-24-80 11:57:46

DESIGN POINT CAPACITY FACTORS

	n STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	800.	1500.	714.	1013.	1391.	1706.	2045.	2695.	3654.	5364.
STORAGE SIZE (HRS)	.00	6.00	.00	3.00	4.69	8.47	12.14	14.08	15.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	2666.	0.	1328.	2081.	3777.	5429.	6315.	6731.	8104.
GENERATING CAPACITY (MW)	102.51	103.48	102.39	102.81	103.33	103.77	104.24	105.15	106.48	108.86
FIELD EFFICIENCY	.383	.383	.383	.383	.383	.383	.383	.383	.383	.383
TRANSPORT EFFICIENCY	.958	.957	.958	.958	.957	.957	.957	.956	.955	.951
STORAGE EFFICIENCY	*****	.967	*****	.960	.966	.967	.966	.966	.967	.965
ENERGY CONV. EFF. (FIELD)	.258	.267	.253	.263	.266	.267	.268	.269	.271	.271
ENERGY CONV. EFF. (STORAGE)	*****	.265	*****	.260	.264	.266	.268	.269	.269	.269
SYSTEM EFFICIENCY	.088	.089	.086	.092	.088	.090	.091	.082	.068	.052
CAPACITY FACTOR	.23	.43	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	67.	67.	67.	67.	67.	67.	67.	67.	67.	67.
FRACTION OF LEC	.364	.385	.351	.365	.387	.381	.376	.393	.417	.436
RECEIVER (\$/M**2)	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.
FRACTION OF LEC	.042	.045	.041	.043	.045	.044	.044	.046	.049	.051
TRANSPORT (\$/M**2)	10.0	10.8	9.9	10.3	10.7	11.0	11.3	11.6	12.1	12.7
FRACTION OF LEC	.055	.062	.052	.056	.062	.063	.063	.068	.075	.082
STORAGE (\$/KWH)	.0	2.5	.0	3.0	2.6	2.4	2.3	2.3	2.2	2.2
FRACTION OF LEC	.000	.026	.000	.021	.023	.030	.034	.031	.026	.022
ENERGY CONV. (\$/KW)	282.	285.	282.	283.	284.	285.	287.	289.	292.	298.
FRACTION OF LEC	.192	.109	.207	.152	.118	.095	.079	.063	.050	.036
BALANCE OF PLANT (\$/KW)	99.	146.	94.	115.	139.	160.	183.	225.	286.	396.
FRACTION OF LEC	.068	.056	.069	.062	.058	.053	.050	.049	.049	.048
INDIRECT/CONT. (\$/KW)	254.	428.	235.	312.	400.	480.	565.	717.	937.	1336.
FRACTION OF LEC	.173	.164	.172	.168	.166	.160	.155	.156	.160	.162
TOTAL INITIAL CAP. (\$/KW)	1315.	2210.	1216.	1611.	2068.	2479.	2919.	3703.	4842.	6902.
FRACTION OF LEC	.894	.848	.891	.867	.860	.826	.800	.806	.826	.836
REPLACEMENT CAPITAL (\$/KW)	0.	146.	0.	56.	104.	234.	384.	471.	514.	661.
FRACTION OF LEC	.000	.064	.000	.035	.049	.089	.120	.117	.100	.092
OPER. AND MAINT. (1000 \$/YR)	1054.	1554.	1006.	1232.	1472.	1708.	1959.	2367.	2946.	4011.
FRACTION OF LEC	.106	.088	.109	.098	.091	.084	.080	.076	.074	.072
LEC (MILLS/KWH)	119.	111.	126.	115.	111.	111.	113.	121.	136.	170.

