DO NOT MICROFILM
COVER

PRELIMINARY DESIGN OF
THE CARRISA PLAINS
SOLAR CENTRAL RECEIVER POWER PLANT
VOLUME I — EXECUTIVE SUMMARY

*Prepared for the Department of Energy,
San Francisco Operations Office,
under Contract DE-FC03-82SF11674*

MASTER

Rockwell International
Energy Systems Group

ARCO Solar Industries

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DO NOT MICROFILM
COVER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**PRELIMINARY DESIGN OF
THE CARRISA PLAINS
SOLAR CENTRAL RECEIVER POWER PLANT
VOLUME I — EXECUTIVE SUMMARY**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Rockwell International

Energy Systems Group

ARCO Solar Industries

DOE/SF/11674--1-Vol.1-Exec.Summ.
DE84 005783
U.S. DEPARTMENT OF ENERGY
OFFICE OF SOLAR ENERGY RESEARCH
SOLAR ENERGY RESEARCH
SOLAR ENERGY RESEARCH
SOLAR ENERGY RESEARCH

CONTRACT: DE-FC03-82SF11674

ISSUED: 31 DECEMBER 1983

This report, *Preliminary Design of the Carrisa Plains Solar Central Receiver Power Plant*, ESG-DOE-13404, consists of three volumes, one of which is further subdivided. These are:

Volume I. Executive Summary

Volume II. Plant Specifications

Volume III. Plant Design

Book 1. Design Description

Book 2. Design Drawings

Book 3. Appendices

Books 1, 2, and 3 in Volume III, Plant Design, are a single document, separated for reasons of format and readability. Book 1, Design Description, contains narrative material, tables, and figures suited to an 8½-in. by 11-in. format. Book 2, Design Drawings, is a 17-in. by 22-in. volume containing material whose readability is benefitted by a larger format. Graphic material cited in Book 1 is referenced as a figure if it appears in Book 1, or as a drawing if it appears in Book 2. Material appearing in Books 2 and 3 is assigned a number in accordance with the section of Book 1 in which it is referenced. Consequently, the numbering in Books 2 and 3 may appear to leave gaps.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

CONTENTS

	Page
1.0 Introduction.....	1-1
1.1 Design Development During Preliminary Design.....	1-3
1.2 Rationale for Design Selection.....	1-5
1.2.1 Receiver Configuration.....	1-5
1.2.2 Steam Cycle.....	1-6
1.2.3 Steam Conditions.....	1-6
1.2.4 Steam Generation Method.....	1-7
1.2.5 Steam Generator Surface Area.....	1-7
1.2.6 Thermal Storage Capacity.....	1-8
2.0 Plant Design Description.....	2-1
2.1 Site Description.....	2-2
2.1.1 Location.....	2-2
2.1.2 Geography.....	2-2
2.2 Facility Design Summary.....	2-8
2.2.1 Collector System.....	2-11
2.2.2 Heat Transport System.....	2-13
2.2.3 Electric Power Generation System.....	2-24
2.2.4 Balance of Plant.....	2-27
2.2.5 Master Control System.....	2-27
2.3 Plant Operations.....	2-27
3.0 Plant Performance.....	3-1
4.0 Operations and Maintenance.....	4-1
5.0 Development.....	5-1
5.1 Final Design Phase.....	5-1
5.2 Construction Phase.....	5-3
5.3 Checkout and Acceptance Testing.....	5-3
5.4 Environmental Impact and Permit Plan.....	5-5

CONTENTS

6.0	Facility Cost Estimate and Economic Analysis.....	6-1
6.1	Introduction.....	6-1
6.2	Construction Cost.....	6-1
6.3	Financial Plan.....	6-3
6.4	Operations and Revenue Stream.....	6-3
6.5	Ownership and Financial Structure.....	6-4
6.6	Present Worth and Economic Evaluation.....	6-6

TABLES

1.	Actual Measured Insolation for 1982/1983.....	2-6
2.	Estimated Direct Normal Insolation at Carrisa Plains.....	2-7
3.	Design Summary of Collector System.....	2-14
4.	Receiver Subsystem Design Summary.....	2-18
5.	Steam Generator Subsystem Design Summary.....	2-23
6.	Operations and Maintenance Personnel.....	4-2
7.	Power Plant Operations and Maintenance Budget.....	4-2
8.	Carrisa Plains Cost Estimate (\$ Million).....	6-2
9.	Cost Breakdown by Calendar Year (\$ Million).....	6-2
10.	Application and Source of All Project Financing.....	6-5
11.	Case II - Carrisa Plains Project Solar Energy Plant Partnership Analysis (\$000).....	6-7

FIGURES

1.	Carrisa Plains Solar Power Plant Artist's Concept.....	1-2
2.	Location of Carrisa Plains Solar Power Plant.....	2-3
3.	Site for Carrisa Plains Solar Power Plant.....	2-3
4.	Site Photographs.....	2-4
5.	Plant Conceptual Drawing.....	2-9
6.	Carrisa Plains Solar Plant Layout.....	2-10

FIGURES

7. Carrisa Plains Solar Plant Flow Diagram.....	2-10
8. Carrisa Plains Solar Plant Collector Field Layout	2-12
9. Receiver Subsystem Layout.....	2-16
10. Panel Assembly Drawing.....	2-17
11. Simplified P&ID of Main Heat Transport Loop.....	2-20
12. Piping Layout.....	2-21
13. Steam Generator Unit Configuration and Physical Interfaces.....	2-22
14. Argon Cover Gas System.....	2-25
15. Solar Plant Heat Balance.....	2-26
16. Major Site Improvements.....	2-28
17. 30-MW Solar Project Single Line Diagram.....	2-29
18. 30-MW Solar Project Master Control System Conceptual Layout.....	2-30
19. Equinox Startup Schedule.....	2-31
20. Design Point Efficiency Diagram (Equinox Noon).....	3-2
21. Annual Energy Efficiency Diagram.....	3-2
22. Carrisa Plains Solar Power Plant Organization.....	4-1
23. Final Design Program Schedule.....	5-2
24. Summary Construction Plan.....	5-4
25. Project Organization.....	6-5

1.0 INTRODUCTION

The preliminary design of the Carrisa Plains solar central receiver power plant has been performed by a team drawn from Rockwell International's Energy Systems Group, the Pacific Gas and Electric Company (PGandE) and ARCO Solar Industries. The work was conducted under a cooperative agreement between the design team companies and the U.S. Department of Energy, Contract DE-FC03-82SF11674. Under this cooperative agreement, the design team companies have contributed more than 35% of the cost of the design.

An artist's concept of the Carrisa Plains plant is shown in Figure 1. This 30 MWe solar power plant is a commercial demonstration plant. It is a measured step from the 10 MWe Solar One pilot plant toward larger solar plants based on the same technology. Successful completion of this project will lead to power generation starting in 1986.

The solar power plant is to be located in PGandE's service territory, at Carrisa Plains, San Luis Obispo County, California. The site is excellent for solar, being flat, rural, and semiarid. Good-quality water is available, and the surrounding hills protect the valley from summer and winter fog in adjacent areas. The site is located along the transmission corridor for PGandE's Morro Bay power plant, and will be serviced by a doubly connected 115 kV line.

The project was initiated in 1981 by the three team participants utilizing their own funding. From its outset, the project team focused on tailoring their next step in solar central receiver technology to the current economic, governmental, and business climates. The plant is intended to be privately owned through an independent power producer (IPP). The plant capacity was set at 30 MWe to balance economies of scale with technical, schedule, and financial risks. This scale permits a rapid construction schedule, which maximizes the utilization of federal energy tax credits. The plant size permits the IPP to fall within Public Utilities Regulatory Policy Act (PURPA) exemptions thus avoiding regulation as a utility, and also making the county rather than the state the lead site agency.

