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SIERRA PACIFIC UTILITY REPOWERING

Final Technical Report, September 24, 1979—June 23, 1980

By
C. R. Easton
D. L. Endicott

June 1980

Work Performed Under Contract No. AC03-79SF10609

McDonnell Douglas Astronautics Company
Huntington Beach, California

and

Sierra Pacific Power Company
Reno, Nevada

U.S. Department of Energy

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MCDONNELL DOUGLAS CORPORATION

SIERRA PACIFIC UTILITY REPOWERING

FINAL TECHNICAL REPORT

June 1980

MDC G8667

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Covering the period of September 24, 1979 through June 23, 1980

Prepared for the U.S. Department of Energy
Under Contract Number DE-AC03-79SF10609

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ABSTRACT

The Sierra Pacific Power Company (SPPCo.) participated with the McDonnell Douglas team to define a conceptual design for repowering their Ft. Churchill plant, Unit 1. This unit has a modern, 110 MWe reheat turbine. The boiler is fired by oil and natural gas. The unit is based loaded at 0.78 capacity factor.

The Ft. Churchill site is located in high desert, 75 km (47 mi) southeast of Reno, Nevada. The estimated annual average insolation is 7.2 $kWh/m^2/day$.

The repowered plant conceptual design was a molten salt receiver fluid and 6 hours storage capacity. A north field collector with 130° azimuth extent was found to be optimum. The partial cavity receiver combines both external and cavity absorber regions to provide a compact, highly efficient design. A two tank storage unit with external insulation buffers system operation and provides for extended operation. A four element, tube and shell heat exchanger produces steam for turbine operation.

The estimated annual average energy collection efficiency is 0.618. The plant annual energy output is about 290 GWhe, displacing the equivalent of 490,000 bbl oil per year.

Repowering was found to be close enough to breakeven, economically, to be very attractive. Legal and institutional barriers are minimal. As a result, a very aggressive repowering program including Ft. Churchill is recommended as a means for reducing dependence on foreign oil.

PREFACE

This report was prepared for the Department of Energy under Contract No. DE-AC03-79SF 10609. It presents the results of a nine (9) month study to define a site specific conceptual design for solar repowering of Sierra Pacific Power Company's Fort Churchill No. 1, located near Yerington, Nevada.

This report is published in a single volume. In addition, the Executive Summary, Section 1, is published as a separate volume with wider distribution.

The guidance and support of the Department of Energy Program Manager, Fred Corona, and the technical assistance and suuport of Dr. J. J. Bartel of the Sandia National Laboratories were of great benefit in the conduct of this study, and we acknowledge their contributions.

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R. G. Richards and W. Branch of Sierra Pacific Power Company
S. Goidich of Foster Wheeler Development Corporation
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Section 1

EXECUTIVE SUMMARY

This section contains an overview of the Sierra Pacific Utility Repowering study conducted under contract to Department of Energy, San Francisco Operations Office (DOE).

1.1 BACKGROUND

1.1.1 Objectives

The objectives of this study were to:

- Develop a conceptual design for repowering Sierra Pacific Power Company's Ft. Churchill plant, unit No. 1 which
  - Will provide a practical and effective use of solar energy
  - Can be constructed and operating in 1985
  - Will provide the best economics for overall plant operation.
- Utilize technology being developed by DOE.
- Show the technical potential and cost effectiveness for electric power plant repowering

1.1.2 Technical Approach

The technical approach to this study is illustrated in the study flow network of Figure 1-1.

The System Requirement Specifications (SRS) were drafted using characteristics of the existing Ft. Churchill plant, the known or estimated site characteristics, DOE guidelines/specifications, and results of previous studies.

A system configuration was defined to meet the requirements through the conducting of trade studies and the application of results from previous studies. Results were used to update the SRS.

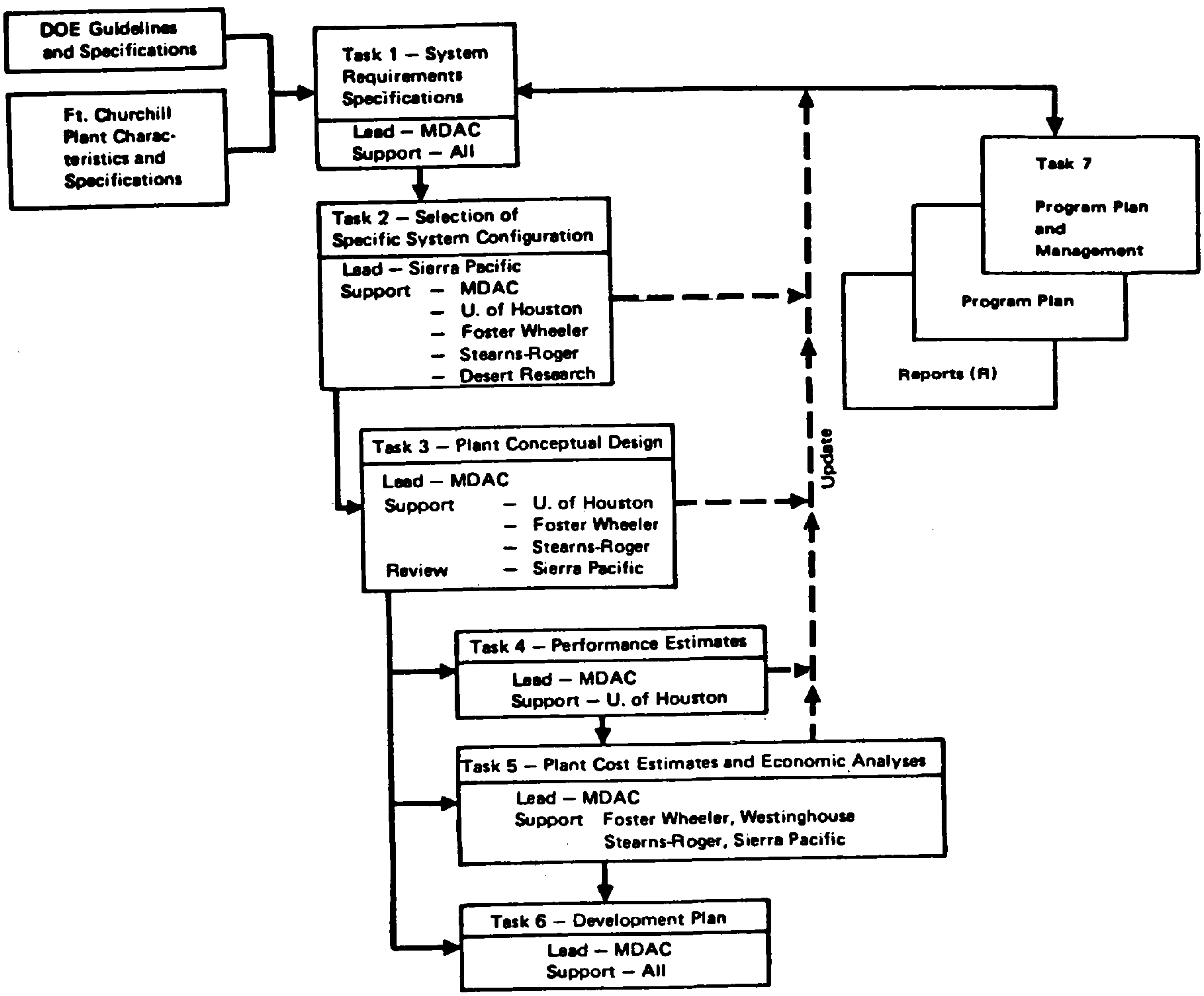

Figure 1-1 Study Flow Network

A conceptual design for the repowered plant was then prepared. Results were used to complete the SRS.

From the conceptual design and the SRS, performance and cost were estimated. The repowered plant economic value was estimated from a detailed, dynamic, grid dispatch analysis that developed the value of fuel displaced and a capacity credit for the repowered plant.

A development plan was prepared to show schedules and significant milestones in preliminary design, detailed design, fabrication, construction, checkout and operation of the repowered plant.

1.1.3 Study Team

The study team and their responsibilities are shown in Figure 1-2. The McDonnell Douglas Astronautics Company (MDAC) was the prime contractor. The Sierra Pacific Power Company (SPPCo.) appears as a subcontractor on the organization chart, providing the utility interface, review/approval, and

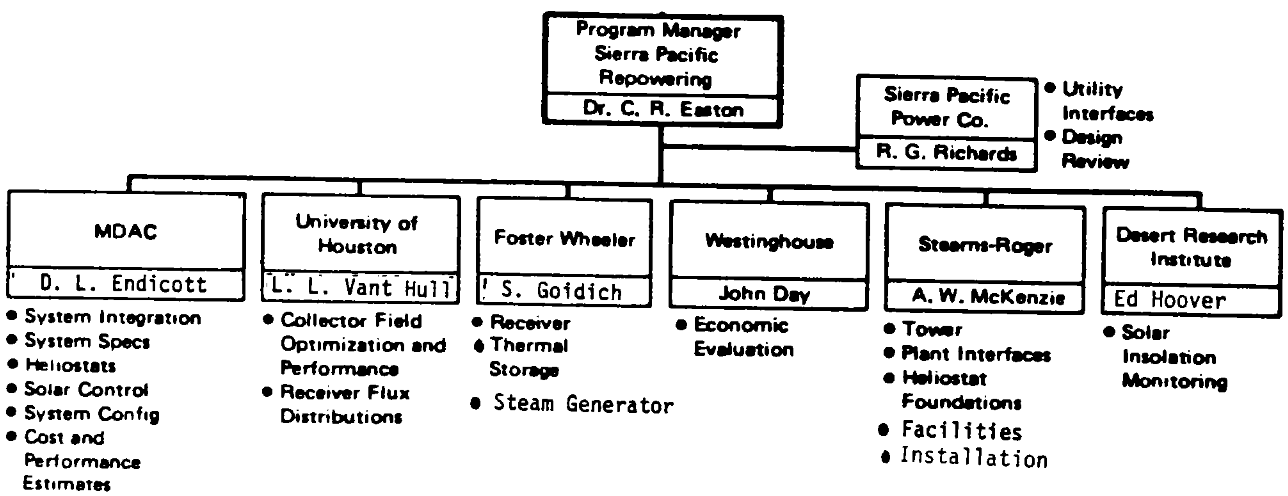

Figure 1-2. Study Organization

utility data. This role for SPPCo. is consistent with their normal practice for new plant expansion/modification. In this organization, MDAC has assumed a solar system design and integration role.