LFDR-TC 200MW
200 MW
09-02-80 09:05:16

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	2000.	3000.	1466.	2050.	2759.	3418.	4108.	5217.	7342.	10783.
STORAGE SIZE (HRS)	.00	6.00	.00	3.15	5.28	8.51	12.00	15.00	15.00	18.00
STORAGE CAPACITY (1000 KWH)	0.	5292.	0.	2769.	4652.	7532.	10654.	13362.	13362.	16089.
GENERATING CAPACITY (MW)	205.66	207.09	204.90	205.73	206.75	207.69	208.67	210.26	213.30	218.22
FIELD EFFICIENCY	.383	.383	.383	.383	.383	.383	.383	.383	.383	.383
TRANSPORT EFFICIENCY	.956	.956	.955	.956	.956	.956	.955	.954	.950	.946
STORAGE EFFICIENCY	*****	.969	*****	.964	.968	.968	.967	.966	.968	.965
ENERGY CONV. EFF. (FIELD)	.254	.267	.246	.260	.265	.268	.269	.271	.272	.273
ENERGY CONV. EFF. (STORAGE)	*****	.265	*****	.260	.264	.266	.268	.269	.269	.269
SYSTEM EFFICIENCY	.081	.089	.084	.091	.089	.090	.090	.083	.068	.052
CAPACITY FACTOR	.26	.43	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	67.	67.	67.	67.	67.	67.	67.	67.	67.	67.
FRACTION OF LEC	.399	.390	.364	.373	.387	.385	.380	.386	.418	.434
RECEIVER (\$/M**2)	8.	8.	8.	8.	8.	8.	8.	8.	8.	8.
FRACTION OF LEC	.046	.045	.042	.043	.045	.045	.044	.045	.049	.051
TRANSPORT (\$/M**2)	11.2	11.8	10.8	11.3	11.7	12.0	12.3	12.6	13.2	13.8
FRACTION OF LEC	.067	.069	.059	.063	.068	.069	.070	.073	.082	.090
STORAGE (\$/KWH)	.0	2.5	.0	2.9	2.5	2.4	2.3	2.2	2.2	2.2
FRACTION OF LEC	.000	.026	.000	.022	.025	.030	.033	.033	.025	.021
ENERGY CONV. (\$/KW)	270.	271.	269.	270.	271.	272.	273.	275.	279.	285.
FRACTION OF LEC	.160	.105	.199	.147	.114	.091	.075	.061	.047	.034
BALANCE OF PLANT (\$/KW)	99.	134.	82.	102.	126.	148.	172.	209.	278.	392.
FRACTION OF LEC	.059	.052	.061	.056	.053	.050	.048	.046	.047	.047
INDIRECT/CONT. (\$/KW)	295.	425.	235.	310.	396.	478.	565.	699.	945.	1352.
FRACTION OF LEC	.175	.165	.174	.169	.166	.161	.156	.155	.160	.162
TOTAL INITIAL CAP. (\$/KW)	1524.	2195.	1212.	1604.	2045.	2471.	2920.	3614.	4881.	6984.
FRACTION OF LEC	.906	.853	.900	.872	.857	.831	.806	.799	.829	.839
REPLACEMENT CAPITAL (\$/KW)	0.	145.	0.	60.	121.	234.	375.	510.	510.	656.
FRACTION OF LEC	.000	.064	.000	.037	.058	.090	.118	.129	.099	.090
OPER. AND MAINT. (1000 \$/YR)	2127.	2888.	1818.	2260.	2728.	3198.	3697.	4436.	5720.	7905.
FRACTION OF LEC	.094	.083	.100	.091	.085	.080	.076	.073	.072	.070
LEC (MILLS/KWH)	119.	110.	125.	114.	110.	110.	112.	120.	136.	171.

