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SOUTHWESTERN PUBLIC SERVICE COMPANY SOLAR REPOWERING PROGRAM

Final Technical Report, Executive Summary

July 1980

Work Performed Under Contract No. AC03-79SF10741

General Electric Company
Energy Systems Programs Department
Schenectady, New York

U.S. Department of Energy

Solar Energy

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FINAL TECHNICAL REPORT

EXECUTIVE SUMMARY

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JULY 1980

PREPARED FOR

UNITED STATES DEPARTMENT OF ENERGY
(CONTRACT DE-AC03-79SF10741)

GENERAL ELECTRIC COMPANY
ENERGY SYSTEMS PROGRAMS DEPARTMENT
SCHENECTADY, NEW YORK

GENERAL ELECTRIC

ABSTRACT

Solar technology needs a successful demonstration project to meet national energy independence goals. General Electric and Southwestern Public Service Company consider the use of solar energy a viable alternative to conventional sources of energy. After an extensive nine-month study, the companies consider the application of the sodium central receiver technically feasible for repowering of fossil fuel installations. Additional engineering required to integrate the solar power source with the existing Plant X Unit 3 represents no major technical problem.

Southwestern Public Service Company participated in the development of a cost estimate for the demonstration project. They believe the cost estimate proposed in the repowering study is valid. In the development plan portion of the study, a management program is presented that will result in a project that can be successfully completed with the lowest practical expenditure. Southwestern would emphasize that maintaining an aggressive schedule for completion and start-up by mid-1985 is important for cost control and a successful project.

We recognize that demonstration project economics are specific to the installation, and a first-of-a-kind facility usually costs more than subsequent ones. The best use of development funds would be to demonstrate solar repowering technology for future commercial applications of solar electric power. The economic advantage of the Plant X repowering project predicted in the report is a fuel savings of over one billion cubic feet of natural gas per year.

Southwestern, an owner/operator of a number of power plant facilities, does not foresee extraordinary safety hazards associated with the sodium central receiver concept. Southwestern has selected sodium for its heat transfer medium because of proven industrial technology which offers superior characteristics in providing for repowering of existing reheat machines.

A General Electric/Southwestern survey for additional solar repowering sites of gas-fired generating system equipment operated by SPS indicated a favorable potential for the solar repowering concept. However, strong economic incentives, component cost reductions, and resolution of regulatory uncertainties will be needed before future solar repowering can become an attractive option to Southwestern and other utilities.

General Electric and Southwestern Public Service Company conclude that the Plant X repowering conceptual design study lays the foundation for construction and operation of a solar demonstration facility. It is our opinion that a repowering demonstration facility is needed to develop acceptable experience for the commercial use of solar technology in the nation's utility industry.

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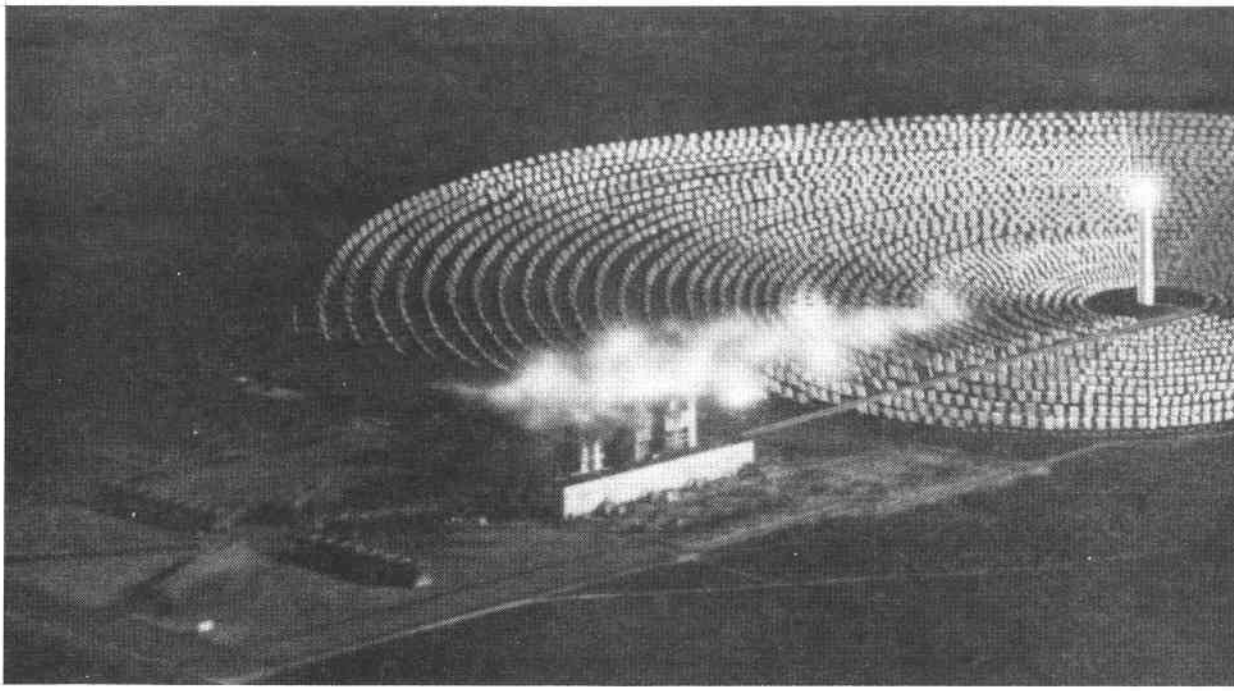
In recent years the United States has been relying increasingly on imported fuels, principally oil, for satisfaction of its domestic energy needs. Legislation such as the National Energy Act of 1978 has attempted to decrease the usage of premium fuels (oil and natural gas) for electric power generation.