The plant maximizes the value of the energy produced by incorporating enough thermal storage to provide reliable power delivery during PGandE's peak demand period. In this way, substantial capacity credit payments are earned and fuel costs are diminished. The heat transport system has been built around Rockwell's tested prototype solar receiver and modular steam generator. The collector system utilizes ARCO's heliostats, based on their successful design and operation at the Fairfield, California forty heliostat solar steam generator.

Plant design responsibilities were divided as follows:

Collector System - ARCO
Heat Transport System - Rockwell
Power Conversion System - PGandE
Master Control System - PGandE
Balance of Plant - PGandE

Figure 1. Carrisa Plains Solar Power Plant
Artist's Concept

ESG-DOE-13404

1.1 DESIGN DEVELOPMENT DURING PRELIMINARY DESIGN

At the initiation of the preliminary design, the privately funded conceptual design was carefully reviewed to assess its completeness and correctness of approach. A further purpose of this review was to identify any changes necessary for the design concept and requirements. It was concluded that the design was fundamentally sound, and that the objectives and constraints described above remained viable. This left the design team free to concentrate on the specifications and drawings, which are the major output of preliminary design. These specifications and drawings are backed up by appropriate design reports. So far the project has produced

- 52 design specifications and requirements documents
- Over 135 drawings and layouts including the systems, subsystems, and components; plant utilities; site preparation; project scheduling and planning; and plant performance and operations.

The drawings include the following specific categories:

- 23 assembly and subsidiary layout drawings of solar-specific and other unique systems, subsystems, and components
- 22 piping and instrumentation drawings (P&IDs), loop diagrams, and other process drawings
- 17 equipment location and design drawings
- 27 structural and architectural drawings
- 5 site and utilities drawings.

Taken together, these specifications and drawings constitute a sound foundation on which final design can be based and ensure ultimate project success.

Comparing the finished preliminary design with the conceptual design as it existed prior to the initiation of the DOE cooperative agreement, several changes have been made in the design focus and implementation in the interest of reliability and economy. The major items are:

- The building housing heat transport and power conversion equipment has been replaced by an open power complex structure providing superior equipment access and lower cost.
- The heat transport system has been designed with a more generous (20%) design margin and redundancy of major hardware and mechanical components. This provides higher availability and helps to ensure a successful project.
- Coding of heat transport system components has been shown to be possible under the Boiler and Pressure Vessel (B&PV) ASME Code Section VIII Division 1. The code stamping of these items to Section VIII will provide confidence in the soundness of the design while permitting fabrication at reasonable cost.
- The use of a drag valve for dissipation of the receiver coolant head at the tower top has been supplanted by the use of two globe valves in series. These are operated with balanced pressure drops to prevent cavitation. This enhances the confidence in the design and reduces the cost.
- A combination active/passive protection system for receiver protection has been implemented in lieu of a purely passive one. This provides more complete receiver protection and immunity from failure.
- Individual valving and control of solar receiver panels has been provided rather than common flow control for the middle six panels.
- The master control system has been made fully digital rather than analog, providing greater flexibility and lower manpower requirements.

The small number of changes in design focus and implementation reflects the fundamental soundness of the Carrisa Plains design project. The absence of major changes has permitted project resources to focus on producing the detailed design work needed to obtain reliable cost estimates and quotations, reliable systems models and performance estimates, warrantee and financial positions needed to produce a third-party venture, and a clear understanding of how the project can proceed through succeeding phases.

1.2 RATIONALE FOR DESIGN SELECTION

The emphasis of preliminary design has been largely on the development of the necessary design detail, specifications, and drawings to ensure that the Carrisa Plains project is able to proceed expeditiously into final design and construction. During the privately funded conceptual design phase, by contrast, the trade studies used to select the design features were emphasized. Since only minor changes were made to these during preliminary design, the rationales developed during conceptual design remain applicable and salient.

Key features considered during conceptual design include the following:

- Receiver configuration--north facing versus cylindrical
- Steam cycle--reheat versus non-reheat
- Steam conditions--temperature and pressure
- Steam generation method--once-through to superheat versus evaporator plus superheater
- Steam generator surface area
- Thermal storage capacity.

These trade studies are described in the following sections.

1.2.1 Receiver Configuration

The configuration of the Carrisa Plains receiver was developed based on alternative external receiver designs. The receiver was assumed to be external due to the compactness and inherent low thermal losses of a sodium-cooled receiver and in light of the Rockwell experience in testing a prototype of such a receiver. Three alternatives were considered: a north-facing vertical billboard, a billboard slanted downward at 20 degrees, and a cylindrical receiver. The corresponding collector field layouts were developed using the Sandia-developed DELSOL computer code. The three alternatives gave costs of

energy within 2%, a minor and unpersuasive difference in view of the uncertainties at that stage. Further consideration was therefore given to other design factors and advantages seen for the various options. On this basis, the vertical, north-facing receiver was selected due to its greater simplicity, similarity to the Rockwell test receiver, and trade studies developed by Sandia showing it to be preferred for small (<50 to 60 MWe) plants.

1.2.2 Steam Cycle

The selection of a reheat or non-reheat cycle was considered by examination of equipment available for use in the size range intended, as well as the economics. Reheat was judged not to be cost effective in this size range. Further, commercial utility turbine in the 30-MWe range was not available, and limited sodium reheater experience was available. This ran counter to the project requirement that tested components be utilized wherever possible. Consequently, a non-reheat steam cycle was adopted.

1.2.3 Steam Conditions

With the cycle established, the steam conditions could be selected. Modern steam conditions needed to be used if possible and economic. Consequently, a baseline condition of 1000°F/1550 psia was selected, and the costs for other options were developed with reference to this baseline.

The use of higher temperatures was rejected due to the lack of current U.S. turbine experience. A reduction in temperature from the baseline did not lead to cost reductions sufficient to justify the lower thermal efficiency.

Pressures in the range of 1650 to 2200 psig were examined and found to entail substantially higher turbine costs. Due to the small turbine size, it was unclear that higher efficiencies would result from higher pressures, and the higher turbine costs could not be justified based on the plant cost saving.

It should be noted that further examination during preliminary design has corroborated the selection of the lower pressure cycle. The later evaluations show that a 1000°F/1450 psig cycle produces the highest thermal efficiency for a 30-MWe turbine. Consequently, the preliminary design utilizes this still lower pressure.

1.2.4 Steam Generation Method

Two alternative means of implementing a non-reheat cycle were considered – once-through to superheat and separate evaporator and superheater units. It was found that the once-through to superheat design offered a slightly lower capital cost.

The principal disadvantage of the once-through design was the requirement for stringent water quality control. Utility experts viewed this requirement as routinely demonstrated in the field. In addition to capital cost, this design has the advantage of a high degree of redundancy should one unit fail. Consequently, the once-through to superheat design was adopted.

1.2.5 Steam Generator Surface Area

Given the adoption of a once-through to superheat configuration for steam generation, the steam generator surface area could be selected. This parameter affects the sodium outlet temperature from the steam generators, as greater area provides a closer approach in temperature between steam and sodium sides of the steam generator. A larger steam generator area will by itself cost more but will increase the difference in temperature between the inlet (hot) and outlet (cold) sodium. This in turn reduces the amount and cost of sodium required for thermal storage of a fixed quantity of energy.

The use of two MSG units, the minimum number required to handle the plant power requirements, was rejected because of the maximum allowable temperature difference between boiler feedwater and outlet sodium. The use of three MSG

steam generators and a sodium outlet temperature of approximately 595°F was the economic design choice.

1.2.6 Thermal Storage Capacity

The amount of thermal storage to be incorporated in the plant was evaluated based on energy production cost and energy value to the utility. Busbar energy costs were evaluated as a function of the amount of thermal energy storage and were found relatively insensitive, varying over a $\pm 10\%$ range from no storage up to 6 h of storage.