LCNT 50MW
50 MW
08-08-80 18154144

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	500.	1750.	498.	698.	915.	1141.	1370.	1601.	1851.	2480.
STORAGE SIZE (HRS)	.00	15.00	.00	2.38	4.98	7.69	10.44	13.21	16.21	18.00
STORAGE CAPACITY (1000 KWH)	0.	4413.	0.	685.	1442.	2236.	3050.	3876.	4779.	5323.
GENERATING CAPACITY (MW)	51.87	53.56	51.87	52.14	52.44	52.74	53.05	53.36	53.70	54.55
FIELD EFFICIENCY	.386	.386	.386	.386	.386	.386	.386	.386	.386	.386
TRANSPORT EFFICIENCY	.855	.852	.855	.855	.854	.853	.853	.852	.852	.848
STORAGE EFFICIENCY	*****	.948	*****	.756	.954	.952	.951	.949	.947	.946
ENERGY CONV. EFF. (FIELD)	.195	.207	.195	.203	.206	.207	.207	.207	.208	.209
ENERGY CONV. EFF. (STORAGE)	*****	.208	*****	.159	.204	.206	.207	.207	.208	.208
SYSTEM EFFICIENCY	.060	.065	.060	.064	.065	.065	.065	.065	.064	.054
CAPACITY FACTOR	.20	.77	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	62.	62.	62.	62.	62.	62.	62.	62.	62.	62.
FRACTION OF LEC	.233	.256	.233	.241	.248	.252	.254	.256	.257	.264
RECEIVER (\$/M**2)	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.
FRACTION OF LEC	.109	.120	.109	.113	.116	.118	.119	.120	.120	.123
TRANSPORT (\$/M**2)	46.2	50.2	46.2	47.2	48.1	48.8	49.4	49.9	50.4	51.4
FRACTION OF LEC	.174	.208	.173	.184	.192	.198	.203	.206	.209	.219
STORAGE (\$/KWH)	.0	4.6	.0	5.7	5.0	4.8	4.7	4.6	4.6	4.5
FRACTION OF LEC	.000	.048	.000	.022	.032	.038	.043	.046	.049	.041
ENERGY CONV. (\$/KW)	378.	389.	378.	380.	382.	384.	386.	388.	390.	395.
FRACTION OF LEC	.142	.046	.143	.106	.083	.068	.058	.050	.044	.034
BALANCE OF PLANT (\$/KW)	156.	395.	155.	194.	235.	278.	322.	367.	415.	529.
FRACTION OF LEC	.059	.047	.059	.054	.051	.049	.048	.047	.046	.045
INDIRECT/CONT. (\$/KW)	457.	1472.	456.	620.	794.	976.	1162.	1350.	1554.	2033.
FRACTION OF LEC	.172	.174	.172	.173	.173	.174	.174	.174	.174	.174
TOTAL INITIAL CAP. (\$/KW)	2363.	7603.	2355.	3202.	4101.	5042.	6003.	6973.	8029.	10506.
FRACTION OF LEC	.889	.899	.889	.893	.895	.897	.898	.898	.899	.901
REPLACEMENT CAPITAL (\$/KW)	0.	9.	0.	1.	2.	4.	6.	8.	10.	12.
FRACTION OF LEC	.000	.001	.000	.000	.001	.001	.001	.001	.001	.001
OPER. AND MAINT. (1000 \$/YR)	994.	2860.	992.	1294.	1613.	1947.	2290.	2636.	3012.	3859.
FRACTION OF LEC	.111	.100	.111	.107	.104	.103	.101	.101	.100	.098
LEC (MILLS/KWH)	245.	205.	245.	221.	212.	208.	206.	205.	207.	240.

LCNT 100MW
100 MW
08-08-80 18:44:38

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	1000.	3000.	991.	1386.	1833.	2290.	2751.	3235.	3745.	4962.
STORAGE SIZE (HRS)	.00	12.00	.00	3.00	5.00	7.74	10.51	13.41	16.47	18.00
STORAGE CAPACITY (1000 KWH)	0.	7179.	0.	1769.	2960.	4607.	6277.	8046.	9930.	10872.
GENERATING CAPACITY (MW)	107.67	110.41	107.66	108.20	108.81	109.44	110.07	110.73	111.43	113.10
FIELD EFFICIENCY	.386	.386	.386	.386	.386	.386	.386	.386	.386	.386
TRANSPORT EFFICIENCY	.853	.847	.853	.851	.850	.848	.847	.847	.846	.842
STORAGE EFFICIENCY	*****	.934	*****	.933	.937	.936	.935	.933	.930	.930
ENERGY CONV. EFF. (FIELD)	.198	.210	.198	.207	.209	.209	.210	.210	.211	.212
ENERGY CONV. EFF. (STORAGE)	*****	.209	*****	.201	.206	.208	.209	.209	.210	.210
SYSTEM EFFICIENCY	.060	.065	.060	.065	.065	.065	.065	.065	.064	.054
CAPACITY FACTOR	.20	.65	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	62.	62.	62.	62.	62.	62.	62.	62.	62.	62.
FRACTION OF LEC	.237	.254	.236	.241	.248	.251	.253	.254	.255	.261
RECEIVER (\$/M**2)	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.
FRACTION OF LEC	.111	.119	.110	.113	.116	.117	.118	.119	.119	.122
TRANSPORT (\$/M**2)	48.4	52.1	48.4	49.5	50.4	51.2	51.8	52.4	52.9	53.9
FRACTION OF LEC	.185	.213	.184	.192	.201	.207	.211	.215	.218	.227
STORAGE (\$/KWH)	.0	4.7	.0	5.6	5.1	4.8	4.7	4.6	4.6	4.6
FRACTION OF LEC	.000	.046	.000	.028	.033	.039	.044	.047	.050	.042
ENERGY CONV. (\$/KW)	363.	371.	363.	364.	366.	368.	370.	372.	374.	380.
FRACTION OF LEC	.138	.051	.139	.102	.080	.065	.055	.047	.041	.032
BALANCE OF PLANT (\$/KW)	135.	326.	134.	173.	215.	258.	302.	349.	398.	508.
FRACTION OF LEC	.051	.044	.052	.048	.047	.046	.045	.044	.044	.043
INDIRECT/CONT. (\$/KW)	454.	1278.	451.	620.	798.	985.	1175.	1375.	1588.	2058.
FRACTION OF LEC	.173	.174	.173	.174	.174	.174	.174	.174	.174	.175
TOTAL INITIAL CAP. (\$/KW)	2345.	6603.	2329.	3203.	4122.	5090.	6072.	7107.	8203.	10631.
FRACTION OF LEC	.895	.901	.895	.897	.899	.900	.900	.901	.901	.902
REPLACEMENT CAPITAL (\$/KW)	0.	7.	0.	1.	2.	4.	6.	8.	11.	12.
FRACTION OF LEC	.000	.001	.000	.000	.001	.001	.001	.001	.001	.001
OPER. AND MAINT. (1000 \$/YR)	1862.	4870.	1851.	2478.	3117.	3801.	4494.	5226.	6004.	7666.
FRACTION OF LEC	.105	.098	.105	.103	.101	.100	.099	.098	.098	.096
LEC (MILLS/KWH)	240.	208.	241.	220.	212.	210.	208.	209.	211.	242.