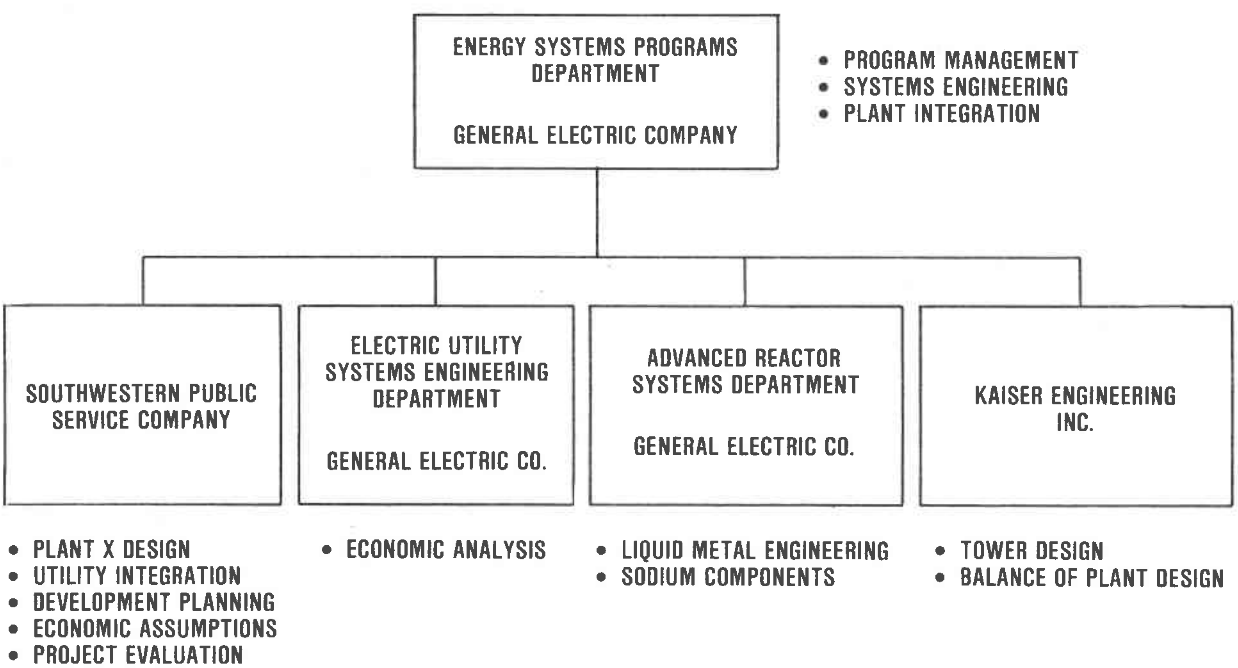
Solar energy is recognized as an inexhaustible source of energy for electric power generation, if cost and performance competitiveness can be achieved. Central Receiver technology has been identified as a promising alternative for electric utility applications, and the use of a solar central receiver at an existing oil or gas fired power station offers several potential advantages for the development of solar technology. First, it allows the use of existing equipment and reduces overall solar plant capital investment. Second, it allows utilities to gain first hand operating experience with a solar plant. And third, repowering displaces natural gas or oil, thereby reducing utility consumption of these premium fuels.

In the Spring of 1979, the Department of Energy awarded a contract to the General Electric Company and the Southwestern Public Service Company for the conceptual design and evaluation of an energy supply to one of Southwestern's existing power plants. The Energy Systems Programs Department (ESPD) of the General Electric Company managed the project, performed the system integration and determined system performance. The Advanced Reactor Systems Department (ARSD) of General Electric provided the expertise in the areas of sodium components and engineering. General Electric's Electric Utility Systems Engineering Department used their extensive background in utility system analysis and economics to assess the value of the solar retrofit. Southwestern provided system requirements and specifications and assisted in the integration analysis. Kaiser Engineers, Inc. of Oakland, California, provided the balance-of-plant design, receiver tower design and cost analysis for construction of the solar power plant. This team provided the Department of Energy with a sound conceptual design which meets utility operational and design requirements, as well as a realistic economic evaluation consistent with this site specific application.

The Department of Energy's concern that the utility user's perspective be reflected in the conceptual design was evident in the request for proposal. At the onset of the study, Southwestern was also concerned that the report should reflect the utility's viewpoint, and agreed to participate in the study only if allowed to review all work conducted in connection with the study and to comment on the applicability and adequacy of the design selected. Southwestern, therefore, assumed a very active part in the program.

This final report reflects Southwestern's utility perspective. Southwestern's design preferences have been incorporated into the study.




ENERGY SYSTEMS PROGRAMS DEPARTMENT
GENERAL ELECTRIC COMPANY
• PROGRAM MANAGEMENT
• SYSTEMS ENGINEERING
• PLANT INTEGRATION
SOUTHWESTERN PUBLIC SERVICE COMPANY
ELECTRIC UTILITY SYSTEMS ENGINEERING DEPARTMENT
GENERAL ELECTRIC CO.
ADVANCED REACTOR SYSTEMS DEPARTMENT
GENERAL ELECTRIC CO.
KAISER ENGINEERING INC.
• PLANT X DESIGN
• UTILITY INTEGRATION
• DEVELOPMENT PLANNING
• ECONOMIC ASSUMPTIONS
• PROJECT EVALUATION
• ECONOMIC ANALYSIS
• LIQUID METAL ENGINEERING
• SODIUM COMPONENTS
• TOWER DESIGN
• BALANCE OF PLANT DESIGN

KEY SYSTEM DESIGN FEATURES

The Solar Repowering Plant has been sized to deliver 60 MWe of electrical power. This size was selected because it meets Southwestern's system criteria and is the best size to meet the dual criteria of lowest cost and adequate size to satisfactorily demonstrate feasibility to the utility industry. The plant will operate in parallel with a fossil boiler maintaining the reliability of the power generating facility.

The plant selected for repowering is a highly efficient reheat plant. There is a potential market of over 1000 MWe of solar reheat repowering in Southwestern's utility system, and over 15,000 MWe in the Southwest, making the reheat market the largest near term opportunity for central receivers in the utility sector.

The nonreheat market is not as attractive for solar because most plants are old and operate at efficiencies less than reheat plants and would require relatively larger, most costly solar plants for repowering. However, there will likely be a few selected opportunities for nonreheat solar repowering and the design presented in this report can be easily adapted to meet the requirements of these installations.