The key personnel and the roles undertaken by the other team members are indicated on Figure 1-2.

1.1.4 Repowered Plant Concept

An artist's sketch of the repowered plant is shown in Figure 1-3, superimposed on an aerial photograph of the site provided by Sandia Laboratories. The collector field, tower and receiver are on the left. The existing Ft. Churchill Units 1 and 2 are on the right, next to the cooling ponds. Switch yards are located to the north and west of the existing units and connect into the two transmission lines which tie the Ft. Churchill plant into the grid. Three oil storage tanks are located to the northwest. Behind the existing units are the thermal storage and steam generator units.

A top level plant schematic is shown in Figure 1-4. The repowering conceptual design uses a 130° north collector field. The partial cavity receiver (combination of external and cavity absorber surfaces) heats molten salt to a temperature of 566°C (1050°F). The heated salt flows to a hot storage tank, while molten salt at 288°C (550°F) is withdrawn from a cold storage tank for receiver feed. A four element steam generator provides superheated steam at 538°C (1000°F) to the turbine and reheats the partially expanded steam to 538°C (1000°F). The molten salt is pumped from the hot storage tank and flows in parallel through the superheater and reheater. The two salt flows are then combined and flow first through the evaporator, then through the preheater, and dump into the cold storage tank.

1.2 SITE/SYSTEM DESCRIPTION

SPPCO's grid network will have seven operating units in three plants in 1985, as shown in Table 1-1. Ft. Churchill Unit No. 1, was selected for this study.