LCNT 200MW
200 MW
08-11-80 10:20:10

DESIGN POINT CAPACITY FACTORS

	0 STR	OPT	.20	.30	.40	.50	.60	.70	.80	.90
PERFORMANCE RESULTS:										
FIELD SIZE (1000 M**2)	2000.	5000.	1984.	2778.	3649.	4560.	5491.	6472.	7497.	10000.
STORAGE SIZE (HRS)	.00	9.00	.00	2.33	4.95	7.68	10.47	13.42	16.49	18.00
STORAGE CAPACITY (1000 KWH)	0.	10351.	0.	2658.	5656.	8817.	12076.	15550.	19208.	21001.
GENERATING CAPACITY (MW)	209.04	213.15	209.02	210.11	211.30	212.55	213.82	215.17	216.57	220.00
FIELD EFFICIENCY	.386	.386	.386	.386	.386	.386	.386	.386	.386	.386
TRANSPORT EFFICIENCY	.850	.841	.850	.848	.844	.842	.839	.836	.834	.829
STORAGE EFFICIENCY	*****	.944	*****	.737	.946	.945	.944	.942	.939	.939
ENERGY CONV. EFF. (FIELD)	.199	.211	.198	.207	.210	.211	.211	.211	.212	.213
ENERGY CONV. EFF. (STORAGE)	*****	.211	*****	.159	.208	.210	.211	.211	.212	.212
SYSTEM EFFICIENCY	.060	.065	.060	.064	.065	.065	.065	.065	.064	.054
CAPACITY FACTOR	.20	.55	.20	.30	.40	.50	.60	.70	.80	.90
ECONOMIC RESULTS:										
CONCENTRATOR (\$/M**2)	62.	62.	62.	62.	62.	62.	62.	62.	62.	62.
FRACTION OF LEC	.239	.251	.238	.243	.248	.250	.252	.253	.253	.259
RECEIVER (\$/M**2)	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.
FRACTION OF LEC	.112	.117	.111	.114	.116	.117	.118	.118	.118	.121
TRANSPORT (\$/M**2)	50.7	53.9	50.7	51.8	52.8	53.6	54.3	54.9	55.4	56.5
FRACTION OF LEC	.195	.218	.195	.203	.211	.216	.220	.224	.227	.236
STORAGE (\$/KWH)	.0	4.8	.0	6.1	5.2	4.9	4.7	4.7	4.6	4.6
FRACTION OF LEC	.000	.040	.000	.023	.032	.038	.042	.046	.048	.040
ENERGY CONV. (\$/KW)	339.	345.	339.	341.	343.	345.	346.	349.	351.	356.
FRACTION OF LEC	.131	.056	.131	.096	.075	.061	.051	.044	.038	.030
BALANCE OF PLANT (\$/KW)	124.	271.	123.	163.	205.	249.	295.	343.	393.	510.
FRACTION OF LEC	.048	.044	.048	.046	.045	.044	.044	.043	.043	.043
INDIRECT/CONT. (\$/KW)	451.	1077.	448.	616.	796.	985.	1180.	1386.	1602.	2094.
FRACTION OF LEC	.174	.174	.174	.174	.174	.174	.175	.175	.175	.175
TOTAL INITIAL CAP. (\$/KW)	2332.	5566.	2316.	3185.	4114.	5091.	6096.	7160.	8278.	10817.
FRACTION OF LEC	.898	.901	.898	.899	.901	.901	.902	.902	.902	.903
REPLACEMENT CAPITAL (\$/KW)	0.	5.	0.	1.	2.	4.	6.	8.	10.	12.
FRACTION OF LEC	.000	.001	.000	.000	.001	.001	.001	.001	.001	.001
OPER. AND MAINT. (1000 \$/YR)	3589.	8139.	3567.	4795.	6098.	7472.	8886.	10387.	11965.	15452.
FRACTION OF LEC	.102	.098	.102	.100	.099	.098	.097	.097	.097	.096
LEC (MILLS/KWH)	238.	209.	239.	219.	211.	209.	209.	210.	212.	246.