Sodium is a particularly attractive working fluid for the reheat repowering market. Its high temperature performance capability exceeds the requirements of the reheat plants, and additional development and properties characterization are not needed. The steam generators can be located at ground level, permitting a low system cost and providing ease of maintenance. There are over 30 years of experience with this technology in the utility and industrial sections, and all of the sodium components in the power plant (with the exception of the receiver) are state-of-the-art. No further development is required for these components.

Design and Performance Characteristics

Only sufficient storage (10 minutes, at full power) is provided to protect the system from solar transients since analysis shows there is no significant benefit in additional amounts of storage (for this application, in Southwestern's system). This small quantity of storage is sufficient to demonstrate the concept and minimizes the cost of the first plant.

The plant will produce 114,475 MWe-hrs of energy per year. This is equivalent to displacement of 200,000 bbls of oil per year. Over the 30-year life of the plant, it is expected the solar plant will displace 15.7 billion cubic feet of gas, and 769,000 tons of coal of Southwestern's system projected fuel consumption.

The plant can be on-line by the end of 1985, assuming a start of detailed design by May 1981. This short time span is made possible through the use of state-of-the-art component technology.

SOLAR PLANT KEY DESIGN FEATURES

Optimum Power Level

- Meets Southwestern's System Criteria
- Adequate Size to Demonstrate Feasibility to Utilities
- Lowest Cost to Meet Above Criteria

Designed for Repowering of Reheat Power Plants

- Major Solar Repowering Market
- Over 15,000 MWe Available for Repowering in Southwest USA

Wide Range of Application

- Can Easily be Adapted to Nonreheat Plants

Attractive Working Fluid (Sodium)

- Exceeds High Temperature Needs of Modern Reheat Plants
- Steam Generators Located at Ground Level
- 30 Years Experience
- State-of-the-Art Components

MAJOR SYSTEM DESIGN AND PERFORMANCE CHARACTERISTICS

• Plant Size	- 60 MWe
• Number of Heliostats	- 4809
• Storage Capability	- 10 Minutes at Full Power
• Modes of Operation	- Solar Alone - Parallel with Fossil Boiler - Fossil Boiler Alone
• Annual Energy Output	- 114,476 MWe-hr/yr - 200,000 bbl/yr (Equivalent)
• Actual Life Time Fuel Displacement	- 15.7 Billion Cubic Feet of Gas - 769,000 Tons of Coal

The comprehensive conceptual design and evaluation of the Solar Repowering Plant at Southwestern has led to several important conclusions with respect to the specific application as well as to solar repowering in general.

1. General

No great barriers have been identified for the design and construction of a solar repowering demonstration plant that would be operational within a time frame useful to the utilities.

The successful completion of the demonstration project is considered an essential next step toward the development of cost effective solar power. The Southwest is an excellent location for such a demonstration since the plant will be operating in the actual environment where large scale implementation is likely. Although the first plant will not be cost-effective there are a number of ways to reduce costs for succeeding installations. One of the most fruitful areas for cost reduction is the heliostat.

2. Technical Feasibility

Solar repowering of existing fossil-fired electric power plants using a Sodium Central Receiver is technically feasible. Early plant demonstration of the concept is possible since no further system or component development is required beyond that planned in the current government program. All plant components - with the exception of the receiver - have been previously demonstrated in operation. A receiver development program is currently in progress under a General Electric contract to DOE, and the receiver concept is scheduled for testing in early 1981.

3. Value of the Demonstration Project to Utility Industry

The real value of the repowering project will be to demonstrate to the utility industry that solar technology can be applied on a commercial scale. However, the growth of a commercial repowering market will depend principally upon three important considerations:

1. The demonstration project must be successfully completed, and it must demonstrate to the utility the technical feasibility of solar power.
2. The cost of succeeding solar power plants must be significantly reduced.
3. Strong governmental economic incentives will be required in the near term to spur initial acceptance and market penetration.

4. Near-Term Market

The largest near-term market for solar power plants in the electric utility sector is for the repowering of modern reheat electric power plants. Emphasis should be placed in the Government Program on the continuation of the development of solar technology for this very important application.

Commercial cost goals for solar equipment and power plants should be established to aid the development of this market. These goals should be established on the basis of likely value to the utilities in order to compete with other power generation equipment. Additional work, expanding the site specific economic analysis performed in this study, should be performed to establish these goals.

5. Economics

Operation of the solar repowering plant results in a significant fuel savings which partially offsets the costs of the demonstration plant. However, strong economic incentives, component cost reductions, and resolution of regulatory uncertainties will be needed before solar repowering can become an attractive option to the utility industry.

Specific economic results presented in this report are extremely site dependent and apply only to the demonstration plant itself. The results cannot, and should not, be generalized to other applications where such factors as insolation level, degree of penetration, system fuel mix, and plans for future plant additions can vary significantly.

6. Working Fluid Technology

With the exception of the sodium receiver, no further technology development is required for the use of sodium as a working fluid. There is a considerable industry experience base with sodium, and existing practices and procedures for the use of sodium are deemed adequate to apply to the design of Central Receiver Systems. Sodium has been used at temperature levels in excess of those required for repowering, and its properties are well known and characterized. Confirmatory work is currently underway to verify acceptability of the receiver material (Incoloy 800) in a sodium environment. Major loop components, including steam generators, pumps, and valves are state-of-the art, and have been built and tested for other applications with design conditions similar to repowering.

7. Storage

Only a small amount of thermal storage is required for the demonstration project, which greatly minimizes cost. The small (10 minute) storage system included in the plant design for transient protection is prototypical of the larger systems and is therefore adequate for technology demonstration.

The Southwestern Public Service Company is an investor-owned utility serving 286,000 customers in a four-state, 45,000 square mile service area. The 3100 MWe generating system consists of coal and gas fuel units distributed through the service area.

Plant X, the existing electric power generation station selected for the solar repowering study, is located south of Amarillo, Texas, in a predominantly agricultural region with low population density. The site has high insolation levels and a flat terrain suitable for installing a large array of heliostats. The area available for the solar power plant is immediately adjacent to Plant X, thereby minimizing the pipe run from the receiver to the fossil plant and minimizing thermal losses.