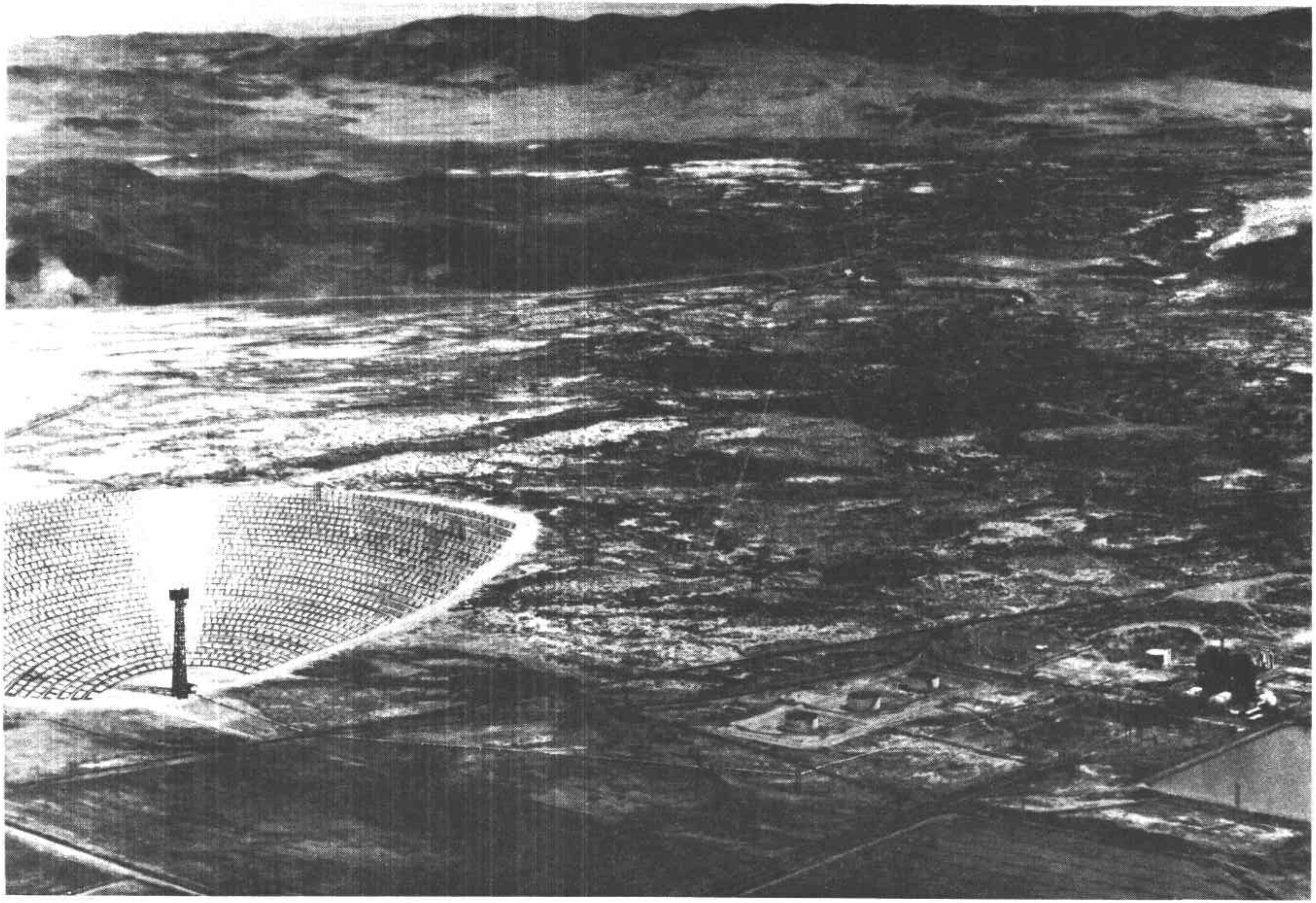

Figure 1-3 Artists Rendition of Repowered Ft. Churchill No. 1

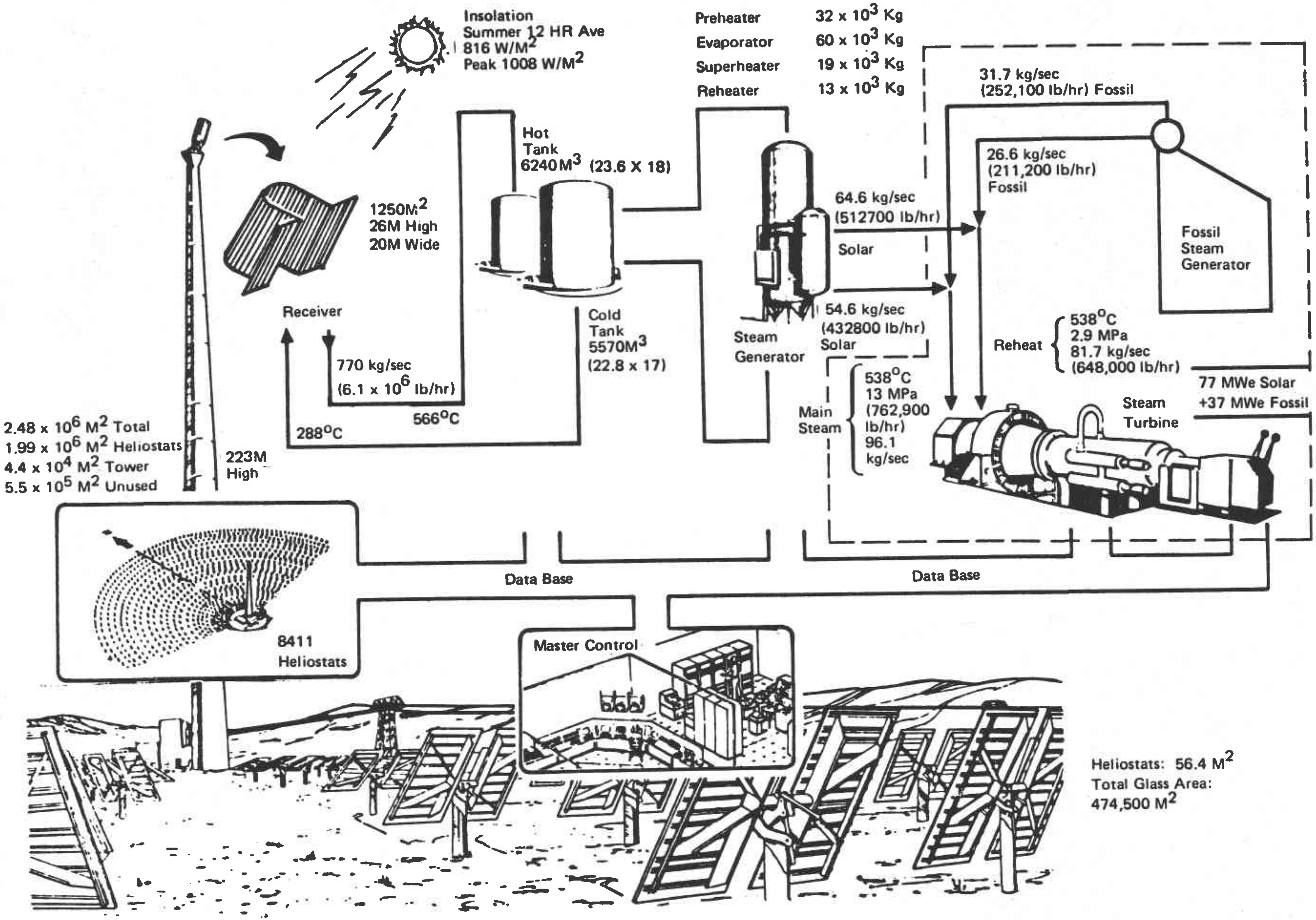

Figure 1-4. Sierra Pacific Power Co. Fort Churchill No. 1

Table 1-1

SIERRA PACIFIC POWER COMPANY NETWORK INCLUDES **THREE** REHEAT UNITS WITH SIGNIFICANT REPOWERING POTENTIAL

Unit No.	Rating (MWe)	Projected 1980 Service	(1985 Scheduled) Service
1. Tracy No. 1	56	Standby/Peak	Standby Peak
2. Tracy No. 2	80	Intermediate	Standby Peak
3. Tracy No. 3	110✓	Baseloaded	Intermediate
4. Ft. Churchill No. 1	110✓	Baseloaded	Intermediate
5. Ft. Churchill No. 2	110✓	Baseloaded	Intermediate
6. North Valmy No. 1	125*	-	Baseloaded
7. North Valmy No. 2	125*	-	Baseloaded

*Note: Both North Valmy Units are rated at 250 MWe each with 50 percent output to Sierra Pacific Power, 50 percent to others.

✓ Potential for repowering.

The higher efficiency reheat units, Tracy 3 and Ft. Churchill 1 and 2 were preferred over the non-reheat Tracy 1 and 2. North Valmy was not considered because it is coal fired. Ft. Churchill was preferred over Tracy because of higher insolation and more accessible land. Ft. Churchill units 1 and 2 and Tracy 3 are all excellent prospects for repowering. The site is located 75 Km (47 miles) southeast of Reno, Nevada. The primary and secondary fuels for this unit are oil and natural gas. Unit No. 1 entered service in 1968, and presently operates at a capacity factor of 0.78. In 1985 the two Ft. Churchill units are scheduled for load-following duty (24-hour service power) in the winter and part of the summer and load-following (24-hour service at variable output to match load requirements).

Typical of newer units in the range of 100 MWe, those at Ft. Churchill operate on a reheat cycle at 13 MPa (1890 psig), 538°C (1000°F) high pressure turbine inlet and 538°C (1000°F) reheat.

The insolation at this site is very favorable for solar repowering. The site is located in the high desert, near Yerington, Nevada, far enough from the mountains to have less cloud cover than either the Reno or Ely locations where insolation data have been collected. Weather data show that for an average year, the sun will shine for 84 percent of daylight hours at Reno. The clear day percentage is believed to be higher at Yerington than at Reno because of the greater distance from the Sierra Nevada range. Insolation at the site is being measured by the Desert Research Institute. Using a combination of measured clear day insolation and Reno cloud cover factors, an average annual insolation estimate of 7.2 $kWh/m^2/day$ was generated for the Ft. Churchil site.

Adequate adjacent land is available for the collector field. The site is surrounded by flat, high desert, of which the land to the immediate northwest is owned partially by SPPCO and partially by the Bureau of Land Management (BLM), as indicated in Figure 1-5. Lands of the Sierra, a holding company of SPPCO, manages company property not occupied by equipment. The specific location of the collector field can be moved to the northwest and tailored to the land boundaries if the indicated land cannot be made available from the BLM.

1.3 PROJECT SUMMARY

The general conclusion of this study is that repowering of existing electric power generation plans is an economic and highly desirable means for reducing our nation's dependence on oil and natural gas. This conclusion has been verified by the present study in three ways:

1. The present value of 30 years of levelized fixed charge against the capital cost of the repowered plant is less than the present value of the fuel displaced if the plant continues to burn oil and gas at the projected capacity factor. This conclusion was reached based on conservative assumptions of:

   - First unit repowering plant costs
   - Levelized fixed charge rate of 15%/year
   - Fuel escalation rate of 10%/year
   - General inflation rate of 8%/year
   - Discount rate for present value of 11.6%/year

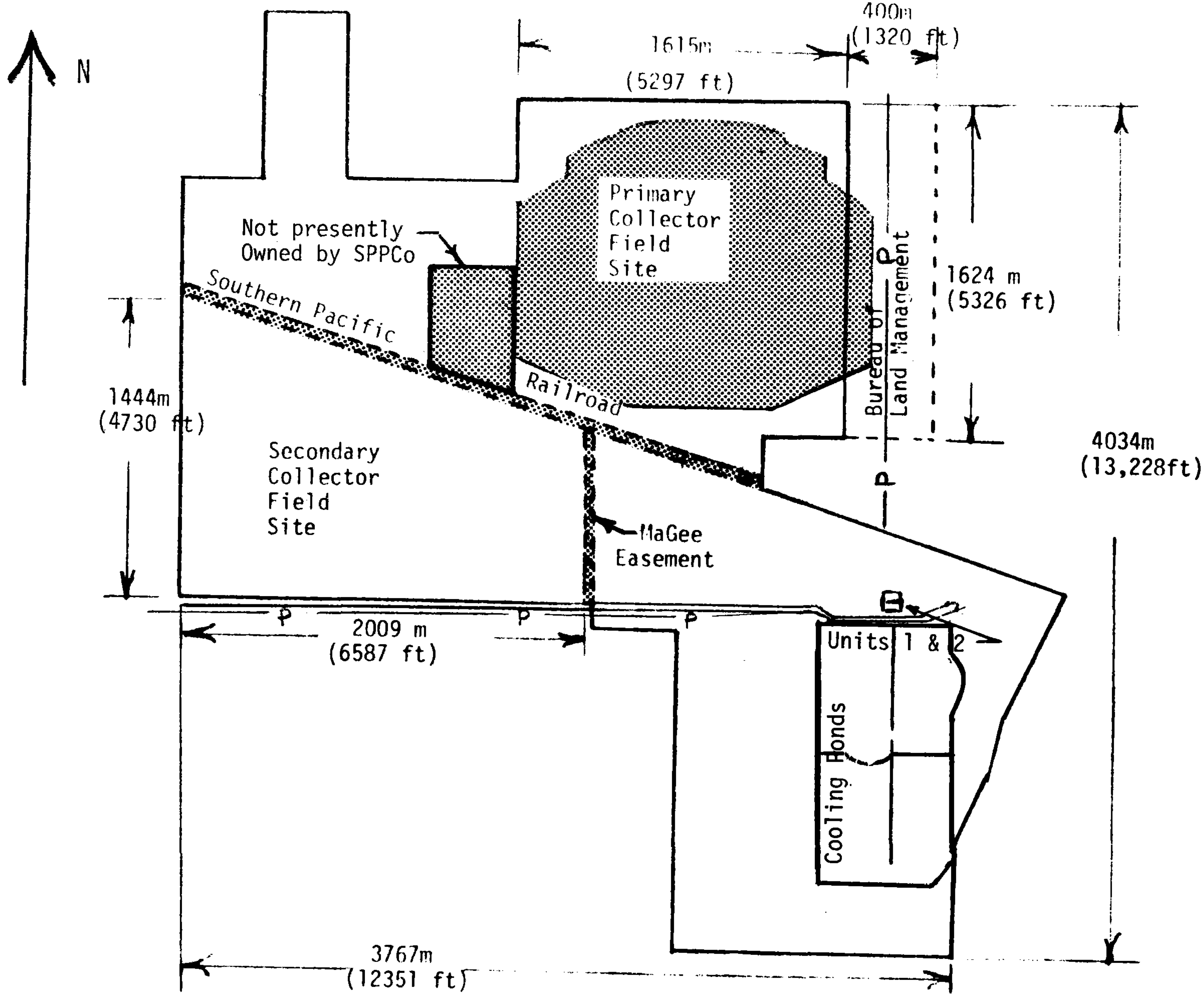

Figure 1-5 Fort Churchill Site Plot

2. The life cycle economics for a repowered plant compare favorably with economics for new coal capacity. At 10 percent per year fuel escalation and the SPPCo estimate of $1000/kWe capital cost for new coal capacity typical of the West, solar stand alone repowering is more economic than new coal capacity if the coal capacity is to replace existing oil/gas fired units at intermediate capacity factor.

3. Solar repowering was compared to published data on coal liquefaction as an alternate means for oil displacement. For an equivalent amount of oil displaced, solar repowering was found to be more economic than coal liquefaction. This result is due primarily to a low efficiency of conversion from energy in coal to energy in the product. It is recognized that coal liquifaction provides a fuel which can replace oil for most applications, whereas the opportunities for solar repowering are geographically and otherwise limited. The Synfuel program is valuable for applications where solid coal cannot be used effectively and solar insolation is low, or solar is otherwise not applicable.

The above conclusions lead to the recommendation that solar repowering of existing power plants should be pursued as aggressively as technology development and funding limitations permit.