APPENDIX C

CONSISTENCY CHECK AND OTHER IMPORTANT ATTRIBUTES

APPENDIX C

CONSISTENCY CHECK AND OTHER IMPORTANT ATTRIBUTES

This appendix discusses the method used to check for consistency between ranks generated for 13 hypothetical solar power concepts by MAUM with those generated by a direct (holistic) approach. Also discussed are the results of the consistency test.

C.1 MAUM CONSISTENCY CHECK

To check whether or not the ranks generated by MAUM are consistent with ranks generated by direct comparison of solar concepts (holistic ranks), a consistency test was devised and built into the questionnaire administered to electric utility decision makers. Decision makers were asked to compare and rank 13 hypothetical solar power concepts; concept attribute levels are listed in Table C.1. Decision makers were also asked to indicate which, if any, of the 13 hypothetical solar concepts were unacceptable and would not be purchased under any circumstances. The results of the holistic ranking process are indicated in Table C.2. The cells in Table C.2 indicate the number of decision makers who assigned a particular solar concept a given rank.

MAUM ranks for each of the hypothetical solar concepts were generated by computing concept scores based on the attribute levels associated with each concept. Solar concepts receiving a concept score of zero were considered unacceptable. The results of the MAUM rank are illustrated in Table C.3, which is interpreted in the same manner as Table C.2. Table C.4 shows the number of people who assigned unacceptable scores to each of the 13 hypothetical solar concepts using both the MAUM and holistic method. Both methods generate similar results for unacceptability of a given concept.

Two types of consistency checks were performed. The first was a logical consistency check to determine if the ranks generated by the holistic approach were logically consistent. It was felt that if holistic ranks were logically inconsistent, they would be of little use in assessing the accuracy of MAUM

TABLE C.1. Attribute Levels for 13 Hypothetical Solar Power Concepts

<u>Plant Code</u>	<u>Levelized Energy Cost (mills/kWh)</u>	<u>Capacity Factor (%)</u>	<u>Forced Outage (%)</u>
YW	50	90	2
YV	50	55	7
ZY	125	90	2
WV	75	90	7
XV	75	55	2
VY	100	20	2
YX	100	90	12
ZZ	125	55	7
ZW	100	20	7
VW	100	55	12
XY	175	55	7
WZ	125	20	12
XW	200	20	12

TABLE C.2. Number of Decision Makers Assigning a Given Rank to Hypothetical Solar Concepts Using the Holistic Approach

<u>Solar Concept</u>	<u>Rank (Holistic)</u>												
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>	<u>12</u>	<u>13</u>
YW	41	0	0	0	0	0	0	0	0	1	0	0	0
YV	1	31	4	1	2	3	0	0	0	0	0	0	0
ZY	0	2	3	2	1	11	8	0	13	0	1	0	1
WV	0	6	30	3	2	0	0	0	0	0	1	0	0
XV	0	3	5	25	6	3	0	0	0	0	0	0	0
VY	0	0	1	1	4	4	4	4	9	9	2	0	0
YX	0	0	0	6	25	2	3	4	1	0	0	1	0
ZZ	0	0	0	1	0	0	3	18	2	18	0	0	0
XW	0	0	0	1	1	3	4	10	5	9	7	2	0
VW	0	0	1	0	2	16	14	6	1	0	2	0	0
XY	0	0	0	0	0	0	0	1	9	2	6	23	1
WZ	0	0	0	0	0	0	1	0	1	2	23	15	0
XW	0	0	0	0	0	0	0	1	0	0	0	1	40