Plant X is situated on 1700-acre site and contains four gas-fired generating units. Units 1 and 2 are nonreheat plants characteristic of pre-1955 vintage machines. Units 3 and 4 are more efficient, modern, reheat cycle facilities, with steam conditions ($538^{o}C/1000^{o}F$) characteristic of the majority of installed power plants in the Southwest suitable for repowering.

Unit No. 3 within Plant X was selected for repowering. It has had a recent major turbine overhaul and inspection in 1979 which showed the turbine to be in excellent condition. To repower with solar, only minor modifications to the plant will be necessary to accommodate variable power operation. The required turbine modifications are similar to those made elsewhere in the system to adapt baseload units to cycling duty and will present no difficulty. The turbine is currently scheduled for retirement in the year 1995, but this can and will be extended if it is repowered with solar.

Southwestern conducted a survey of its own system to identify additional solar repowering sites. Although limited in scope because of time and budget constraints, this survey identified existing generating facilities on Southwestern's system which have potential for being repowered. The potential is significant. Eight of the 32 gas-fired units now in operation on the electrical system represent a solar repowering potential of approximately 1,000 MW.

CHARACTERISTICS OF PLANT X POWER GENERATING UNITS

	UNIT #1	UNIT #2	UNIT #3	UNIT #4
Net Capability	49.5 MWe	106 MWe	106 MWe	200 MWe
In-Service Date	1952	1953	1955	1964
Main Steam Conditions	850 psig 900°F	1450 psig 950°F	1450 psig 1000°F	1800 psig 1000°F
Reheat Steam Temperature	Non-Reheat	Non-Reheat	1000°F	1000°F
Expected Retirement Date	1992	1993	2014*	2004
Fuel	Gas	Gas	Gas	Gas

*If repowered with solar

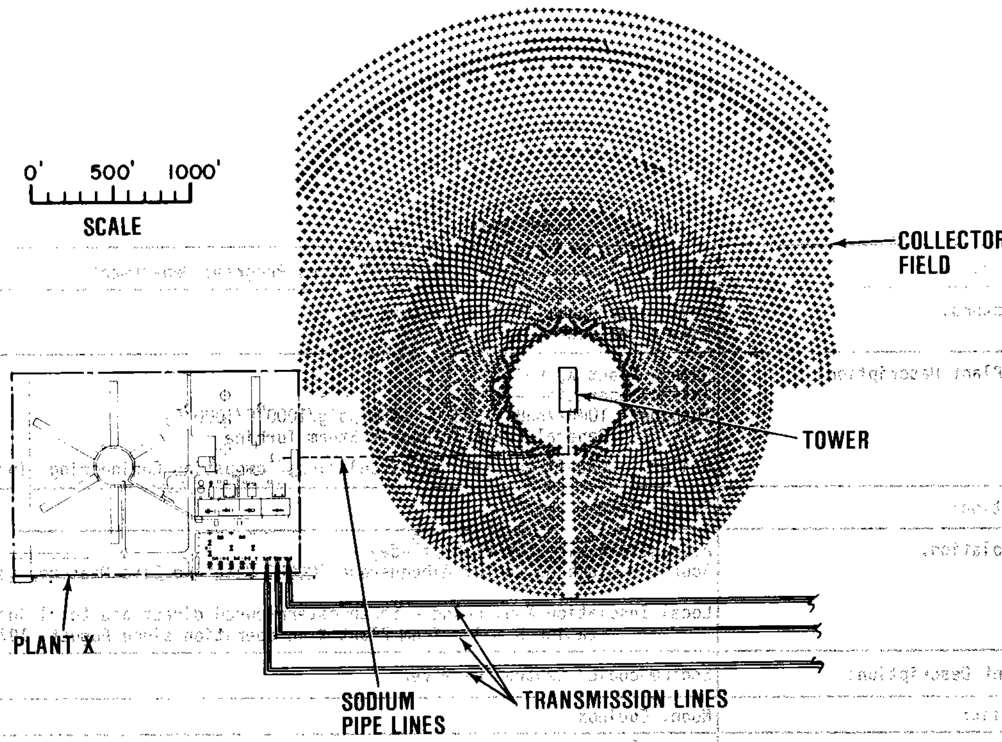
A 212-acre collector field will contain 4809 glass heliostats in a surround configuration. At noon equinox, the design point, the heliostats will deliver 158 MWth to the receiver which is mounted on top of a 140-meter tower. The cylindrical receiver consists of 24 absorber panel subassemblies. Sodium is pumped to the top of the tower by a constant speed centrifugal pump and enters the lower portion of the absorber panels at 293°C (560°F). It exits from the single pass receiver at 593°C (1100°F). The heated sodium flows down the tower to a hot storage tank located at ground level. From there a variable speed centrifugal pump delivers the sodium to a three-module steam generator facility (evaporator, superheater and reheater). The cooled sodium returns to the cold tank and is then pumped to the top of the tower.

The solar plant supplies steam to the Plant X, Unit 3, 100 MWe reheat turbine-generator. The plant is designed to operate in parallel with the Unit No. 3 fossil boiler and, in the hybrid mode, the steam produced by the solar plant is combined with the steam from the boiler prior to entering the turbine. Although the hybrid mode is the usual operating mode, the solar and fossil plants are capable of operating separately when appropriate.