1.3.1 Programmatic Conclusions

THE STATE OF NEVADA IS SUPPORTIVE OF SOLAR ENERGY DEVELOPMENT

Sierra Pacific Power Co. is actively working with the Nevada State Legislature and the Public Service Commission to develop risk sharing legislation for solar and geothermal development. The positive state government posture on solar and geothermal development is expected to benefit the energy development risk sharing legislature initiatives planned for the 1981 session.

SPPCO'S FT. CHURCHILL PLANT IS AN OUTSTANDING APPLICATION FOR REPOWERING.

This conclusion is based on the following findings:

- The site insolation level is high for both clear day and average annual insolation.
- An adequate amount of suitable land is already available at the site.

- The plant is relatively new (1968 IOC) and in excellent condition.
- The reheat cycle provides the high cycle efficiency desirable for solar repowering.
- The plant has proven to be extremely reliable, with a forced outage rate less than 1%, and a total outage less than 5%.
- The plant is of a standard design used for many plants in the west and southwest. There are three such units in Sierra Pacific's grid. Equipment and concepts developed for this unit can be used with minimum redesign for many other applications.
- The economic outlook for solar repowering is quite favorable because of the high fraction of capacity in SPPCo's grid using oil/gas.

OPERATION OF THE REPOWERED PLANT IN 1985 IS FEASIBLE

This conclusion is based on the following considerations:

- There are no component development requirements which cannot be successfully completed in the time allotted for the development program.
- Components which require development and/or qualifications are identified in the development plan and alternate approaches are provided where required by the development risk.
- The full repowering plant requirements for the production of 8411 second generation heliostats plus spare parts can be accomplished with the DOE plans.
- It is assumed that the DOE will provide for the production process development and capitalization of appropriate heliostat production facilities.
- The receiver development takes maximum advantage of the current DOE salt receiver development program. Molten salt receiver test results at the Central Receiver Test Facility (CRTF), at Sandia National Laboratories, Albuquerque will be utilized. In addition, a configuration test at CRTF is recommended, but final qualification must be conducted in the repowered plant.

THE SOLAR COLLECTOR FIELD MAY BE DIVIDED INTO TWO HALF SIZED MODULES

Collector and receiver subsystem capital costs are projected to be insensitive to dividing the collector field into two half sized modules, if heliostat costs are not affected. Non-recurring costs and thermal storage subsystem costs are expected to be the same. Modularization may be advantageous because it provides for reduced initial repowering demonstration costs to DOE and the user. The added flexibilities of modularity may also be desirable for subsequent applications.

1.3.2 Technical Conclusions

There are seven important technical conclusions which result from this study, as listed below:

Full Repowering Capability is Desirable - The initial operation of the plant as a hybrid will be desirable. However, during low demand times of the year and during the later portion of the life of the plant, it will be more economic to operate as a solar stand-alone plant at full rated power.

Repowered Design Lifetime is 30 Years - Solar repowering will cause design life critical components of the existing plant such as the fossil boiler to operate on a reduced duty cycle. Hence, the expected lifetime of the plant after repowering (1985) is 30 years.

A Molten Salt Receiver Fluid is Preferred - Molten salt and water/steam receiver fluids were compared. The molten salt system showed slightly lower costs per unit thermal energy collected, much simpler system control, capability for storage for extended/deferred operation, much higher fossil fuel displacement, no requirement to burn fossil fuel to operate the solar portion of the plant, and less imposing technical feasibility issues. User operating personnel are not familiar with molten salt systems. Operations and maintenance personnel require retraining for the safe operation and maintenance of the molten salt system. Development testing will also be required for the molten salt system. Molten salt was preferred over sodium primarily because of reduced costs for thermal storage.

A Northerly Collector Field is Preferred - A northerly collector field was found to be preferred because of several factors including a shorter piping run to the plant; the higher latitude, which accentuates the heliostat efficiency difference between north and south heliostat locations; and a new design approach to the receiver, which allows both a wide azimuthal extent of the north field and a high receiver efficiency. The key issues in selection the northerly field appear to be the partial cavity receiver and wide azimuth extent of the field.

Partial Cavity Receiver is Preferred - The partial cavity receiver concept was found to combine high efficiency with minimum absorber area and low system cost. The initial promise which led to our interest in the partial cavity approach has been realized. The partial cavity receiver concept is new, and many of the potentially desirable options have not been fully explored. These additional options are expected to lead to an even more beneficial final design.

Two Tank Thermal Storage is Preferred - A two tank thermal storage approach with external insulation is preferred. Technical risks appear to be excessive for developing a dual medium thermocline storate unit for the first repowering application. However, its cost advantage promises to be significant. Internal insulation poses excessive technical risk, and its cost advantage is small at best.

Repowering at Normal Operating Conditions is Feasible - The normal operating conditions of 13 MPa (1890 psia) at 538°C (1000°F) can be achieved in reasonable size heat exchangers with 566°C (1050°F) molten salt bulk temperature. A maximum receiver film temperature of 593°C (1100°F) appears feasible for achieving 566°C bulk temperature. These values are all within the state-of-the-art.

1.3.3 Economic Conclusions

The principal economic conclusion of this study is that repowering would be economically preferable to continued operation on oil/gas present capacity factors. Even at first unit costs and conservative economic assumptions, the present value of fuel saved is greater than the present value of the fixed charge against the capital investment to repower. However, the plant would not be projected to continue to operate at its present capacity factor. A portion of the fuel displacement for the repowered plant would come against oil/gas, but the majority of the fuel displacement would come against coal and lower cost purchased power.

The repowered plant operation was simulated in the changing mix of generation capacity expected for SPPCo. Approximately 55% of the fuel displacement for the repowered plant was against coal combustion and purchased power. The model used cost escalation rates for purchased power which are believed to be unrealistically low. As a result of low costs of power displaced, the plant did not show breakeven economics for the first plant cost model. However, even the first plant costs were within 10-30% of breakeven. This result was felt to be very encouraging.

1.4 CONCEPTUAL DESIGN SUMMARY

The conceptual design of the repowered plant is summarized in Table 1-2. The three possible operating modes for the repowered plant are illustrated in Figure 1-6. In the baseline mode, Unit No. 1 will be repowered for hybrid operation with the fossil side operated continuously at at least 37 MWe (gross) and the solar providing load-following up to 77 MWe (gross) during the high demand periods of the day. In addition, capacity will be provided for up to six hours of thermal storage. The plant would thus deliver up to 77 MWe from solar for up to 18 hours in mid-summer, and would displace about 80 percent of the fossil fuel annually. On low insolation days, the fossil boiler can be operated at a higher power level with lower power from the solar generator to avoid ramping of the fossil boiler. The repowered plant can also operate in solar stand-alone and fossil only modes. An option to generate full rated power in the solar stand-alone mode seems to be advantageous.

The system layout was shown in Figure 1-4, and the baseline is summarized in Table 1-3. The 130° north field is located to the northwest of the plant, and will occupy about 2.0×10^6 m^2 land area. The collector field will contain 8411 MDAC second generation heliostats at 56.4 m^2 each for a total mirror area of 474,500 m^2. The University of Houston has optimized the collector field layout as a radial staggered field.

The baseline receiver design is a partial cavity, as illustrated in Figure 1-7. The receiver uses a molten-salt working fluid. The front and side walls of the receiver are arranged in series/parallel sets of uncontrolled preheater panels. The east and west halves of the receiver each have two series passes

Table 1-2 (Page 1 of 3)

CONCEPTUAL DESIGN SUMMARY

		Comments
Prime Contractor	McDonnell Douglas Astronautics Company	Provides program management, system engineering, collector, and solar master control
Associate Prime Contractor	Sierra Pacific Power Company	Associate prime contractor, design review, evaluation, approval, and utility data
Major Subcontractors	Foster Wheeler Development Company	Receiver, thermal storage unit, steam generator
	Stearns-Roger, Inc.	Plant interfaces, facilities, A&E services
	University of Houston	Collector field optimization, layout, and performance
	Westinghouse Advanced Systems Technology	Economic evaluation
	Desert Research Institute	Site insolation and weather measurements
Site Process	Utility Electric Power Generation	115 MWe General Electric, reheat turbine manufactured in 1967 . Rated turbine inlet conditions are 12.4 MPa (1800 psia), 538°C (1000°F) with 538°C (1000°F) reheat
Site Location	Fort Churchill Plant	75km (47 miles) southeast of Reno, Nevada, near Yerington
Design Point	Equinox Noon	Design point insolation is 1008 W/m^2
Receiver Design		
Fluid	Molten Salt	Eutectic sodium and potassium nitrate, normal melting point 221°C (430°F), maximum safe operating temperature 649°C (1200°F)

Table 1-2 (Page 2 of 3)

CONCEPTUAL DESIGN SUMMARY

		Comments
Receiver Design (Cont'd)		
Configuration	Partial Cavity	156 m^2 external absorber, 1100 m^2 cavity absorber
Flow Routing	4 Pass	Two uncontrolled preheater passes in series followed by two controlled passes in series
Elements	20 Absorber Panels	12 preheater, 8 high temperature
Tube Size	25 mm (1 in.) O.D.	Incoloy 800 (may change to 304 S.S.)
Inlet Temperature	288°C (550°F)	
Outlet Temperature	566°C (1050°F)	
Heliostat		
Number	8411	MDAC Second Generation (Meets Sandia Specification Drawing A10772)
Area	56.42 m^2 (606 ft^2)	
Cost	$224/$m^2$	Assumes 5000 u/yr production rate
Type	Non-Inverting	Site safety, dust buildup do not warrant the cost of inverting
Collector Field	North	130° azimuth angle in field with 25° receiver tilt
Storage		
Duration	Six Hours	1150 MWh_{th} storage capacity
Type	Two Tank	External insulation preferred. Storage in receiver fluid.