TABLE C.3. Number of Decision Makers Assigning a Given Rank to Hypothetical Solar Concepts Using the MAUM Approach

Solar Concept	Rank (MAUM)												
	1	2	3	4	5	6	7	8	9	10	11	12	13
YW	40	0	1	0	0	0	0	0	0	0	0	0	1
YV	2	15	10	5	6	3	0	0	0	0	0	0	1
ZY	2	5	9	1	10	5	4	1	4	0	0	0	1
WV	1	15	15	5	2	2	0	0	0	0	0	0	1
XV	2	5	7	19	5	4	0	0	0	0	0	0	1
VY	0	0	0	1	3	4	9	8	4	12	0	0	1
YX	0	0	0	7	13	10	4	1	1	5	0	0	1
ZZ	0	0	0	1	1	3	13	12	4	6	1	0	1
ZW	0	0	0	0	1	0	2	8	9	5	17	0	1
VW	0	0	0	0	1	8	10	8	4	2	7	0	1
XY	0	0	0	1	1	1	3	9	11	6	4	5	1
WZ	0	0	0	0	0	0	0	2	0	0	5	34	1
XW	0	0	0	0	0	0	0	2	0	0	0	17	23

TABLE C.4. Number of Decision Makers Assigning Unacceptable Scores to 13 Hypothetical Solar Concepts Using the MAUM and Holistic Methods

Solar Concept	MAUM Method	Holistic Method
YW	3	4
YV	6	4
ZY	18	17
WV	7	7
XV	8	7
VY	24	27
YX	17	15
ZZ	19	21
ZW	24	28
VW	18	16
XY	25	35
WZ	30	38
XW	35	41

ranks. The second check compared the MAUM and holistic ranks for each decision maker and used a Spearman's Rho test to statistically determine whether or not those ranks were correlated.

The logical consistency check performed on holistic ranks compared the preference ordering of the hypothetical solar concepts based on a logical rule with the preference order indicated by holistic ranks. The logical rule used states that decision makers must prefer a concept that has at least one attribute at a more favorable level than another concept and no attributes at less favorable levels. On the basis of this rule, a logical preference hierarchy matrix (Table C.5) was constructed for the 13 hypothetical solar concepts.

The logical preference matrix indicates which concepts should logically be preferred, less preferred, and noncomparable. A value of 1 indicates that a concept in the row is preferred or indifferent to a concept in the column. Similarly, a value of 0 indicates that a concept in a row is less preferred than a concept in the column and a value of 2 indicates that both concepts are noncomparable.

A logical error rate was calculated for each decision maker by dividing the number of logical mistakes committed by the number of possible errors. Because decision makers could not make errors when comparing a concept with itself or when comparing two noncomparable concepts, the total number of possible errors was 102. Logical error rates for each decision maker are presented in Table C.6.

Spearman's Rho statistics are also presented in Table C.6. Of 42 decision makers surveyed, 38 had highly significant (0.01 level) Spearman's Rho statistics, indicating a significant degree of correlation between the MAUM ranks and the holistic ranks assigned by these decision makers. Of the four decision makers who obtained nonsignificant Spearman's Rho statistics, three considered every hypothetical solar concept unacceptable using both the MAUM method and the holistic method. Even though the Spearman's Rho statistic suggests that the MAUM and holistic ranks assigned by those decision makers may not be correlated, other measures of association, not as restrictive as Spearman's Rho, would show that the MAUM and holistic ranks of these three decision makers are