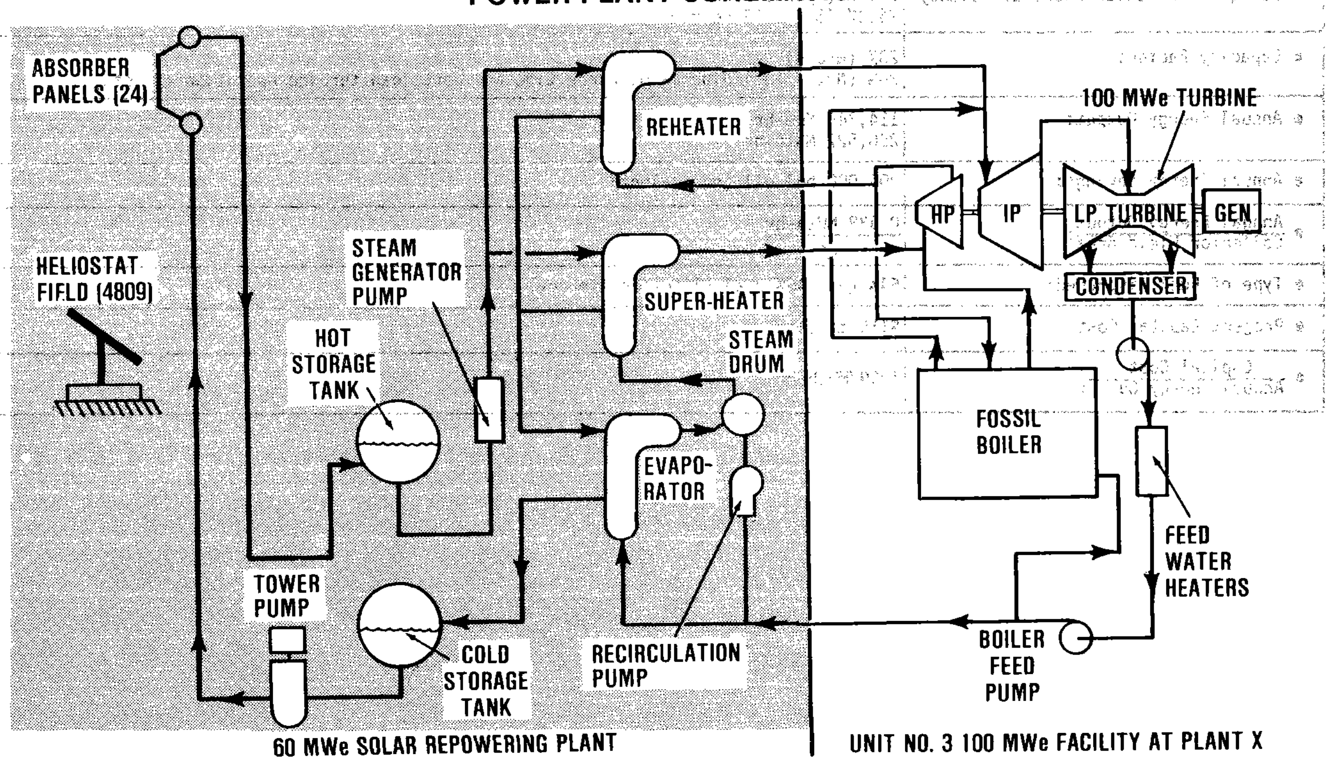
A 10 MWe-hr storage subsystem is provided to buffer the Unit No. 3 plant output from solar transients. In the event of a loss of solar power due to a cloud transient, the storage subsystem enables control of the solar plant shutdown rate to a sufficient degree to allow the fossil plant to assume the load, thus maintaining constant power output.

The overall plant will be controlled by a master control computer. This device monitors and integrates the activities of the distributed control loops and enables the plant to operate in the solar alone, fossil alone, or hybrid modes.

The sodium central receiver design developed in the program will demonstrate the repowering technology for the full range of utility applications. The 538°C (1000°F) steam temperature and the reheat application are the critical design features to be demonstrated. All repowerable facilities operate at these temperatures or below and have reheat cycles or less complicated nonreheat cycles.



POWER PLANT SCHEMATIC



PLANT DATA

• Prime Contractor:	General Electric Company, Energy Systems Programs Department
• Subcontractors:	Southwestern Public Service Company Kaiser Engineers, Inc.
• Existing Plant Description:	Name: Plant X, Unit 3 Initial Operation - 1955 Turbine - 10MPa/538°C/538°C (1450 psig/1000°F/1000°F) General Electric Reheat Steam Turbine Boiler - Gas-fired; Natural Circulation; Combustion Engineering, Inc. Boiler
• Site Location:	Earth, Texas
• Solar Insolation:	Average Annual - 6.5 kW-hr/m^2-day Source - Combination of Albuquerque SOLMET Data and Site Measured Data Local Insolation Monitoring - Southwestern-owned direct and total insolation monitoring station 8 miles from Plant X in operation since August, 1979
• Solar Plant Description:	Sodium-cooled Central Receiver
• Design Point:	Noon, Equinox
• Design Point Insolation:	940 W/m^2 (site-measured)
• Solar Fraction:	60%
• Design Point Solar Plant Efficiency:	25.7% (Hybrid Mode) 25.4% (Solar Alone Mode)
• Capacity Factor:	23% (Gross) 20% (Net - including maintenance time and part load turbine operation effects)
• Annual Energy Output:	114,745 MWe-hr 290,527 MWth-hr
• Annual Energy Savings:	200,000 bbl oil (equivalent)
• $\frac{\text{Annual Energy Output}}{\text{Collector Field Area}}$:	$\frac{0.338 \text{ MWth-hr}}{m^2}$
• Type of Fuel Displaced:	54% gas; 46% coal (lifetime average)
• Project Capital Cost:	$116 million
• $\frac{\text{Capital Cost}}{\text{Annual Energy Output}}$:	$399/MWth-hr

SUBSYSTEM DATA

COLLECTOR SUBSYSTEM	RECEIVER SUBSYSTEM
• Field Config: Surround • Heliostats: 4809, $49m^2$, 2nd Generation Glass • Area: 212 Acres • Cost: $\$230/m^2$	• Receiver: 12m x 12m External Cylindrical • Flow Control: 12 Electromagnetic Pumps • Tower: 140M Slip-Formed Concrete • Working Fluid: Sodium • Operating Temp: 293^oC (560^oF) inlet 593^oC (1100^oF) outlet • Sodium Flow: 1.34×10^6 kg/hr (2.95×10^6 lbs/hr)
STORAGE SUBSYSTEM	**STEAM GENERATOR SUBSYSTEM**
• Design: Hot and Cold Tank Buffer • Capacity: 10 MWe-hrs • Storage Medium: Sodium • Tank Design: Field Fabricated Double-Wall	• Modules: Evaporator, Superheater, Reheater • Steam Conditions: 10 MPa/538^oC/538^oC (1450 psig/1000^oF/1000^oF) • Steam Flow: 1.9×10^5 kg/hr (4.1×10^5 lbs/hr) • Sodium Flow: 1.34×10^6 kg/hr (2.95×10^6 lbs/hr)
FOSSIL ENERGY SUBSYSTEM	**ELECTRIC POWER GENERATING SUBSYSTEM**
• Boiler Manufacturer: Combustion Engineering • Design: Natural Circulation, Gas-Fired, Reheat Boiler • Efficiency: 84-85%	• Turbine Manufacturer: GE • Design: 10 MPa/538^oC/538^oC (1450 psig/1000^oF/1000^oF) Reheat, Condensing Turbine • Efficiency: 42% (Full Load)