The value of the energy produced, however, was found to vary more dramatically. In particular, in accordance with PGandE's standard offer for the sale of power by a privately owned power plant, a capacity credit would be paid for a reliable delivery of power during a peak demand period. The thermal storage level was therefore set at the minimum level sufficient to obtain this capacity credit payment, 70 full-power minutes.

2.0 PLANT DESIGN DESCRIPTION

The concept of the Carrisa Plains solar power plant is depicted in Figure 1. The plant uses a vertical flat-panel ("billboard") solar receiver located at the top of a tower to collect solar energy redirected by approximately 1900 heliostats located to the north of the tower. The solar energy is used to heat liquid sodium pumped from ground level from 610 to 1050°F. The hot sodium is returned to ground level for use in steam generation, and is then recirculated to the receiver. Sodium is also stored in tanks for delayed power generation. The power conversion system is a non-reheat system, cost-effective at this size level, and designed for high-efficiency performance in an application requiring daily startup.

The plant has been designed around several success-oriented project requirements which maximize the value of a plant to its owner:

- High plant reliability and availability
- Simplified plant operations and rapid startup
- Low operations and maintenance (O&M) cost
- High net plant efficiency.

Achieving high plant reliability and availability is of paramount importance to project success. Consequently, redundant and spare components, large design margins, and operational flexibility have been emphasized in the design. Plant operations have been simplified and made less sensitive to operator error, and the design has avoided critical operator actions or surveillance wherever possible. Startup, in particular, has been subjected to careful examination to ensure facile plant operation. O&M costs are held down by using a small plant operating staff, made possible by controls integration and the inherent flexibility of a thermal storage-buffered solar system. High net plant efficiency is achieved through an efficient power conversion system design and through plant operations which reduce parasitic energy consumption, particularly during the startup. The key design features of the Carrisa Plains solar plant are summarized in the following sections.

2.1 SITE DESCRIPTION

2.1.1 Location

The plant location, shown in Figure 2, is at 35.3° north latitude and 120.0° west longitude. The plant site, shown in Figure 3, is Section 34 near the town of Simmler, California. Site photographs are shown in Figure 4. PGandE holds a lease option on Section 34.

Access to the site from the east is along Highway 58 for about 64 km (40 miles) from Interstate 5 in the San Joaquin Valley. Access from the west is along Highway 58 for 80 km (50 miles) from State Highway 101 near San Luis Obispo. This highway is built to adequate state standards, and no limitations are imposed on the equipment sizes for this project. The nearest sizeable populations and road distances from Carrisa Plains are summarized in Figure 2.

Access to the grid is available either by the 115-kV circuit from San Luis Obispo to Midway in the San Joaquin Valley, or the two 230-kV circuits from the Morro Bay Power Plant to Midway. The more economical connection is to the 115-kV circuit, which does not need reinforcement for a 30-MW installation. These circuits are within 1.6 km (1.0 miles) of the site.

Section 27, directly north of this project, is being developed by ARCO for a 16.5 MWe photovoltaic system.

2.1.2 Geography

Carrisa Plains is a sparsely populated, enclosed valley, about 65 km (40 miles) long and 13 km (8 miles) wide in southeastern San Luis Obispo County. The floor of the valley is about 600 m (2000 ft) above sea level. The site is flat, is currently used for farming, and has a slope of about 0.5% to the southwest. The soil load-bearing capacity is suitable for supporting the heliostat pedestals, tower, and plant equipment.

CITY	DISTANCE km (mi)		POPULATION
ATASCADERO	80	(50)	10,000
BAKERSFIELD	97	(60)	75,000
SAN LUIS OBISPO	80	(50)	30,000
TAFT	64	(40)	5,000

Figure 2. Location of Carrisa Plains Solar Power Plant

Figure 3. Site for Carrisa Plains Solar Power Plant

NORTH

EAST

WEST

SOUTH

Figure 4. Site Photographs

The site is 10 km (6 miles) southwest of the San Andreas active fault zone. It is also 8 km (5 miles) northeast of the San Juan, Big Spring, and Chimeneas faults classed with Quaternary activity. Two short faults are mapped in the southwest portion of the area with pre-Quaternary activity. The site is 95 km (57 miles) south of the epicenter of the 2 May 1983, 6.5 magnitude earthquake at Coalinga, on a previously unmapped fault proximate to the San Andreas fault. ARCO's forty heliostat solar steam generator is about as close as Carrisa Plains to this earthquake epicenter. It operated without interruption by the earthquake.

A solar resource measurement program at Carrisa Plains was instituted by PGandE in early 1982. In late 1982, this program was augmented to include direct normal insolation measurements. Table 1 shows the measured horizontal insolation for Fresno and Carrisa Plains in 1982/1983 and the measured direct normal insolation at Carrisa Plains for the 4 months available (December 1982 through March 1983).* Fresno records horizontal insolation only.

Two methods were used to estimate the long-term average direct normal insolation at Carrisa Plains. The first was to average the three closest stations - Fresno, Santa Maria, and China Lake - which form a triangle around Carrisa Plains. China Lake is about the same latitude and elevation as Carrisa Plains, and has a similar desert-type atmosphere. The second method involves a seasonal adjustment to Fresno and Santa Maria conditions, since Carrisa Plains weather is similar to Santa Maria's coastal weather from October through March, and is like Fresno's valley weather the remainder of the year. Table 2 gives the results of the two methods. The three-station average gives an annual total of 2552 kWh/m^2 , and the seasonal adjustment gives an estimated $2524 \text{ kWh/m}^2 \text{ yr}$. Since these estimates are quite close, the estimated annual direct normal insolation will be taken at the lower

*Solar resource measurements are outside of the scope of this contract and are provided (at no cost) by PGandE for the benefit of this design.

TABLE 1
ACTUAL MEASURED INSOLATION FOR 1982/1983

	1982											1983			
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
	Measured Horizontal Insolation														
Carrisa Plains	91	99	117	181	236	231	246	221	164	134	83	78	88	86	134
Fresno	46	73	98	167	213	214	233	NA	NA	121	57	49	42	67	109
	Measured Direct Insolation														
Carrisa Plains												106	125	77	109

TABLE 2
ESTIMATED DIRECT NORMAL INSOLATION AT CARRISA PLAINS

Location	Latitude/ Longitude (deg)	Eleva- tion (ft)	Direct Normal Insolation (kWh/m ² month)												Total
			Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	
Fresno	36.77/119.72	336	95	126	195	229	273	279	285	262	224	186	122	79	2356
Santa Maria	34.93/120.42	234	149	149	199	211	221	225	239	225	188	178	149	148	2281
China Lake	35.65/117.00	2440	182	181	249	272	297	297	285	272	248	218	190	179	2870
Carrisa Plains (three-station average)	35.30/120.00	2020	142	152	214	237	264	267	270	253	220	194	154	185	2552
Carrisa Plains (seasonal correction)	35.30/120.00	2020	149	149	199	229	273	279	285	262	224	178	149	148	2524

Source (except for Carrisa Plains): P. Berdahl et al., California Solar Data Manual, March 1981
California Energy Commission (CEC) Publication

value. The daily average is 6.9 kWh/m^2 . Because of the cloudy weather this winter, the measured direct insolation (Table 1) is less than the estimated values.

The Carrisa basin ground water storage capacity, as listed by the California Department of Water Resources (DWR) in 1975, is 0.49 km^3 (400,000 acre ft). Ground water wells in the Carrisa basin yield instantaneous average flows of $0.03 \text{ m}^3/\text{s}$ (500 gpm) with maximum flows of $0.05 \text{ m}^3/\text{s}$ (1000 gpm). The proposed solar power plant will require an average flow of only $0.01 \text{ m}^3/\text{s}$ (120 gpm, 185 acre ft/yr), which is less than typical agricultural use. Available ground water quality data for the eight state-numbered wells show the water quality to be acceptable.