TABLE C.5. Hierarchical Matrix for 13 Hypothetical Solar Concepts

	<u>YW</u>	<u>YV</u>	<u>ZY</u>	<u>WV</u>	<u>XV</u>	<u>VY</u>	<u>YX</u>	<u>ZZ</u>	<u>ZW</u>	<u>VW</u>	<u>XY</u>	<u>WZ</u>	<u>XW</u>
YW	1	1	1	1	1	1	1	1	1	1	1	1	1
YV	0	1	2	2	2	2	2	1	1	1	1	1	1
ZY	0	2	1	2	2	2	2	1	2	2	1	1	1
WV	0	2	2	1	2	2	1	1	1	1	1	1	1
XV	0	2	2	2	1	1	2	1	1	1	1	1	1
VY	0	2	2	2	0	1	2	2	1	2	2	1	1
YX	0	2	2	0	2	2	1	2	2	1	2	1	1
ZZ	0	0	0	0	0	2	2	1	2	2	1	1	1
ZW	0	0	2	0	0	0	2	2	1	2	2	1	1
VW	0	0	2	0	0	2	0	2	2	1	2	1	1
XY	0	0	0	0	0	2	2	0	2	2	1	2	1
WZ	0	0	0	0	0	0	0	0	0	0	2	1	1
XW	0	0	0	0	0	0	0	0	0	0	0	0	1

perfectly associated (Hildebrand, Laing, and Rosenthal 1977). Only decision maker 40 assigned ranks that appear to be inconsistent between methods. Both his logical error rate and Spearman's Rho statistic indicate substantial inconsistency. The reason for his inconsistency lies in the fact that he, alone, had a nonmonotonic preference function for an attribute (CF). Thus, with the exception of decision maker 40, the MAUM ranks appear to correspond closely to holistic ranks for the decision makers interviewed.

To compare how well the group MAUM rank would compare with a group holistic rank, it is necessary to compute a group holistic rank. Because holistic ranks, unlike MAUM ranks, show order but not intensity of preference, it is necessary to formulate a rule for transforming individual holistic ranks to a group rank. The rule used is to calculate a running total for each row of Table C.2 and, for any rank, pick the concept having the highest total at that point that has not been assigned a rank already. In the case of a tie on a given rank, go to the next lower rank and pick the one with the highest total. The group ranks calculated for the MAUM and holistic approaches are shown in

TABLE C.6. Logical Error Rates and Spearman's Rhos
For All Decision Makers

DM	Logical Error Rate (%)	Spearman's Rho(a) MAUM Rank versus Holistic Rank
1	0	0.82**
2	0	0.99**
3	0	0.96**
4	2	0.72**
5	2	0.93**
6	0	0.93**
7	0	0.96**
8	2	0.94**
9	0	0.96**
10	0	0.96**
11	0	0.96**
12	14	0.88**
13	0	0.78**
14	0	0.81**
15	6	-0.79(b)
16	0	0.74**
17	0	0.71**
18	4	0.90**
19	0	0.91**
20	0	0.78**
21	0	0.89**
22	1	0.79**
23	0	0.96**
24	0	0.84**
25	0	0.82**
26	0	0.91**
27	4	0.97**
28	0	0.99**
29	0	0.94**
30	2	0.84**
31	0	0.77**
32	0	0.87**
33	0	0.93**
34	0	0.79**
35	0	0.85**
36	0	0.82**
37	2	0.91**
38	0	0.88**
39	0	0.42(b)
40	45	0.40(c)
41	0	0.89**
42	0	0.50(b)

(a) Significance Levels $0.05 > r_s \geq 0.55^*$
 $0.01 > r_s \geq 0.68^{**}$

(b) These decision makers ranked
all solar concepts unacceptable
using both ranking methods.

(c) This decision maker had nonmono-
tonic preferences.

Table C.7. The Spearman's Rho statistic comparing the group MAUM and holistic concept ranks indicates highly significant agreement between the two methods.

The conclusion reached in the consistency check is that MAUM ranks tend to agree with holistic ranks. Thus, the MAUM approach used in this study appears to perform satisfactorily as compared to a holistic approach. Given its simplicity, relatively low cost, and satisfactory performance, this simple MAUM approach seems to be an adequate predictor of how decision makers would rank alternative solar concepts, based on the attributes LEC, CF, and F0.