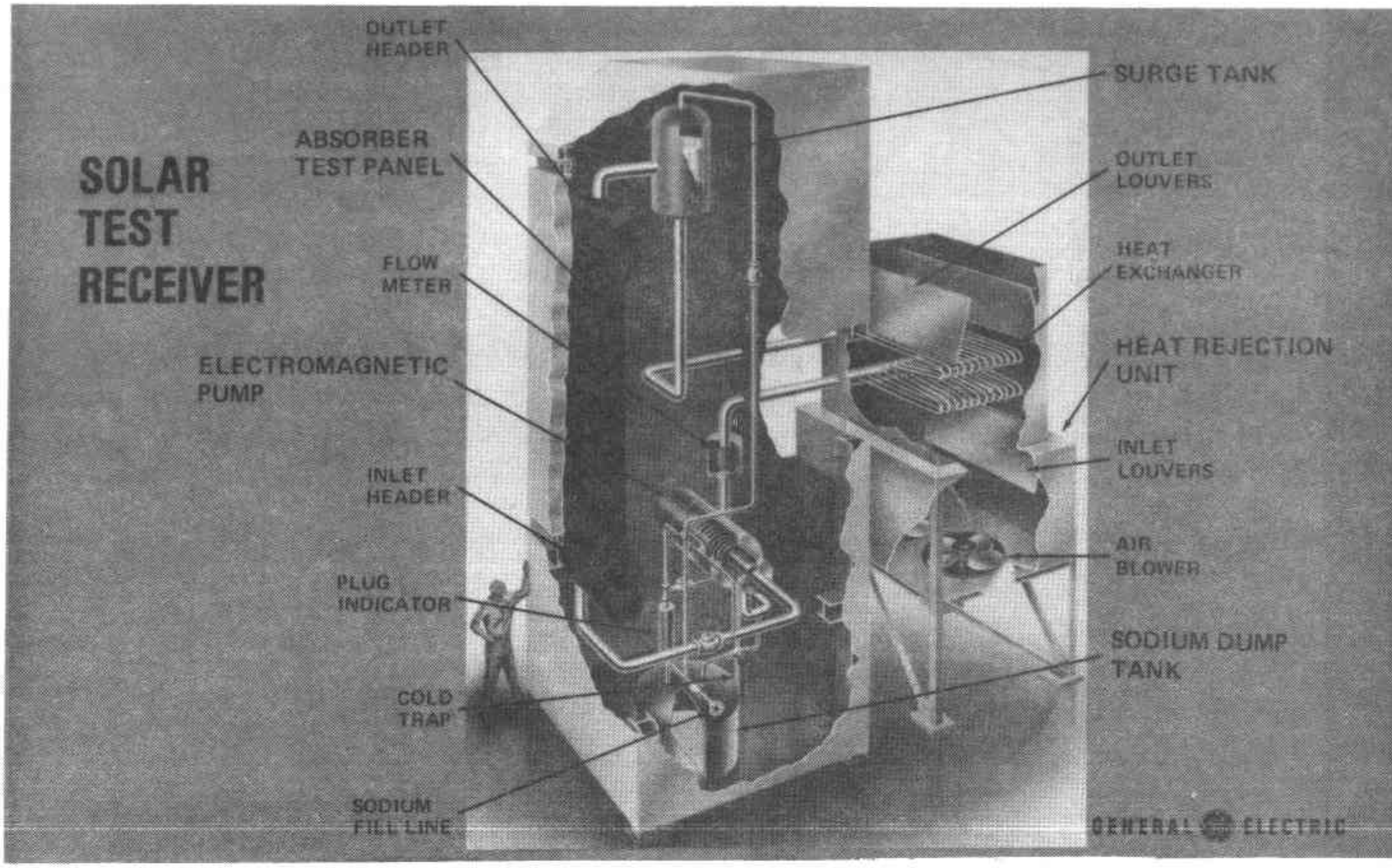
MASTER CONTROL SUBSYSTEM
• Design: Distributed Control Loops with Supervision By Redundant CPU Master Control System

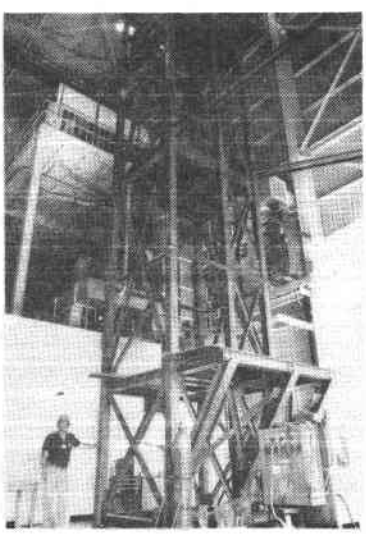
RECEIVER DEVELOPMENT

The sodium cooled receiver is the only plant element not yet demonstrated either in actual operation or in test. However, at the current time, the General Electric Company under the Alternate Central Receiver Power System Program, Sandia Contract No. 83-7550, is preparing a sodium cooled test receiver to be tested at CRTF in early 1981. The receiver concept presented in this report is an evolution from the test receiver and has been updated to incorporate the lessons learned from component fabrication.

The 2.5 MWth test receiver contains a single receiver panel and the necessary sodium components to complete a closed loop. An electromagnetic pump provides flow control and several sodium valves are included in the test loop. The test panel will be subjected to heat fluxes similar to those expected on the repowering receiver and will be operated at the maximum expected sodium temperature of 593°C (1100°F). Test loop control methodology will be prototypical of the repowering receiver.

The receiver test will be an adequate demonstration of the repowering receiver design. The close interaction of the receiver test program and the repowering design project has resulted in a timely, effective receiver development program. The test receiver is sufficiently prototypical of the repowering design that additional large scale testing will not be necessary prior to full-scale use on the solar repowering demonstration power plant.