2.2 FACILITY DESIGN SUMMARY

The 30-MWe Carrisa Plains plant is similar in concept to the 10-MWe Solar One plant being successfully operated at Barstow, California. A perspective view of the plant and its major features are shown in Figure 5. A plant layout (Figure 6) covers 295 acres. The fan-shaped collector field is approximately 3600 ft deep by 4600 ft at the widest point. The plant uses a north-facing vertical flat panel solar receiver of a tested design supported by a 352-ft steel truss tower. The receiver intercepts the solar energy redirected from the 1877 third-generation ARCO heliostats. The receiver aperture is approximately 40 ft high by 52 ft wide. The solar energy heats liquid sodium flowing through the receiver tubes. Figure 7 is a flow diagram of the system. The cold (610°F) sodium is pumped to the receiver by conventional sodium pumps from a 40-ft-diameter by 54-ft-high atmospheric pressure storage tank located at ground level. As the sodium passes through the receiver tubes it heats to 1050°F . The heated sodium then drains by gravity to a hot storage tank located at grade level. From the hot storage tank it is pumped through the steam generators, cools to 610°F , and returns to the cold storage tank. The three once-through-to-superheat steam generators are connected in parallel to deliver 270,000 lb/h of steam at 1000°F and 1450 psig to

Figure 6. Carrisa Plains Solar Plant Layout

Figure 7. Carrisa Plains Solar Plant Flow Diagram

the turbine, which generates 32.7 MWe (gross). The three parallel steam generator units provide redundancy to 90% of full power with one unit out of service. The modern steam condition yields high efficiency with conventional turbine equipment.

The plant design uses proved components and systems, thereby achieving high plant availability and low operating and maintenance costs. Redundancy has been provided at critical points to ensure that a single component failure will not compromise plant availability. The plant is designed to meet the appropriate engineering codes and standards throughout.

Incorporation of in-line thermal storage permits the solar portion of the plant (the collector and receiver) to start up and operate independently from the electric power generation portion of the plant (the steam and turbine generators) without sacrificing efficiency. This leads to a smaller operating staff since startup and shutdown can be carried out sequentially. In addition, the in-line thermal storage moderates cloud and other thermal transients, thus simplifying control functions. The plant is operated so that plant revenues are maximized. The plant control scheme matches power levels with flows and trims the flows to set final temperatures.

2.2.1 Collector System

The collector system redirects and concentrates sunlight so that it may be collected at high temperature. To provide the 107-MWt peak power requirements of the plant, the collector system requires 1877 third-generation ARCO heliostats. The heliostat field pattern is shown in Figure 8.

The heliostat is the latest in a design evolution from ARCO's second-generation heliostat. The ARCO heliostat has 95 m² of reflective area, divided into 24 mirror modules. The module support structure is composed of open-web beams connected to a horizontal tubular axis and drive unit. The entire heliostat is mounted on a pedestal and foundation, which is planted in

Figure 8. Carrisa Plains Solar Plant Collector Field Layout

an augered hole and grouted in place. Power and control wiring is placed in trenches throughout the field. The drive unit, under computer control, orients the heliostat continuously to track the sun and reflect the sunlight on the receiver. Initial heliostat aiming is accomplished by using a beam characterization system panel located on the tower. The heliostat rate of motion is $11^{\circ}/\text{min}$ ($22^{\circ}/\text{min}$ for the reflected beam). In an emergency the reflected energy can be removed from the receiver in less than 20 s.

In addition to the successful test program conducted at Sandia National Laboratories' CRTF, the heliostats have undergone extensive testing to determine design margins and have gained considerable operational time in collector field arrays in oil field steam generation applications and in tracking photovoltaic systems.

The ARCO heliostat is modular, with rapid field diagnosis of faults and field-replaceable hardware to maximize availability and minimize the operation and maintenance cost.

The key collector field design features are given in Table 3.

2.2.2 Heat Transport System

The heat transport system (HTS) is divided into six parts: the receiver subsystem, heat transport loop, thermal storage, steam generation subsystem, auxiliaries, and electrical instrumentation and controls (EI&C). The entire heat transport system utilizes hardware tested at full scale or prototype level. This gives the highest assurance of successful plant operation. System and component design follows the pattern of the DOE Sodium Component Test Installation (SCTL), operated by Rockwell.

TABLE 3
DESIGN SUMMARY OF COLLECTOR SYSTEM

Key Design Parameters	
Number of heliostats	1877
Total mirror area, km ² (10 ⁶ ft ²)	0.178 (1.92)
Collector land area, km ² (10 ⁶ ft ²)	1.064 (11.46)
Mirror area per heliostat, m ² (ft ²)	95 (1024)
Peak incident receiver flux limit, MWt/m ²	1.2
Aiming strategy	12-point aim
Performance	
Insolation	
Design point, W/m ²	950, March 21, noon
Annual, clear day, kWh/m ²	3249
Annual, average, kWh/m ²	2397.8
Performance	
Design point power, incident, MWt/m ²	116, March 21, noon
Annual receiver energy, MWht/m ² yr	261,020
Design point efficiency, %	67
Annual average efficiency, %	57
Flux distribution	
Maximum heat flux, MWt/m ²	1.20
Average heat flux, MWt/m ²	0.61, design point
Maximum panel power, MWt/panel	18.0
Design Model Basis	
Insolation, clear day	Barstow typical day
Insolation, annual average	Seasonal shift based on Fresno and Santa Maria
Collector performance calculations	Proprietary ARCO codes
Collector performance verification	30 heliostat enhanced oil recovery site

2.2.2.1 Receiver Subsystem

The receiver subsystem, shown in Figure 9, absorbs the redirected solar energy from the collector field. The energy absorbed raises the sodium coolant temperature from 610°F to 1050°F. The receiver is supported on a structural steel tower 108 m (352 ft) high.

The receiver is a north-facing, external, flat panel configuration mounted on a steel tower with a panel centerline height of 125 m (410 ft). It consists of eight panels as shown in Figure 10. Each panel consists of 102 19-mm (3/4-in.) diameter, Type 316 stainless steel tubes with a wall thickness of 1.24 mm (0.049 in.). The panel is constructed using a Rockwell-patented tube support system that reduces thermal stresses and extends operating life. Predicted panel life exceeds 30 years. This system was proved in the successful CRTF test of the prototype receiver. The inlet manifold is anchored to the supporting structure (Figure 10), while the outlet manifold accommodates thermal growth along with the piping. Table 4 summarizes the receiver subsystem design parameters.

The inlet piping to each panel has a flow control valve and a flowmeter. Each panel has a flow control system that senses panel flux as a feed forward signal to control flow rate and also senses panel outlet temperature as a trim signal to control the outlet temperature to the set point.

In the event that coolant flow is lost, an accumulator tank will supply cooling flow until the beam is moved off the receiver. In the event of a simultaneous field power and pump failure, the heliostat beams will be moved off the receiver by a combination of sun image drift and heliostat slewing powered from the uninterruptable power supply (UPS).

41028-86A

Figure 9. Receiver Subsystem Layout

ESG-DOE-13404

41028-87A

Figure 10. Panel Assembly Drawing

TABLE 4
RECEIVER SUBSYSTEM DESIGN SUMMARY

Key Design Parameters	
Midplane elevation	125 m (410 ft)
Receiver aperture	
Width	16 m (52 ft)
Height	12 m (40 ft)
Number of panels	8
Panel characteristics	
Width	2.0 m (6.6 ft)
Height	15.2 m (50 ft)
Number of tubes	102
Tube diameter	19.1 mm (0.75 in.)
Tube wall	1.24 mm (0.049 in.)
Material	Type 316 stainless steel
Performance	
Incident power	116 MWt
Absorbed power	107 MWt
Inlet temperature	321°C (610°F)
Outlet temperature	566°C (1050°F)
Maximum flux	1.2 MWt/m ²
Average flux	0.61 MWt/m ²
Pump flow/head	0.39 m ³ /s (6200 gpm)/ 198 m (650 ft)
Design Model Basis	
Test of Rockwell prototype receiver at CRTF	

The receiver has been designed to Section VIII Division 1 of the ASME Boiler and Pressure Vessel Code (B&PVC), ANSI B31.1, and the creep-fatigue requirements of addendum N-47 to Section III of the Code.