Table 1-2 (Page 3 of 3)

CONCEPTUAL DESIGN SUMMARY

		Comments
Project Cost	$\$196 \times 10^6$ 1980 Dollars	Uses estimated heliostat cost of $\$224/m^2$.
Construction Time	Four Years	
Power Rating - Solar	77 MWe	May have provision for 110 MWe solar stand-alone.
Capacity Factor - Solar	0.34	Corresponds to solar fraction of 0.8 to 1.0.
Fossil Energy Saved	490,000 bbl/year	
Type of Fuel Displaced	#6 Oil/Natural Gas in Plant	1985 displacement 58% oil/gas,42% purchased. 1995 - 19% coal, 44% oil/gas, 37% purchased.
Annual Energy Produced	0.759×10^9 kWh_{th}	Thermal energy delivered to the turbine.
Ratio of Annual Energy Produced / Total Heliostat Mirror Area	1.5 MWh_{th}/m^2	Fuel displacement is 1.75 MWh_{th}/m^2 because of boiler efficiency
Ratio of Capital Cost / Annual Fuel Displaced	$\$258/MWh_t$	
Site Insolation	2.63 MWh/m^2/year	Based on 5 months direct normal measurements for clear day, University of Houston insolation model extrapolation for remaining 5 months, and modified Reno weather factor. Measurements began November 19, 1979, and will end June 15, 1980.

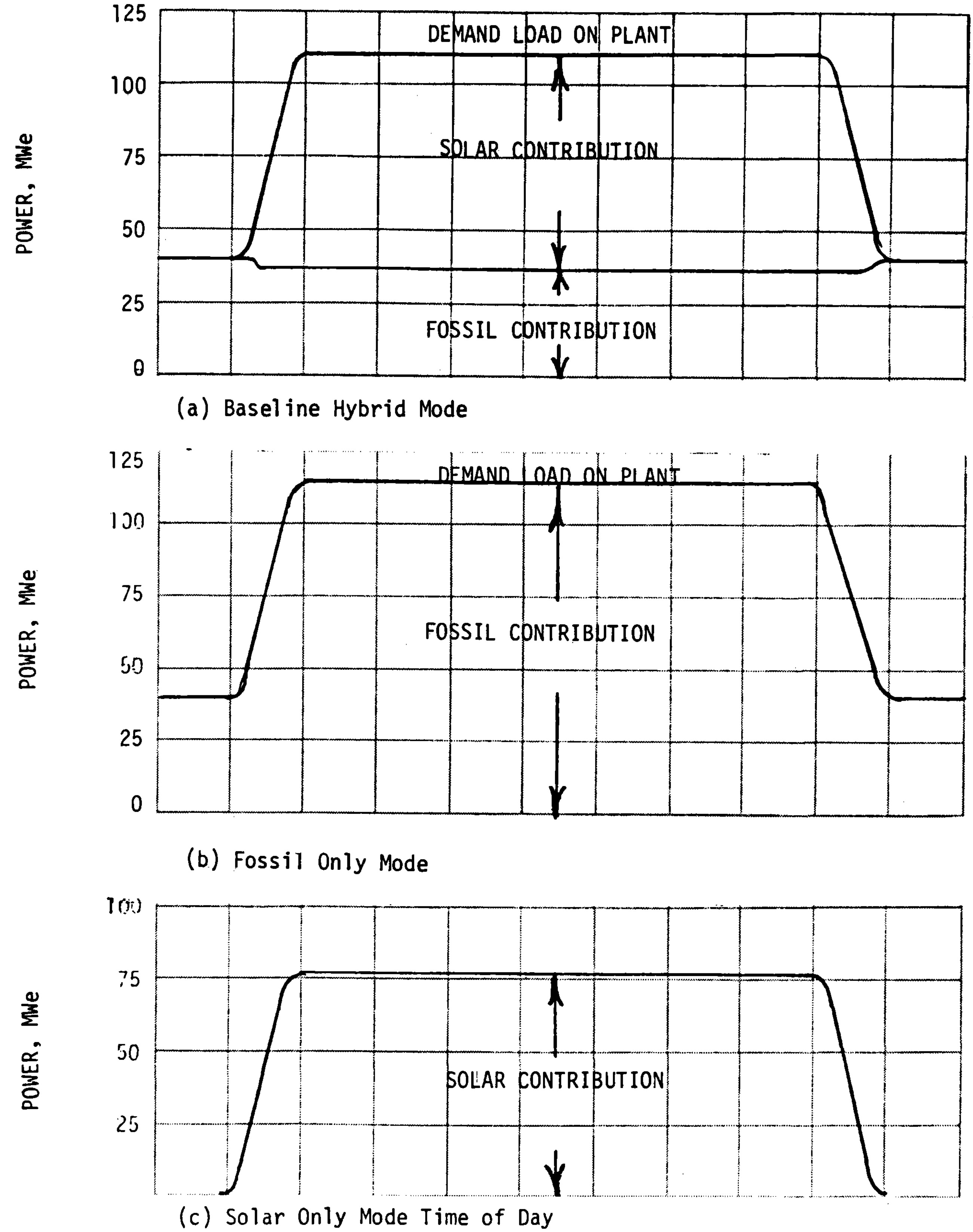

Figure 1-6 Plant Operating Modes

Table 1-3

BASELINE SYSTEM SUMMARY

Plant	Baseline Selection	Rationale
Utility	Sierra Pacific Power Co. Ft. Churchill No. 1	Ideal repowering conditions, equipment in excellent condition, large oil displacement potential, progressive management outlook, high probability of repowering.
System	Rankine Cycle with Reheat	Represents majority of systems in the 50-150 MWe size range, large commercial potential with other utilities, low risk building on Barstow technology.
Mode	Hybrid with Solar Stand-Alone Option	Provides maximum design data, includes Solar only, Solar/Fossil Hybrid and Fossil Only scenarios, greatest flexibility for 1985 requirements, large potential oil displacement, ease of matching load requirements.
Turbine Cycle	Reheat	High performance in large power size, typical of late model system with equipment in good shape. Represents largest commercial market for fuel displacement. (6,800 GW_e)
Receiver Fluid	Molten Salt	High performance with reheat system. No fossil fuel fired reheaters required. Utilizes existing technology with lower risk/cost than sodium system in storage coupled mode.
Field	130° - North	Minimum total system cost for energy collected optimum utilization of land available, shortest piping run to plant, utilizes Barstow technology.
Receiver	Partial Cavity	Best cost/performance characteristics, best peak/average flux ratio with North Field, minimizes aiming sensitivity for Solar Field, minimum receiver weight for output. High receiver efficiency.
Tower	Concrete	Minimum risk
Thermal Storage	Two Tank	Minimum project risk, simple operation completely decouples systems for Solar-Only, Hybrid or Fossil-Only operation.
Heliostat	Second Generation Design	Minimum cost for equivalent performance, represents commercial production unit in 1985, utilizes latest Solar technology.