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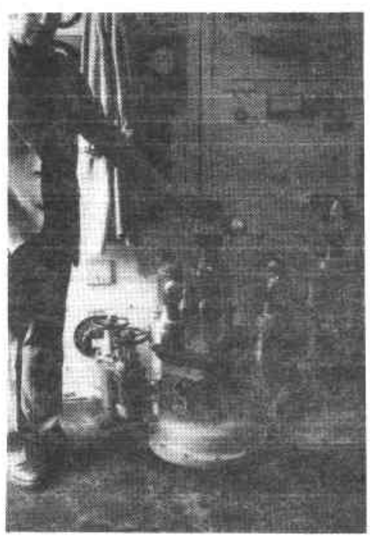
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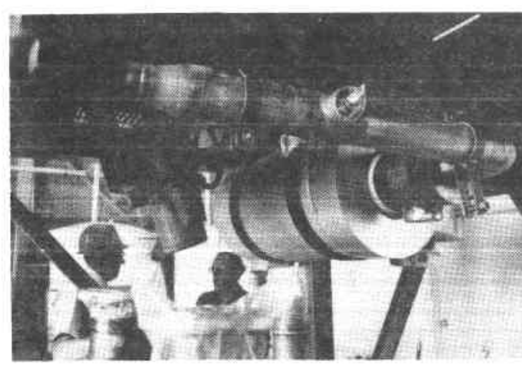
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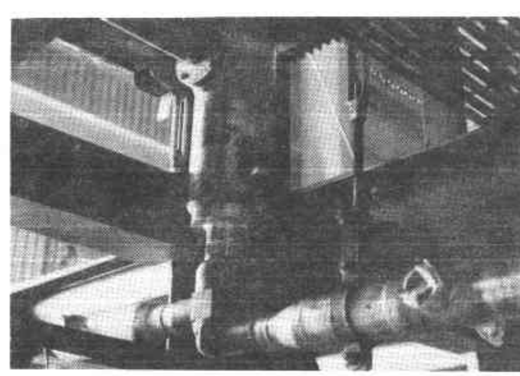
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1 TEST RECEIVER STRUCTURE SHOWING FRONT FACE

2 TEST RECEIVER SODIUM VALVES

3 EM PUMP MOUNTED IN TEST RECEIVER

4 MOTOR OPERATED 2" SODIUM VALVE IN TEST RECEIVER PUMP OUTLET LEG

During the course of the year, the solar plant will operate either in the hybrid mode or the solar-alone mode, depending upon utility dispatch requirements. Design calculations, to size solar equipment, were based on hybrid operation which results in slightly higher operational power levels.

At the noon equinox design point, the solar portion of the plant will contribute 57 MWe to the total plant output of 100 MWe. This output, representing a solar plant design point efficiency of 25.7%, was calculated using a clear day insolation level of 940 W/M^2, the value measured at a monitoring station eight miles from the plant site. The system losses were established through detailed calculations of the performance of individual subsystems and components.

Assuming constant operation in the hybrid mode for a full year, the average annual solar plant efficiency would be 20.2%, based on an hour by hour assessment of plant performance, including weathering effects. The performance of all individual subsystems and major components was determined as a function of appropriate time dependent variables such as sun position, wind speed, temperature, and plant power level. Hourly insolation and weather data based on local measurements were used in the Sandia-developed performance analysis code STEAEC, together with the subsystem and component performance data. The code determined hourly solar output for a reference year.

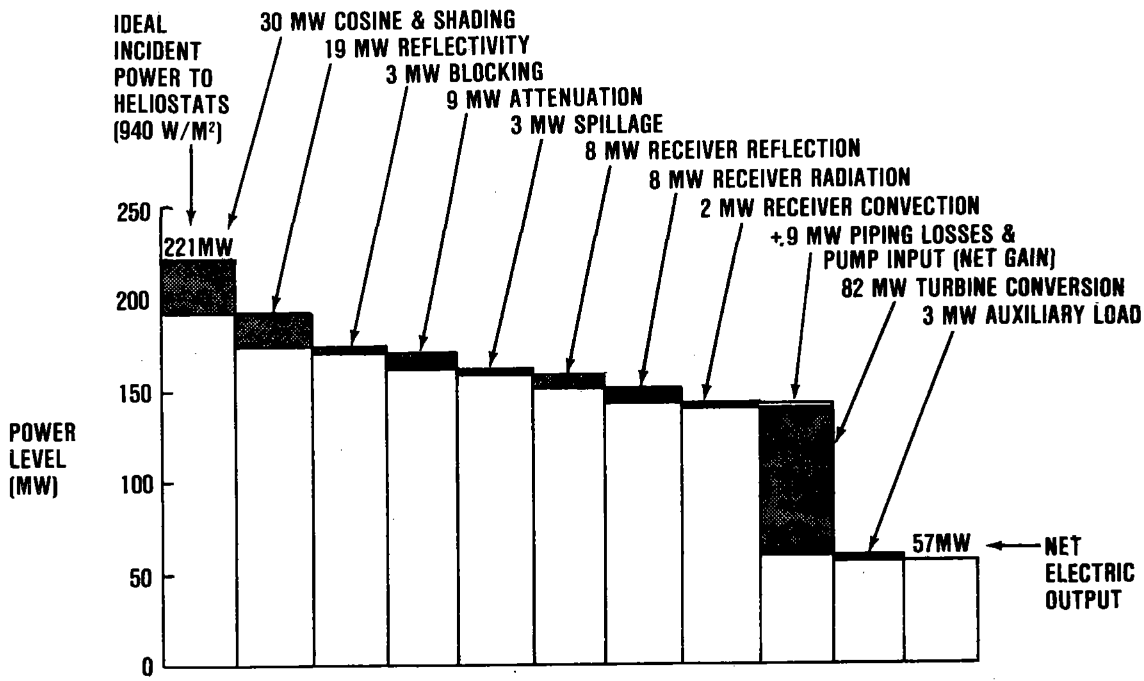
If the plant is operating in the solar-alone mode at noon equinox, the maximum power output will decrease about 1% to 56.5 MWe. This results from lower turbine efficiencies at partial load operating conditions. Assuming the plant operates for a full year in the solar-alone mode, the annual plant efficiency drops to 18%.