Rockwell has conducted a successful test of the sodium-cooled prototype receiver at Sandia's CRTF. The peak solar flux on the prototype, which causes the main stress in the tubes, was more than 25% above the Carrisa Plains plant flux, thus providing a 25% margin on stress and a 100% margin on stress cycles. The test unit was operated at an outlet temperature of 593°C (1100°F) compared with the plant unit temperature of 566°C (1050°F), providing a further design margin.

2.2.2.2 Heat Transport Loop

The heat transport loop consists of two independent flow paths – one from the cold storage tank through the receiver to the hot storage tank for solar operations, and another from the hot storage tank through the steam generators to the cold tank (see Figure 7). Two pumps are used in each flow path to provide a 20% design margin and redundancy to 70% of operating flow for coolant circulation.

The loop components have been designed to Section VIII, Division 1 of the Code, and the piping to ANSI Standard B31.1. A piping and instrumentation diagram for the sodium heat transport system is shown in Figure 11. The heat transport loop layout, including thermal storage and steam generators, is shown in Figure 12.

2.2.2.3 Thermal Storage

Thermal storage consists of two storage tanks, with foundations and insulation. The hot and cold thermal storage tanks are 12.1 m (40 ft) in diameter and 16.5 m (54 ft) high. The hot tank is Type 304 stainless steel and operates at 566°C (1050°F); the cold tank is mild steel and operates at 321°C (610°F). The tanks operate at atmospheric pressure with an argon cover gas. The tank foundations include provisions for cooling. The tanks have electric heaters for preheating and maintaining temperature as required.

2.2.2.4 Steam Generator Subsystem

The steam generator subsystem utilizes three once-through sodium-heated steam generators (Figure 13), operating in parallel to generate the 34.0 kg/s (270,000 lb/h) of steam need for full-power operation. The steam generator subsystem performance is summarized in Table 5. The thermal performance of the modular steam generator (MSG) has been verified using the proprietary Rockwell MODULE code for load conditions from 10% under startup conditions to

Figure 11. Simplified P&ID of Main Heat Transport Loop

Figure 12. Piping Layout

42600-100

Figure 13. Steam Generator Unit Configuration and Physical Interfaces

TABLE 5
STEAM GENERATION SUBSYSTEM DESIGN SUMMARY

Key Design Parameters	
Number of units	3
Size	
Diameter	0.45 m (18 in.)
Length	21.1 m (69.3 ft)
Number of tubes per unit	158
Tube dimension	
OD	1.59 cm (0.625 in.)
Wall	0.277 cm (0.109 in.)
Heat transfer area per unit	139 m ² (1,500 ft ²)
Performance	
Design power per unit	28.3 MWt
Steam conditions	
Pressure	10.45 MPa (1515 psia)
Temperature	538°C (1000°F)
Feedwater temperature	224°C (436°F)
Sodium conditions	
Inlet temperature	566°C (1050°F)
Outlet temperature	308°C (587°F)
Inlet pressure	0.69 MPa (100 psia)
Flow rate per unit	
Steam	11.32 kg/s (89,820 lb/h)
Sodium	86.21 kg/s (684,200 lb/h)
Pressure drop	
Steam side	0.42 MPa (61 psia)
Sodium side	0.07 MPa (10 psia)
Pump flow/head	0.33 m ³ /s (5,300 gpm)/58 m (190 ft)

120% of full load. Each unit delivers 28.3 MWt at full load. Plant reliability is enhanced by the ability of two steam generator units to deliver 90% of full plant power without derating steam conditions.

The steam generator pressure boundary is 2-1/4 Cr - 1 Mo steel. The steam generator has a 30-year design life, and meets or exceeds the design requirements of Section VIII, Division 1 of the ASME B&PVC. It will be code stamped.

2.2.2.5 Sodium Auxiliaries

The sodium auxiliaries include: (1) the sodium receiving and purification stations, (2) the argon supply and handling equipment, (3) the sodium mixing tank, and (4) the sodium/water reaction products tank.

Sodium is shipped to the plant in tank trucks and is unloaded at the receiving station through low-temperature (300°F) 10- μ m filters. Sodium purity is maintained during operation by flowing a side stream through a cold trap for oxygen impurity control. The low oxygen concentration, below 6 ppm, will keep the corrosion rate below 0.2 mil per year throughout the system.

The mixing tank is provided to match the sodium supply temperature to steam generator conditions, and to prevent excessive steam temperature excursions on startup.

The argon system, shown in Figure 14, provides ullage for the tanks, vessels, and pumps, and provides hydraulic balance in the loop. The argon is recycled to conserve it.

Although care is taken to ensure steam tube integrity, a flaw could lead to a steam or water leak into the sodium. A stainless steel rupture disk assembly, installed in the steam generator outlet piping, protects against overpressurizing the steam generator shell and discharges the steam generator contents safely to a tank. Hydrogen produced is vented through a safety stack.

2.2.3 Electric Power Generation System

The electric power generation system, which consists of the turbine-generator set, feedwater equipment, condenser, and cooling tower, converts the energy in the steam supplied by the heat transport system into electric power. The system utilizes a conventional regenerative Rankine cycle turbine as shown in Figure 15. The turbine is a two-section, single-shell machine

42600-101

Figure 14. Argon Cover Gas System

with five extraction points. The steam conditions at the turbine inlet are 1450 psig, 1000°F. The final feedwater temperature is 436°F. The condenser operates at 2.4 in. HgA and is cooled by water from an evaporative cooling tower.

The main generator is designed to produce 12 kV, 3-phase, 60-Hz power. It is connected through a generator breaker to the main step-up transformer which raises the voltage to 115 kV. A circuit breaker connects the 115-kV transformer to the 115-kV San Luis Obispo-to-Midway transmission line. The connection to the transmission line is a T connection with a disconnect switch in each leg of the T.

LEGEND		LOSS BALANCE		PERFORMANCE	
	MAIN STEAM LINE	SINK TEMPERATURE OF 70° = 52.967°R			
	STEAM LINES	NET WORK	31 283 3 KW	THROTTLE FLOW	268762 PPH
	MAIN FEEDWATER LINES	PUMP LOSS	92 8 KW	GENERATOR ELECTRICAL OUTPUT	32 740 KW
	WATER LINES	TURBINE LOSS	4907 4 KW	POWER CONVERSION SYSTEM AUXILIARY POWER	
PPH	FLOW, LBS PER HOUR	HEAT ADDED LOSS	41,395 9 KW	FEEDWATER AND CONDENSATE PUMPS	5571 KW
S	ENTROPY, BTU PER FT PER POUND	LINE PRESSURE LOSS	1,665 4 KW	CIRC WATER AND COOLING TOWER FANS	350 KW
F	TEMPERATURE, DEGREES FAHRENHEIT	HEAT EXCHANGER LOSS	624 2 KW	OTHER	350 KW
H	ENTHALPY BTU PER POUND	SHAFT LOSS	316 5 KW	TOTAL	14571 KW
P	ABSOLUTE PRESSURE (PSIA)	GENERATOR LOSS	316 5 KW	SYSTEM NET OUTPUT	31,283 KW
%ΔP	FRICTION LOSS	PLANT AUXILIARIES	900 0 KW	POWER CONVERSION SYSTEM HEAT RATE	9271 BTU/KWH
TD	TERMINAL TEMPERATURE DIFFERENCE	AVAILABILITY REJECTED (CONDENSER)	3498 0 KW	POWER CONVERSION SYSTEM EFFICIENCY	36.8%
		TOTAL	85,000 0 KW	CONDITIONS	
		STEAM GENERATOR HEAT INPUT	85,000 0 KW	CONDENSER BACKPRESSURE	2.16
		HEAT ADDED EFFICIENCY	51.3%	AMBIENT AIR TEMPERATURE	70°
		CYCLE EFFECTIVENESS	71.7%		