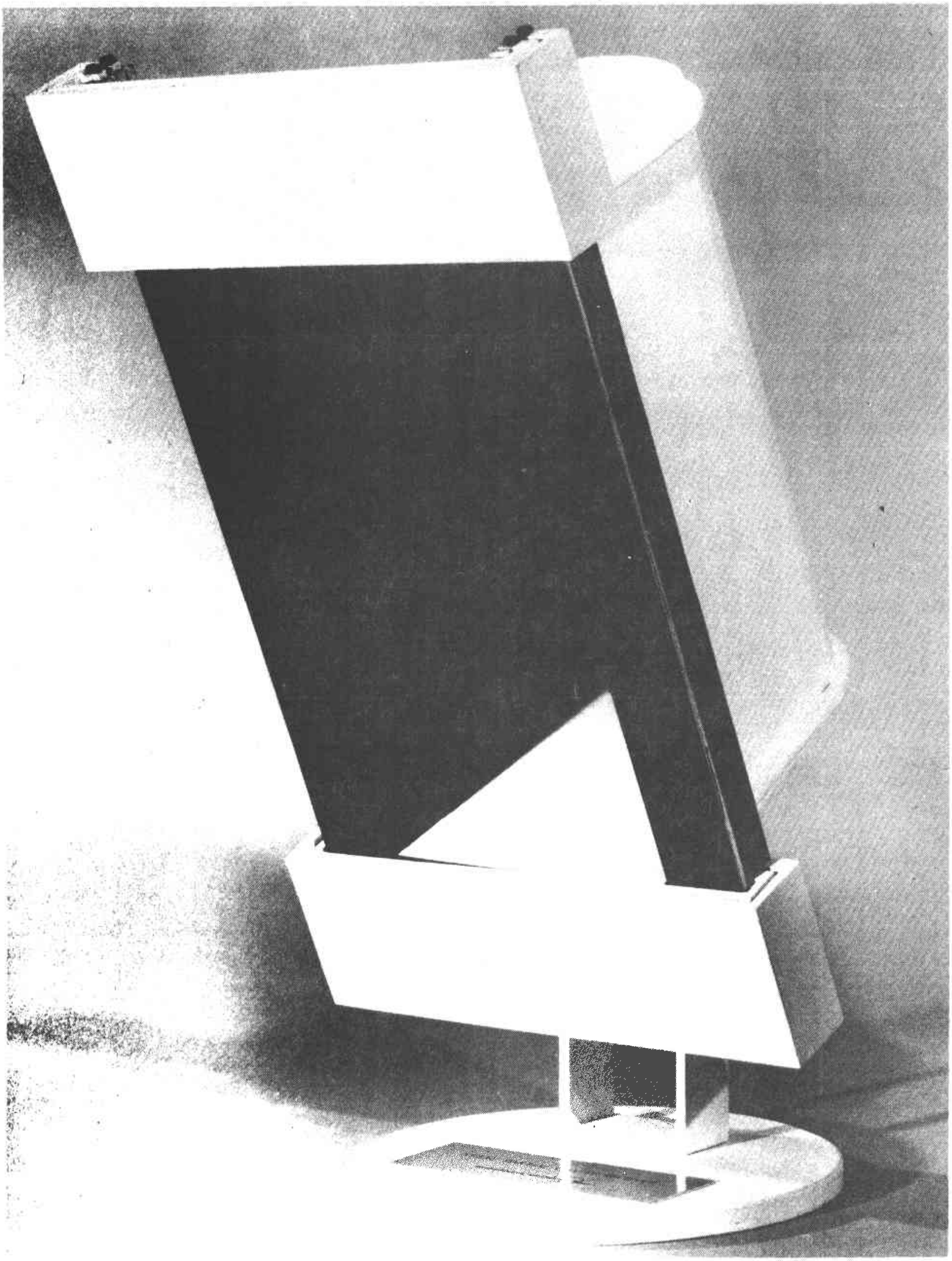

Figure 1-7 Photograph of Scale Model Receiver

of uncontrolled preheater panels. The cylindrical portion contains four parallel circuits of two panels each. Each circuit is series connected to provide an adequate heated path length and load.

The thermal storage baseline is a two tank, externally insulated unit. The hot tank is 23.6 m (77.4 ft) in diameter and 18m (59 ft) high. The cold tank is 22.8 m (74.8 ft) in diameter and 17 m (55.8 ft) high. A four element steam generation heat exchanger is also baselined. The cold salt line is carbon steel, 0.41 m (16 in) in diameter, and the hot salt line is 316 stainless steel 0.3 m (12 in) in diameter.

The center of the receiver aperture plane is 223 m above the ground, and the receiver is supported on a concrete tower. The tower is 24.2 m (79.5 ft) in diameter at the base and 20.3 m (66.7 ft) in diameter at the top. The wall thickness tapers from 0.38 m (15 in) at the base to 0.33 m (13 in) at the top. A slab foundation is preferred for withstanding seismic loads.

The present plant has a dual, manual/automatic, turbine lead (boiler following) control system located at the site. The repowered plant will retain the present automatic control (having manual override), and will add a separate automatically coordinated control system for the solar equipment. The plant operator will provide the primary control interface between the fossil and solar equipment. The repowered plant can be operated in hybrid, solar stand-alone and fossil, only modes.

The steam flow interfaces are located in the high and intermediate pressure turbine inlet lines, and flow control valves modulate the feedwater and cold reheat steam flow to the solar and fossil-fired sides to provide the correct mass flows for the grid required turbine power.

1.5 SYSTEM PERFORMANCE

System performance is discussed from the standpoints of insolation (how much solar energy is there to collect), collection efficiency (how much energy gets into the receiver fluid), plant cycle efficiency (how much of the thermal energy is delivered to the grid as electricity), and annual energy output.

1.5.1 Insolation

The insolation data establish that the Ft. Churchill site has approximately 7.2 kWh/m^2 average annual insolation. Hence, Ft. Churchill is an excellent site.

This insolation estimate was established from a combination of clear day insolation measurements at the site, clear day correlations for portions of the year for which no measurements are available, and weather factors (cloud cover reduction of clear day insolation) based on historic data from Reno. Site measurements of both direct normal insolation and total horizontal insolation, ambient temperature, wind speed, barometric pressure, and relative humidity were taken by Desert Research Institute.

Results from about five months site insolation measurements are available from the Desert Research Institute's station to support this study. These data were used to refine parameters in the University of Houston's computer program for calculating daily and annual insolations. Clear day total insolation levels and design point insulation levels are shown in Table 1-4.

No single year is reliably typical for measurements of cloud cover. Hence, no attempt has been made to correlate cloud cover at the Ft. Churchill site, as measured during this study, with other historical data sources. However, simultaneous measurements of total horizontal insolation at Ft. Churchill and Reno, together with Reno weather factors based on long term observations, were

Table 1-4

DIRECT NORMAL INSOLATION - SUMMARY

Season	Design Point Insolation (W/m^2)	Clear Day Insolation (kWh/m^2)	Weather Factor**	Annual Average Insolation ($kWh/m^2/day$)
Winter	840 (0900 hours)	7.1	0.67	4.7
Spring	1008 (1200 hours)	9.6	0.68	6.5
Summer	750* (0700 hours)	10.8*	0.85	9.2
Autumn	---	9.0*	0.92	8.3
ANNUAL	---	9.1	---	7.2

*Estimated - No confirming site data available

**Long term weather factors from Reno sunshine switch data, modified by estimates from simultaneous measurements of total horizontal insolation at Reno and Ft. Churchill.

used to estimate Ft. Churchill weather factors. Estimated weather factors are also shown in Table 1-4.

The product of clear day total insolation and weather factor gives the average insolation, as shown in Table 1-4 for the four seasons. The values shown in the table are generally higher than forecast because of higher than expected clear day insolation levels in the winter and higher weather factor. There is still an error band in site insolation estimates, and little or no significance should be attached to the second "significant" figure.

1.5.2 Collection Efficiency

Collection efficiency is defined as the ratio of the thermal energy absorbed into the receiver fluid to the thermal energy which would be incident on the collector field if all the mirrors were oriented normal to the sun. The constituent efficiencies making up the collection efficiency are shown in Figure 1-8. The design point efficiency (equinox noon) for the SPPCo field is 0.687. The annual average efficiency for clear days is 0.618. The actual annual efficiency may be a bit lower, because receiver radiation and convection losses are nearly constant, rather than proportional to the incident flux.

The design point and average annual efficiency waterfalls are shown in Figure 1-8. In addition to the usual constituent efficiencies, a field geometry factor has been added. The theoretical packing densities of heliostats as optimized by the University of Houston's RCELL program series cannot be achieved in practice. For example, RCELL does not account for the slip planes in a radial stagger layout. Experience with the detailed layout of the DOE 10 MW Pilot Plant collector field indicates that the average heliostat performance is over estimated by RCELL by about three percent. The field geometry factor includes this effect.

1.5.3 Plant Cycle Efficiency

The plant cycle efficiency includes conversion of heat energy to electricity and efficiency reductions due to plant parasitic loads. The net turbine-generator cycle efficiency is 0.426. Parasitic losses vary with the plant operation mode, as indicated in Table 1-5. The efficiency factor for parasitic loads ranges from 0.905 for direct solar operation to 0.958 for hybrid operation from storage.