TABLE C.7. Comparison of Holistic and MAUM Group Ranks and Calculation of Spearman's Rho

<u>Plant</u>	<u>Holistic Rank</u>	<u>MAUM Rank</u>	<u>Δ</u>	<u>Δ^2</u>
YW	1	1	0	0
YV	2	2	0	0
ZY	7	5	2	4
WV	3	3	0	0
XV	4	4	0	0
VY	8	9	1	1
YX	5	6	1	1
ZZ	9	8	1	1
ZW	10	11	1	1
UW	6	7	1	1
XY	12	10	2	4
WZ	11	13	1	1
XW	13	13	0	0
			$\Sigma \Delta^2 =$	14

$$\rho = 1 - \frac{6\Sigma\Delta^2}{N(N^2 - 1)}$$

$$\rho = 1 - \frac{84}{2184}$$

$$\rho = 0.96^{**}$$

** Highly Significant

C.2 OTHER IMPORTANT ATTRIBUTES

The final section of the questionnaire administered to electric utility decision makers included questions intended to ascertain what attributes, other than LEC, CF and FO, might have an impact on how decision makers rank alternative solar concepts. Table C.8 shows the questions asked. All questions except Question I dealt with technical characteristics of solar concepts. Question I was included to determine whether or not decision makers had negative feelings about the interview process.

In response to Question A, 28 decision makers thought cost was a major concern in purchasing a 50- to 200-MWe solar thermal electric power system. Eleven thought availability, reliability, and dependability were major concerns. Land, in general, was mentioned by nine. This suggests that future MAUM studies might include land use as an attribute in addition to LEC, CF, and FO.

In response to Question B, 30 decision makers considered cost to be the major obstacle to commercial acceptance of large solar thermal electric power systems. Eleven mentioned demonstration, and five thought lack of proven and developed technology was a big obstacle. Eight considered availability and reliability to be obstacles.

Questions C and D asked decision makers how much they would be willing to increase LEC to lower the amount of startup time by a specified amount. If startup time could be reduced from 1 hour to 30 minutes, 22 decision makers would not be willing to accept an increase. Thirteen would be willing to accept less than a 10% increase in LEC, three would accept more than a 10% increase, and four gave no response. If startup time could be reduced from 30 minutes to 10 minutes, 21 decision makers would be unwilling to accept any increase in LEC, 14 would be willing to accept less than a 10% increase, three would be willing to accept more than a 10% increase, and four gave no response. Overall, decision makers had little interest in lowering the startup time for 50- to 200-MWe solar power systems.

TABLE C.8. Questions Asked to Determine Other Important Attributes

- A. What are your major concerns, if any, about purchasing a 50-200 MWe solar thermal electric power system?
- B. What do you consider to be the major obstacles to commercial acceptance of large solar thermal electric power systems?
- C. If startup time is 1 hour, what percentage increase in levelized energy cost would you be willing to accept if startup time could be reduced from 1 hour to 30 minutes? _____
- D. If startup time is 30 minutes, what percentage increase in levelized energy costs would you be willing to accept if startup time could be reduced from 30 minutes to 10 minutes? _____

	<u>Strongly Agree</u>		<u>Neutral</u>		<u>Strongly Disagree</u>
E. I am interested in process heat capability.	1	2	3	4	5
F. I would be positively influenced in my decision on whether or not to purchase a solar thermal electric system if I was allowed to burn fossil fuels to keep the capacity factor up.	1	2	3	4	5
G. It is important to me to be able to add capacity easily.	1	2	3	4	5
H. Grid energy storage is important to me.	1	2	3	4	5
I. Participation in this interview has been a pleasant experience.	1	2	3	4	5

In response to Question E, 3 decision makers indicated strong interest in process heat capability, 14 indicated interest, 12 were neutral, 9 showed little interest, and 3 showed no interest. Overall, process heat did not seem to be extremely important to decision makers in the sample.

Decision makers seem to be quite interested in being able to burn fossil fuels to keep the capacity factor for a solar power system up. Sixteen

strongly agreed that the use of fossil fuels would positively influence their decision to purchase solar power systems; 16 agreed, 5 were neutral, and only 5 disagreed.

Decision makers also seem to be interested in being able to add capacity easily. On this issue, 16 strongly agreed that ability to easily add capacity was important, 19 agreed, 5 were neutral, and only 2 disagreed.

On the issue of grid power storage, 13 strongly agreed that it was important, 14 agreed, 6 were neutral, 4 disagreed, and 5 strongly disagreed.

In response to Question I, 17 decision makers strongly agreed that the survey was a pleasant experience, 17 agreed, and 7 were neutral. None of the 42 decision makers found the survey to be unpleasant.

REFERENCE

Hilderbrand, D. K., J. D. Laing, and H. Rosenthal. 1977. Analysis of Ordinal Data. Sage Publications, Beverly Hills, California.

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