Figure 15. Solar Plant Heat Balance

2.2.4 Balance of Plant

The balance of plant encompasses all the utilities, facilities, and structures necessary to support the other plant systems, including site improvements, grading, roadways, fencing and landscaping, foundations, equipment supports and structures, the cooling tower basin, water supply treatment and disposal facilities, compressed air supply, electrical power distribution, ground grids, and switch yard. It supplies physical and logistics support to the other plant systems and subsystems. The major site improvements are shown in Figure 16. This subsystem includes power plant water, fire water, and domestic water supplies. The electrical distribution single line diagram, shown in Figure 17, shows that backup power is provided in two levels: a station battery for UPS, and a diesel generator. The UPS can maintain all computer and field operations and power conversion requirements, and can scramble (defocus) the heliostats in approximately 20 s.

2.2.5 Master Control System

The master control system functions to integrate the operation of the independent plant systems and to monitor, integrate, and report all plant and system parameters necessary to ensure safe and efficient operation of the plant. The major components include a redundant central computer and peripherals, control and display consoles, process control software, hard-wired safety trip circuits, and a data acquisition system. The master control system layout, shown in Figure 18, permits the plant to be operated with the smallest possible operating staff.

2.3 PLANT OPERATIONS

To qualify for full-capacity credit, the plant must meet an 80% availability from 12 noon to 6 p.m., May through September. To provide the largest margin in meeting this goal, the annual scheduled maintenance is in December. This gives an estimated availability of 86% during the critical months and provides a substantial availability margin for the key period.

Figure 16. Major Site Improvements

Figure 17. 30-MW Solar Project Single Line Diagram

Plant operations have been planned to permit rapid daily startup while maintaining a low standby power consumption. Several steps have been taken to achieve this. The receiver startup is rapid, utilizing the experience gained at CRTF with the prototype receiver. From an overnight shutdown, the steam system can be brought up to air, to full power in 70 min as a result of an integrated design and operating plan. The overall plant startup schedule shown in Figure 19 avoids excessive standby power consumptions until solar operations are imminent.

Figure 18. 30-MW Solar Project Master Control System Conceptual Layout

Figure 19. Equinox Startup Schedule

3.0 PLANT PERFORMANCE

The plant performance is summarized in the diagrams of Figures 20 and 21. These are drawn on a design-point (equinox noon) and annual average basis. Net plant efficiency is approximately 22% at the design point.

9479-24

Figure 20. Design Point Efficiency Diagram (Equinox Noon)

9479-25

Figure 21. Annual Energy Efficiency Diagram

4.0 OPERATIONS AND MAINTENANCE

Plant operations and maintenance (O&M) costs have been estimated based on PGandE experience with other small (<50 MWe) power plants. Projected plant staffing is shown in Figure 22. The total plant complement is 27, including 8 plant operators and 11 maintenance staff.

Projected staff salaries are given in Table 6 by job category; the O&M budget is given in Table 7. The O&M budget includes provision for annual maintenance contract labor.

Figure 22. Carrisa Plains Solar Power Plant Organization

TABLE 6
OPERATIONS AND MAINTENANCE
PERSONNEL

	Number of Persons	1982 Salary (\$/Year)	Shifts/ Week	Person Shifts Available	Persons/ Shift
Superintendent	1	44,000			
Supervisor/PP Engineer	3	41,500	7	29	4
Chemist/Engineer	2	39,300			
Operator	3	29,900			
Assistant Operator	4	27,300	14	33	2 or 3
Operator Trainee	1	25,300			
Maintenance, Mechanic, Electrician, Welder, Technician	7	26,900 to 31,100			
Apprentice or Helper	4	25,300 to 27,600	7	45	6 or 7
Clerk	<u>2</u>	27,820			
Total	27				

TABLE 7
POWER PLANT OPERATIONS AND MAINTENANCE BUDGET

	1986 Dollars, Thousands	
	Years 1 and 2	Later Years
Operations		
Labor	1040	890
Supplies and Contracts	800	800
Maintenance		
Labor	670	670
Supplies and Contracts	<u>260</u>	<u>260</u>
Total	2770	2620

5.0 DEVELOPMENT

The Carrisa Plains Solar Power Plant project schedule is based on the assumption that power will be fed to the grid before the end of 1986. This schedule requires a tight control over construction interest costs (AFUDC), a substantial contributor to overall project costs.

The final design and construction plan developed to satisfy the schedule constraints has several key factors vital to the success of the project:

- Maximum utilization of the preliminary design outputs to reduce design time and cost
- Tight coordination between team participants to ensure that the design is complete and coherent
- Use of a program management system to track cost and performance and to identify corrective actions needed
- Assembly of a dedicated, knowledgeable, and experienced team able to bring the plant through construction and on line.

The following sections describe the overall development plan for final design, specifications, construction, and operation.

5.1 FINAL DESIGN PHASE

The final design phase is scheduled to last 12 months. The detailed design of long-lead and critical path items, including the receiver panels, steam generators, turbine-generator, and major pumps, will be completed early in the final design phase, with procurement documents for these items available within 4 months of initiation of the final design. The final design activities will use the vendor contacts made during the preliminary design phase to facilitate these procurement-related activities. The final design schedule is shown in Figure 23.

MILESTONES	
1	COLLECTOR SYSTEM SPECIFICATION
2	COLLECTOR EQUIPMENT AND CABLING LAYOUT
3	COLLECTOR FABRICATION AND INSTALLATION SCHEDULE
4	RECEIVER PANEL FABRICATION DRAWINGS
5	RECEIVER STRUCTURAL DRAWINGS
6	STORAGE TANK SCD'S
7	STORAGE TANK DESIGN
8	STEAM GENERATOR FABRICATION DRAWINGS
9	HEAT TRANSPORT LOOP P&ID RELEASED
10	HEAT TRANSPORT LOOP PIPING AND SUPPORT DRAWINGS
11	ELECTRICAL DRAWINGS RELEASED
12	INSTRUMENTATION AND CONTROL DRAWINGS AND SPECIFICATIONS
13	AUXILIARY SYSTEMS DRAWINGS
14	EPGS SPECIFICATION
15	EPGS CONSTRUCTION DRAWINGS
16	MASTER CONTROL SPECIFICATIONS AND INTERFACE REQUIREMENTS
17	GEOTECHNIC REPORT AND DESIGN CRITERIA
18	SITE PREPARATION DRAWINGS
19	POWER COMPLEX CONSTRUCTION DRAWINGS
20	RECEIVER TOWER FOUNDATION AND STRUCTURAL DRAWINGS
21	SITE STRUCTURES DRAWINGS
22	UTILITIES CONSTRUCTION DRAWINGS
23	SWITCHYARD AND INTERCONNECT DRAWINGS
24	ELECTRICAL AND GROUND DRAWINGS
25	PLANT PERFORMANCE ANALYSIS
26	SITE PREPARATION BID PACKAGES
27	SITE PREPARATION BIDS RECEIVED
28	CONSTRUCTION AND EQUIPMENT BID PACKAGES
29	CONSTRUCTION AND EQUIPMENT BIDS RECEIVED
30	PLANT COST ESTIMATE COMPLETE
31	CONSTRUCTION PLAN COMPLETE
32	KICKOFF MEETING
33	NOTICE OF ENERGY RD&D
34	TECHNICAL PROGRESS REVIEWS
35	TOPICAL REPORT
36	FINAL REPORT

Figure 23. Final Design Program Schedule

After completion of the work on these critical path items, the final design efforts will be directed toward the remainder of the plant. Principal outputs will be drawings and specifications from which subcontractors bid and awards are made, for site preparation, foundations, structural, electrical, mechanical, process piping, insulation and weatherization, and painting.