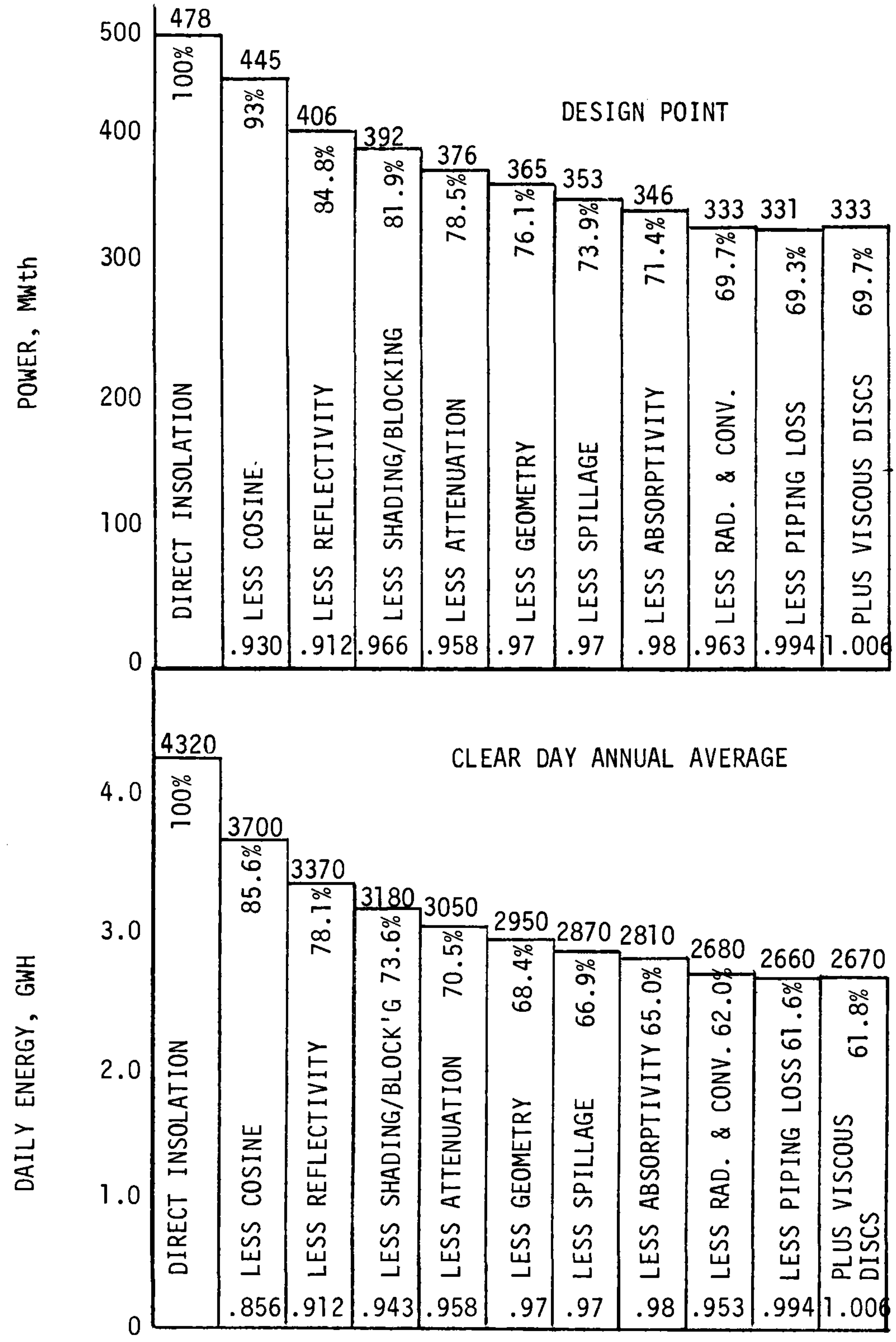

Figure 1-8 Design Point and Clear Day Average Collection Efficiency

Table 1-5

PLANT PARASITIC LOSSES

(KWe LOAD)

Mode	Forced Draft Fan	Solar Equipment	Other	Total	Parasitic Efficiency Factor
Fossil, Only	1200	1715	3065	5980	0.948
Hybrid, Direct Solar	300	4340	3550	8190	0.929
Hybrid, Solar	300	1835	3545	5680	0.950
Solar, Only Direct	0	4340	2980	7320	0.905
Solar, Only Storage	0	1835	2975	4810	0.937

1.5.4 Annual Energy Output

The average annual efficiency for energy collection was found to be 0.618, and the average solar conversion efficiency is estimated from Table 1-4 as 0.405, giving a net efficiency 0.246. With the average annual insolation of 7.2 KWh/m^2/day from Table 1-4, and the predicted availability of 0.958, the annual energy production from solar is 288 GWhe delivered to the grid.

The solar capacity factor is about 0.3, and the fuel savings is about the equivalent of 3.0×10^{15}J(490,000 bbl oil) per year.

The above are specific design point data and are believed to be near the optimum. The indications are that 100 percent repowering for a baseline stand-alone operating mode, with a solar multiple of about 1.4 and 6 hour storage for extended and deferred operation, would be desirable.

1.6 ECONOMIC FINDINGS

The economic findings of this study are summarized by five major conclusions as discussed below. Supporting data are provided in Table 1-6.

1.6.1 Repowering is Economically Preferable to Continued Oil/Gas Usage

This conclusion is drawn under the following assumptions, consistent with SSPCo's current economic parameters:

a. First unit plant costs of \$196 x 10^6, as summarized in Table 1-7.

b. Net levelized fixed charge rate of 15% (includes effects of a 10% investment tax credit)

c. Present worth discount rate of 11.6%

d. Fuel escalation rate of 10%/year

e. 1980 fuel cost for oil of \$5/GJ (\$30/bbl), based on \$27/bbl 1979 actuals for SPPCo

f. Useful life of the repowered plant of 30 years

The present worth of 30 years fixed charge against the capital cost of the plant plus O&M is about \$275 x 10^6. The present worth of 30 years fuel displacement, assuming 100 percent of the displacement is against oil and gas, is \$330 x 10^6.

However, the entire fuel displacement will not be against oil and gas. For the first 10 years of operation, the fuel displacement is about 60% against oil and gas and 40% against purchased power from Pacific Gas and Electric. For the remaining 20 years, the displacement is about 45% oil/gas, 20% coal, and 35% purchased power. Hence, the real benefit is reduced by about 35-40%. If, however, coal, oil/gas, and purchased power all escalated at 12%, the savings would grow to \$275 M.

1.6.2 Repowering is Competitive with New Coal Capacity

For an equal capacity factor from a new coal fired plant and current costs, SPPCo estimates a coal plant would cost about \$100 x 10^6 and the present worth of 30 years fuel cost would be about \$96 x 10^6. The present worth of 30 years

Table 1-6

ECONOMIC FINDINGS FOR SPPCo REPOWERING
(ALL COSTS IN 10^6 1980 DOLLARS)

Finding		Comments
<u>Repowering Compared to Continued Oil/Gas Use</u>		
Present worth of capital and O&M cost	$275	Varies with plant cost, includes O&M
Present worth of energy if displacement were all in oil/gas	$330-425	Fuel escalation at 10 and 12%
Probable present worth with real mix of fuel displacement	$210-275	10-12% escalation with displacement 20% coal, 35% purchased power, 45% oil/gas
<u>Repowering Compared to New Coal Capacity</u>		
Present worth of capital cost	$132	Assumes 42-44% capacity factor 10% fuel escalation
Present worth of O&M costs	$ 60	
Present worth of fuel cost	<u>$ 96</u>	
Total present worth of new coal capacity	$288	
<u>Repowering Compared to Coal Repowering</u>		
Present worth of capital cost	$ 66	
Present worth of O&M cost	$ 30	
Present worth of fuel cost	<u>$106</u>	
Total present worth of coal repowering	$202	
<u>Repowering Compared to Coal Liquefaction</u>		
Present worth of capital cost	$111	Costs to achieve the same total electric energy output if liquefied coal repowers Ft. Churchill
Present worth of O&M cost	$ 50	
Present worth of fuel cost	<u>$217</u>	
Total present worth cost of coal liquefaction	$378	

Table 1-7

PROJECT CAPITAL COST SUMMARY

Subsystem/Activity	Description	Cost Estimate (10^6 1980 Dollars)
Site Preparation	Grading, roads, soil tests, fences.	2.3
Site Facilities	Buildings and building modifications.	0.3
Collector Subsystem	Heliostats at $224/m^2 including installations, controls, wiring, and checkout.	136.6
Receiver Subsystem	Tower, receiver, receiver support structure, riser/downcomer piping and receiver feed pumps.	32.7
Solar Master Control Subsystem	Includes all subsystem controllers and software development.	5.0
Energy Storage Subsystem	Includes tanks, fluid, steam generators circulation equipment and piping.	15.0
Electric Power Generating Subsystem	Includes modifications and interfaces to the existing plant.	3.8
TOTAL		195.7

Note: Each subsystem and activity cost carries its own allocated portion of indirects and distributables, including contingency and fee.

fixed charge on the cost of the coal plant is about $\$132 \times 10^6$. Additional O&M costs are estimated at $\$60 \times 10^6$ present value for 30 years O&M. The total cost is, then, about $\$288 \times 10^6$.

Again, one would not normally build a coal plant for operation at 40 percent capacity factor. If one did build such a plant, it would receive a capacity credit which would add to its value. However, 10 percent fuel escalation is still quite conservative. Such a plant would take 6-8 years to build, and the interest during construction would add about 40% to the cost to SPPCo.

Without a detailed analysis, it appears that repowering is in a cost range competitive with new intermediate capacity factor coal plants which would replace existing oil/gas plants retired early by excessive oil/gas costs or uncertain availability.

1.6.3 Solar Repowering Requires Incentives to Compete with Coal Repowering

A plant such as Ft. Churchill could be retrofit with coal fired boilers. A 1979 study conducted by Stone and Webster for SPPCo showed that the Ft. Churchill plant could be retrofit to coal combustion for about $420/net kW in 1979 dollars. Some loss of capacity would also occur because of the power required to operate the scrubbers.

Allowing for inflation and derating, we estimate the coal repowering direct cost to be $\$50 \times 10^6$. The present worth of 30 years fixed charge aginst capital cost is $\$66 \times 10^6$. The cost of fuel would be slightly higher than before because of a lower projected net heat rate, or about $\$106 \times 10^6$. The O&M costs are estimated at $\$30 \times 10^6$. The total cost is, then, $\$202 \times 10^6$. An additional subsidy of about $\$75 \times 10^6$ would be required to achieve breakeven life cycle economics at the nominal solar repowering cost.

1.6.4 Solar Repowering is More Economic than Coal Liquefaction

A coal liquefaction plant design described by Fluor Company in a recent article in the Los Angeles Times had the following characterizations:

1. Cost $\$3.5 \times 10^9$

2. Produces 58,000 bbl/oil per day

3. Consumes 40,000 tons coal per day.

To achieve the same fuel displacement as one repowering plant, the cost and coal consumption are scaled linearly to $\$84 \times 10^6$ capital cost and $\$10.5 \times 10^6$ annual fuel cost, both in 1980 dollars. The present worth of 30 years fuel costs is $\$217 \times 10^6$, and the present worth of 30 years fixed charge against capital is $\$111 \times 10^6$. The present worth of 30 years O&M cost is about $\$50 \times 10^6$ for a total life cycle present value cost of $\$378 \times 10^6$. This cost exceeds the repowering cost by about $\$110 \times 10^6$ in 1980 dollars.

1.6.5 Solar Repowering is Economically Feasible

Calculations of the performance of a solar repowering of Ft. Churchill unit by Westinghouse for this study show close to breakeven economics for the nominal first plant. The cost estimates, the performance models, the economic models and the optimization of the system and its dispatch are not sufficiently accurate at this time to make precise statements of cost/value ratios. However, cost reductions which would surely result from repowering several similar plants would almost certainly lead to early, positive economic benefits.