5.2 CONSTRUCTION PHASE

Detailed construction plans and schedules have been prepared to ensure that the project can be completed on schedule without excessive recourse to costly overtime or other preferential payments. The schedule shown in Figure 24 is a summary of the detailed planning.

The construction manager will be responsible for the major construction, including all site preparation, security, warehousing, installation of all site facilities, utilities, and equipment with the exception of heliostats. After the project suppliers provide the construction manager with applicable specifications for construction requirements, he will obtain equipment suppliers and craft services to fulfill the specifications. The unification of all construction activities within the power complex (exclusive of the heliostats) will prevent excessive construction interference and scheduling delays, thereby increasing productivity factors and lowering the project cost.

5.3 CHECKOUT AND ACCEPTANCE TESTING

Each system has provisions for an internal checkout prior to the integrated plant checkout. All checkouts will be controlled by the construction manager, supported by representatives of the major equipment suppliers. Operator training will begin prior to internal and integrated checkouts. Plant acceptance testing will be arranged to demonstrate plant capabilities to the satisfaction of the plant owner, including the power level, startup, and energy output.

Figure 24. Summary Construction Plan

5.4 ENVIRONMENTAL IMPACT AND PERMIT PLAN

The issuing of permits and the environmental review of the Carrisa Plains Solar Thermal Power Plant project will be under the jurisdiction of San Luis Obispo County. The county will require a Land Use Permit Application to be accompanied by an Environmental Description Form. The Land Use Permit Application is limited in scope and requires minimal information on the applicant, property information, and project information.

The Environmental Description Form is a more detailed application requiring information on (1) general project description and information; (2) physical site characteristics; (3) water sources and quality; (4) waste disposal proposals for sewage and solid wastes; (5) impacts on community services such as schools, police, and fire protection; (6) noise levels and air emissions; (7) vector control such as insects and rodents; and (7) miscellaneous information.

In addition, the San Luis Obispo County Environmental Coordinators' Office has requested detailed information on issues where they feel there may be adverse impacts and may require mitigation. These issues include:

- A cultural/archaeological resource field investigation by a professional archaeologist
- An investigation of the existence and location of rare and/or endangered plant or animal species
- An analysis of water availability and the effect additional pumping may have on the ground water table
- Socioeconomic impacts, particularly on the small Carrisa Plains school
- Safety issues regarding the use of sodium and the problem of mis-directed solar radiation
- Cumulative impacts of all Carrisa Plains solar projects on traffic, water use/availability, loss of agricultural land, and socioeconomic impacts on schools and community character.

Information to complete the Land Use Application and Environmental Data Form is being collected. The more detailed studies can be done concurrently.

6.0 FACILITY COST ESTIMATE AND ECONOMIC ANALYSIS

6.1 INTRODUCTION

Economic viability of the Carrisa Plains project is determined by an acceptable rate of return (ROR) to the equity investor, the size and risk of the investment, the time period involved, and the assurances provided on net revenue and return. The advanced state of readiness of the Carrisa Plains plant has positioned the project to be able to offer the entire plant at a fixed price and with a warranty, considerably reducing the risks to a private investor.

The conditions under which a private venture could be put together have been examined in depth with the investment community. This has been done using private funds and is outside the scope of this study. The conditions necessary or favorable for development of a third-party venture have been used as guidelines for the design.

The recent decrease in the cost of oil and gas and the lower projected rate of future increase in their cost, has decreased the near-term attractiveness of solar energy sources. This requires an effective decrease in the capital cost of the plant to the investor. Tax credits are essential to achieving this and to the economic attractiveness of this project.

6.2 CONSTRUCTION COST

The plant construction cost estimate developed during the preliminary design phase is summarized in Table 8. This estimate has been developed from manufacturing cost estimates, vendor quotes, and cost estimating services. The estimates for the collector and heat transport systems are similar to the conceptual design cost estimates, while the estimate for the Balance of Plant has increased moderately as a result of the increased requirements recognized during the design. Higher reliability and availability requirements have increased costs, but are deemed cost-effective.

TABLE 8
CARRISA PLAINS COST ESTIMATE (\$MILLION)

Land and site permits		0.5
Collector system		37.6
Heat transport system		33.9
Receiver	8.0	
Thermal storage	6.1	
Heat transport loop	6.9	
Steam generation	9.7	
Auxiliaries	1.3	
Electrical, instrumentation, and control	1.0	
Spares and miscellaneous	0.9	
Electric power generating system		15.1
Mechanical systems	12.3	
Plant electrical	1.1	
Switchyard equipment	1.3	
Spares	0.4	
Master control system		1.9
Balance of plant		4.6
Site improvements, foundations, and structures	3.9	
Water supplies, disposal, and fire protection	0.3	
Telecommunications	0.2	
Permanent tools	0.2	
Field construction - power complex		24.1
Construction management		<u>2.8</u>
		120.5

*These estimates were made by Rockwell and are based on data supplied by the subcontractors. These cost estimates are provided for information purposes only, and do not represent an offer on the part of the team members.

Additional costs from construction interest, placement fee, and construction reserve brings the total plant estimated cost to \$147.4 million in escalated dollars. Shown in Table 9 is the cost breakdown by year, which is based on a construction schedule developed during this phase.

TABLE 9
COST BREAKDOWN BY CALENDAR YEAR (\$ MILLION)

	1983	1984	1985	1986	Total
Capital cost	3.8	41.9	72.0	2.8	120.5
Indirect cost	<u>-</u>	<u>12.0</u>	<u>11.7</u>	<u>3.2</u>	<u>26.9</u>
Total	3.8	53.9	83.7	6.0	147.4

6.3 FINANCIAL PLAN

The tax credits available to the project, taking into account the 10% general and 15% energy credits and qualifications for these credits, total \$26.6 million. The depreciation of plant costs has been evaluated, noting that the Economic Recovery Tax Act of 1982 decreased the depreciation basis by one-half the tax credits, and revised the Accelerated Capital Recovery Schedule (ACRS) to a 150% double declining depreciation schedule. However, the shorter life basis of 5 years for non-utility equipment enacted in the Economic Recovery Tax Act of 1981 was retained. Because this is a qualifying facility not subject to utility regulation, legal advisors have indicated that the project qualifies for the more generous 5-year depreciation schedule as indicated in IRS letter rulings 8238071 and 8234039.

6.4 OPERATIONS AND REVENUE STREAM

The plant has been designed for a 30-year life, which allows a 15-year amortization of the debt. The following financial projection is based on plant characteristics developed early in preliminary design. Some characteristics (e.g., annual energy production) have been subsequently refined, but these do not appreciably impact the economics.

The operations, maintenance, and materials cost of the proposed plant were evaluated by PGandE, and are summarized in Section 5.0. O&M costs are expected to escalate at the same rate as general inflation. PGandE will continue to work with the venture partners on various financial arrangement packages that will make the project viable.

Expenses incurred other than O&M are property taxes, insurance, partnership expenses, warranty/oversight expenses, taxes, and debt service. A one-time insurance premium covering performance shortfalls is included. Partnership expenses include accountant and legal fees to the limited partners and are budgeted at \$50,000 a year. Taxes paid are actually a tax benefit in the early years because of tax credits and ACRS depreciation. This tax benefit is passed on to the owners.