Because of the very positive economic benefits of repowering shown above, MDAC and SPPCo recommend that an aggressive repowering program be undertaken. In particular, the earliest feasible go-ahead for the detailed design and construction of the repowering plant for Ft. Churchill is recommended.

1.7 DEVELOPMENT PLAN

A top level view of the development schedule is shown in Figure 1-9. A total development period of 51 months is indicated, beginning 1 June 1981. The two pacing items in the schedule are heliostat production and receiver development and production. Both issues were discussed in paragraph 1.3.1, and will not be repeated here. The schedule of Figure 1-9 is very tight. Any slippage in the start date will result in a slippage of the entire schedule. MDAC further believes that a 9 month preliminary design phase beginning in early FY '81 would benefit the program.

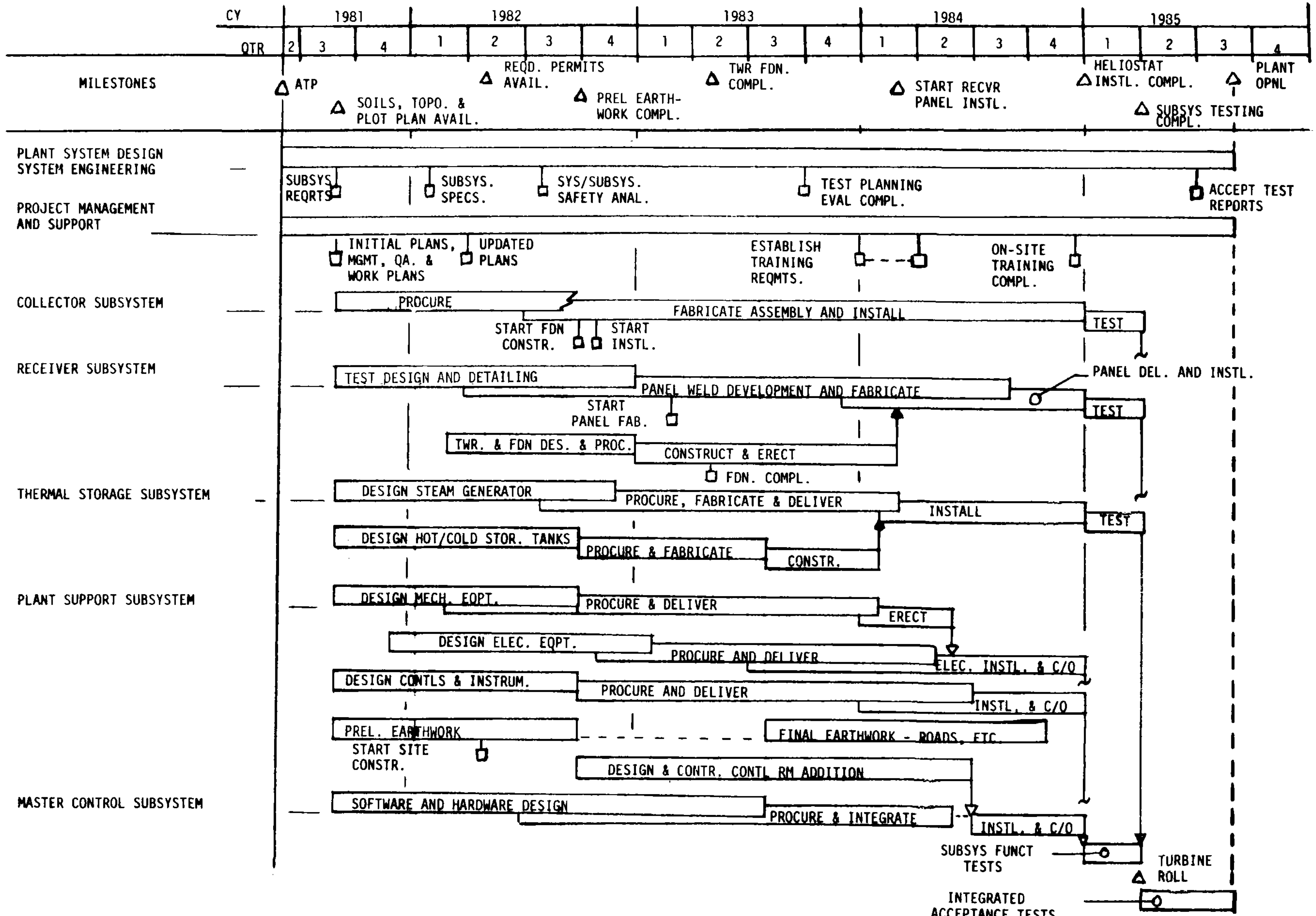

Figure 1-9 Development Plan Executive Summary

The program schedule provides for limited development and testing of critical components. Key issues include:

- Receiver panel fabrication method development
- Creep rupture life analysis on receiver tubes
- Receiver transient flow analysis
- Receiver configuration testing at CRTF
- Receiver feed pumps and seals testing
- Hot storage tank weld joint analysis at the floor/wall joint
- Insulation optimization for the thermal storage tanks
- Detailed analysis of thermal storage tank losses through the ground and temperatures and movement.

1.8 SITE OWNERS ASSESSMENT

1.8.1 Overview

In today's uncertain natural gas and petroleum market conditions, alternate energy repowering concepts for existing oil and gas fired plants are becoming attractive indeed. Coal repowering can create adverse environmental impacts at certain sites, and adds to future dependence on a single energy resource. Nevada's high solar insolation level is one of the bases for Sierra's interest and participation in the Solar Thermal Repowering Program.

We feel that the Conceptual Study produced for the Sierra Pacific Power Ft. Churchill Station project describes a practical and operationally acceptable repowering system. The projected oil or gas displacement of about one half million barrels of oil equivalent energy per year is perhaps the most dramatic indicator of the national significance of the Solar Thermal Repowering Program.

1.8.2 Value of Solar Repowering

Nevada is a state without significant natural fossil and surface water energy resources. The generally long highway, railway and transmission line distances to available energy resources add significant costs to our energy supply. The abundance of solar and geothermal energy in Sierra's northern Nevada service territory is the basis for our serious New Energy Systems development program.

The U.S. Department of Energy's Solar Thermal Repowering Program is a unique opportunity to accelerate the evaluation and development of our solar resource. The program is of particular value as its implementation secures and possibly extends the planned useful life of existing fossil generation facilities while dramatically reducing our oil and natural gas dependence. Experience gained through the program may well lead to participation in future hybrid and stand-alone solar plants exploiting the attractive projected benefits in solar hardware manufacturing economies of scale.

Sierra's future energy supply decisions will be based on both hard economics and often less tangible benefits including energy resource diversity. Industrial demonstration of new technologies provides essential hard operational data for energy system decisions.

1.8.3 System Repowering Potential

Sierra's two plant repowering potential represents slightly over 460 MWe. The portion of that total involved in future Fuel Use Act requirements and voluntary repowering is presumed large. The land availability at both sites is good, being a combination of Sierra Pacific ownership and Public Lands without competing beneficial use. The solar insolation at both sites is high, benefiting from buffering provided by the Sierra Nevada mountains and the general lack of heavy industrialization.

Of the total, 136 MWe are in two nonreheat units and 330 MWe are in three almost identical reheat units. This mixture provides a range of repowering system application. By 1985, 136 MWe will be scheduled for standby/peaking service and 330 MWe for intermediate service. This diversity should yield reasonable flexibility in developing repowering schedules and offer capacity combinations similar to Sierra's anticipated ownership portion of future joint new coal projects.

1.8.4 Operational and Environmental Considerations

The proposed integration of the controls and facilities into our existing operation is smooth and provides minimal impact to our existing plant operation. The control features and philosophy will minimize operator training requirements and allow hybrid operation of the total facility by existing personnel.

Substantial thermal storage facilities are an important operational plus, allowing relatively normal daily operation following the daily load cycle with reasonable short term isolation from solar insolation variations.

Although operating experience with molten salt is not widespread in industry, the location of the salt system components is such that safety hazards to plant personnel performing normal plant operation and maintenance activities should be low. The large temperature difference between the salt's melting point and the ambient, is viewed as a positive safety feature for containment and localization of spills.

Of Sierra's two generation plant sites, the Tracy site may suffer significant environmental impacts from direct coal repowering. Coal repowering might have to take the form of liquification or gasification to be environmentally safe. Both the Tracy and Ft. Churchill sites have a high potential for Solar Repowering. Although heliostat field construction and maintenance activities have a higher negative impact potential for fugitive dust than would arise for a coal conversion, solar repowering presents lower negative impact potentials in nearly all other categories.

1.8.5 Solar Repowering Development Plan

Sierra Pacific concurs with the Department of Energy's ambitious project schedule. The practical opportunity for repowering efforts is not a long term proposition. We also agree to the reasonableness of the extent of the proposed Federal cost sharing.

Sierra Pacific is a serious evaluator of the Solar Repowering option, and is prepared to commit to its share of the costs as the Department of Energy completes its program risk and extent definition.

The means of Federal cost sharing must provide complete ownership of the energy produced from the plant as it will be dispatched to our system grid. As Sierra must begin earning on its capital investments when the facilities become productive, or during construction if allowed, the means of Federal cost sharing in the construction must provide clear ownership definition.

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