The revenue stream is based on energy production of 75,600 MWh per year. A representative power sales agreement may include the following: a fixed rate of 9¢/kWh for the first 5 years; the higher of a price floor of 10¢/kWh or 100% of fuel avoided costs for the years 6 through 10; the higher of 10.5¢/kWh or a sliding scale of 98 to 90% of fuel-avoided costs for years 11 through 15; and 90% of fuel avoided costs for the remaining 15 years. The total revenue stream for year 1986 (a half year) is expected to be \$4.3 million, of which \$3.5 million is fuel-avoided cost and \$0.8 million is as-delivered energy capacity credit. The total revenue stream for year 1987, the first full year of operation, is \$10.3 million, of which \$6.8 million is fuel-avoided cost, and \$3.5 million is firm-capacity credit.

6.5 OWNERSHIP AND FINANCIAL STRUCTURE

Under the terms of the Public Utilities Regulatory Policy Act (PURPA), new forms of ownership can make it economically attractive for non-utility investors to own a power plant, connect to a utility grid, and sell the power generated to that or another utility. This category of ownership is referred to as the Independent Power Producer (IPP). If the size of the plant is small, 30 MWe being the applicable cutoff for a solar repowering plant under Section 16, USCA 796 et seq. of PURPA, the IPP will not be regulated as a utility. The IPP is, therefore, freed from regulatory controls on investments and allowable returns, and is able to make full use of existing solar investment tax credits, which are denied to utilities. A typical third-party venture arrangement is shown in Figure 25. The three team members are major subcontractors to the IPP and also contribute through the partnership. While the arrangement described has been examined extensively by the team members, it is presented herein as a typical arrangement since there is no formal commitment on the part of the team members at this time.

The Investment Company will raise equity funds from qualified investors, up to a maximum of \$74.4 million. It is expected that the financing fees will be 8% of all equity funds raised. Table 10 summarizes the sources and applications of all project capitalization funds.

Figure 25. Project Organization

TABLE 10
APPLICATION AND SOURCE OF ALL PROJECT FINANCING

	(\$Million)
Application of Funds	
Plant construction cost	\$131.5
Construction interest at 10%	8.6
Financing fees	7.3
Loan repayment	8.5
Total	\$155.9
Source of Funds	
Equity	74.50
Long-term debt	49.9
ARCO equity	2.83
Rockwell equity	2.83
A&E equity	2.84
PGandE R&D contribution	17.00
DOE	6.00
Total	\$155.9

6.6 PRESENT WORTH AND ECONOMIC EVALUATION

Project cash flows for numerous scenarios have been examined. Of particular concern was the debt-to-equity ratio. The ultimate debt limit of 43% was due to at-risk provisions of the tax laws. Several assumptions were made on operating cash flows that will be dependent on subsequent approvals by the CPUC, by San Luis Obispo County, and by the team members. Table 11 is the baseline partnership cash-flow analysis. The expected rate of return to the limited partners of the Investment Company is 17.8% with an after-tax payback of 3.5 years from operational start date.

Table 11
CASE II - CARRISA PLAINS PROJECT SOLAR ENERGY PLANT PARTNERSHIP ANALYSIS
(\$000)

Equity \$ 67,128.61 Loan Proceeds 49,912.34 Cash Flow 0.00 Contribution to Eq. 0.00 Other 0.00 Total Funded \$117,040.95					Equipment \$108,460.00 Land 0.00 Interest 8,580.95 Other 0.00 Other 0.00 Total Use \$117,040.95						
Before Tax Yield 50.00% Tax 35.627183% per year After Tax Yield MISF 17.813591% per year Equity/Total Funded 57.354805% Loan Interest Rate 12.500000% per year Sinking Fund Rate 0.000000% per year					Inherent Profit \$238,600.67 203.8609% of Total Use Sinking Fund Earnings 0.00 0.0000% Residual Value 0.00 0.0000% Claimed ITC 26,621.65 22.7456% Recaptured ITC 0.00 0.0000% Fees 7,300.00 6.2371% Equity and Fees 74,428.61 63.5919%						
Period Ends	Total Income	Depre- ciation	Interest on Loan	Amort. + Other Expense	Taxable Income	Taxes Paid	Debt Service	B.T. Cash	A.T. Cash	Invest. + Fee	Net Cash Balance
12/1983	0	0	0	0	0	-69	0	0	69	0	69
12/1984	0	0	0	29	-29	-8,417	0	0	8,417	12,855	-4,369
12/1985	0	0	0	48	-48	-16,076	0	0	16,076	15,392	-3,685
12/1986	4,260	14,008	2,588	1,333	-13,669	-8,932	8,500	2,978	11,910	14,960	-6,734
12/1987	10,420	20,726	5,500	2,094	-17,900	-8,950	5,500	2,877	11,827	15,611	-10,518
12/1988	10,420	19,829	5,500	2,201	-17,110	-8,555	5,500	2,770	11,325	15,611	-14,804
12/1989	10,420	19,829	5,500	2,315	-17,224	-8,612	5,500	2,656	11,268	0	-3,535
12/1990	10,420	19,829	5,500	2,436	-17,345	-8,672	5,500	2,535	11,208	0	7,672
12/1991	11,158	994	5,500	2,563	2,101	1,050	5,500	3,146	2,095	0	9,768
12/1992	11,900	994	5,427	2,699	2,780	1,390	7,829	1,423	33	0	9,801
12/1993	12,411	994	5,118	2,843	3,457	1,728	7,829	1,790	62	0	9,863
12/1994	13,341	994	4,768	2,995	4,584	2,292	7,829	2,568	276	0	10,139
12/1995	14,437	994	4,374	3,157	5,913	2,956	7,829	3,502	546	0	10,685
12/1996	15,875	838	3,928	3,328	7,780	3,890	7,829	4,769	879	0	11,564
12/1997	16,893	682	3,426	3,510	9,275	4,637	7,829	5,605	967	0	12,532
12/1998	17,958	682	2,858	3,703	10,715	5,357	7,829	6,477	1,120	0	13,651
12/1999	18,678	682	2,217	3,890	11,889	5,944	7,829	6,992	1,048	0	14,699
12/2000	18,970	682	1,494	4,101	12,693	6,347	7,829	7,067	720	0	15,419
12/2001	19,600	284	677	4,331	14,307	7,154	7,829	7,466	313	0	15,732
12/2002	20,692	0	0	4,576	16,116	8,058	0	16,142	8,084	0	23,816
12/2003	22,747	0	0	4,836	17,911	8,955	0	17,937	8,982	0	32,797
12/2004	24,479	0	0	5,112	19,367	9,693	0	19,393	9,710	0	42,507
12/2005	26,367	0	0	5,405	20,962	10,481	0	20,988	10,507	0	53,014
12/2006	28,425	0	0	5,716	22,709	11,354	0	22,735	11,391	0	64,395
12/2007	30,668	0	0	6,047	24,622	12,311	0	24,648	12,337	0	76,732
12/2008	33,114	0	0	6,398	26,716	13,358	0	26,742	13,384	0	90,116
12/2009	35,779	0	0	6,770	29,009	14,504	0	29,035	14,530	0	104,646
12/2010	38,684	0	0	7,166	31,518	15,755	0	31,544	15,785	0	120,431
12/2011	41,851	0	0	7,587	34,264	17,132	0	34,290	17,158	0	137,589
12/2012	45,302	0	0	8,034	37,268	18,634	0	37,294	18,660	0	156,245
12/2013	49,064	0	0	8,509	40,556	20,278	0	40,582	20,304	0	176,553
12/2014	53,165	0	0	9,003	44,162	22,081	0	44,178	22,097	0	198,650
12/2015	57,635	0	0	9,527	48,108	24,054	0	48,112	24,058	0	222,708
12/2016	30,168	0	0	11,113	19,505	9,752	0	25,645	15,892	0	238,601
Total	755,751	103,041	64,376	153,276	434,959	190,858	114,288	503,887	313,029	74,429	