In actual use, annual plant efficiency will be between 18 and 20.2% depending upon the dispatch requirements for the facility.

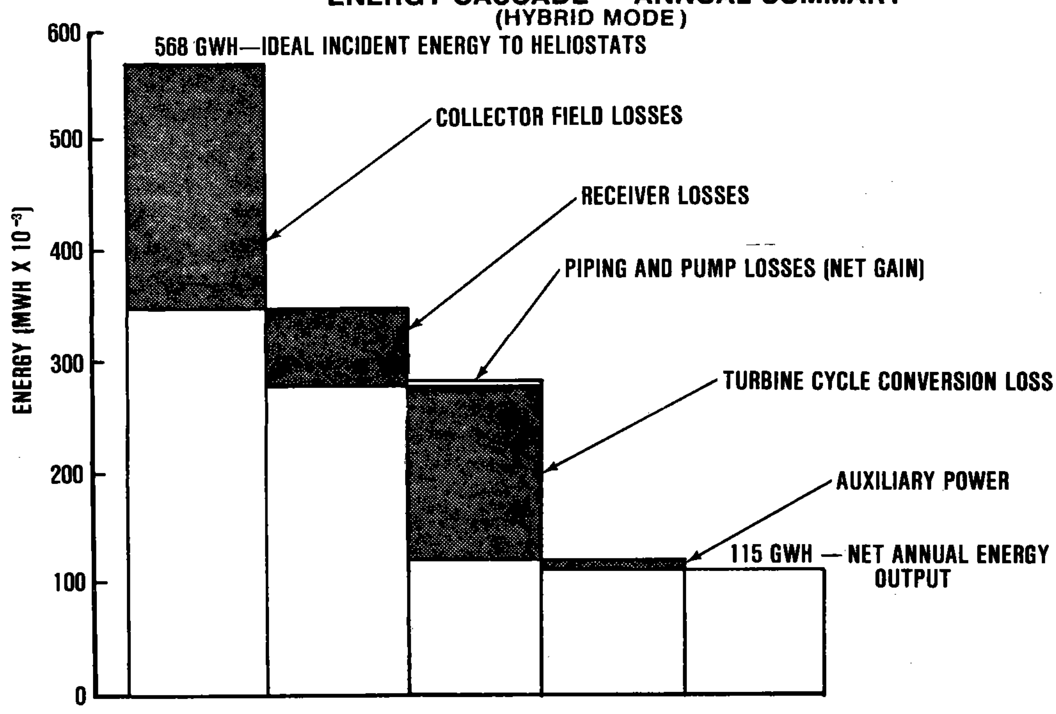
PLANT POWER OUTPUT AND EFFICIENCY

	Net Power Output (MWe)			Solar Plant Efficiency (%)	
Mode of Operation	Fossil Boiler	Solar Plant	Combined Output	Peak	Annual Average
Hybrid	43	57	100	25.7	20.2
Stand Alone	0	56.5	56.5	25.5	18.0

POWER CASCADE
(HYBRID MODE, DESIGN POINT)



ENERGY CASCADE — ANNUAL SUMMARY
(HYBRID MODE)



Plant Costs

The total estimated capital cost of the Solar Repowering Plant is $116 million, in 1980 dollars. This includes all costs associated with design, construction, test, and integration into Unit #3 at Plant X. The major uncertainty in the cost of the power plant is the collector subsystem, which is estimated to be $56.7M. It was assumed in the cost analysis that heliostats would be available at $230/m^2, installed (in 1980 dollars).

The owner's cost of $989,000 includes the site owner's expenses related to the plant construction. These include, for example, costs for items such as environmental assessment studies, licensing and permits, taxes, and insurance.

Southwestern plans to lead the design and construction of the Solar Repowering Plant, eliminating the need for the services of the architect-engineer normally required for such projects. This is the normal procedure followed by Southwestern for the design and construction of power plant additions to its service area. The cost savings to the repowering project using this approach are estimated to be between 10 and 20 million dollars.

A significant portion of the existing plant modification costs and all the indirect project costs were estimated by Southwestern. The design and engineering, home office, and construction management costs were taken from actual Southwestern construction experience but were substantially increased due to the engineering uncertainty inherent in this type project. The contingency figure was arrived at by the same method. Southwestern supplied actual union craft rates effective at Company construction sites.

To cover the uncertainties in the cost estimate, and to be conservative, a 15% contingency ($7.6M) was added to all elements of the project (with the exception of the collector subsystem, since the $230/m^2 estimate contains its own contingency).

Southwestern has reviewed the plant cost estimate in detail. It is Southwestern's opinion that the cost estimates are realistic for this type of study.

PLANT CAPITAL COSTS

(1980 DOLLARS)

Cost Element	Cost (Thousands)
Site Improvements	$ 3,627
Site Facilities	3,130
Collector Subsystem	56,697
Receiver Subsystem (Includes Steam Generators)	34,083
Control Subsystem	3,893
Fossil Energy Subsystem	1,392
Energy Storage Subsystem	1,721
Electrical Power Generating Subsystem	2,066
Miscellaneous Items	752
Owner's Cost	989
Contingency	7,600
Total Cost	$115,950

In general, the value of a solar repowering plant will depend upon many factors including the quantity and cost of fossil fuel displaced by operation of the solar plant, the operation and maintenance costs, which tend to offset the fuel savings, the capacity credit which can be attributed to the solar plant, and major economic assumptions. All of these factors are site specific. The value of the solar repowering demonstration plant to Southwestern was determined from a detailed solar plant performance model to determine fuel displacement and from economic assumptions provided by Southwestern.

FUEL DISPLACEMENT

The net annual electric energy produced by the solar plant is 114,745 MWh, which is equivalent to 200,000 barrels of oil. Initially, this output displaces mostly gas or synfuel. However, as Southwestern begins to retire gas plants and to expand generating capacity with coal plant additions, the solar plant will increasingly displace coal. In the first year of operation, 78% of the solar plant output displaces gas or synfuel; by 1996, 56% of the output will be displacing coal. Based on realistic dispatch scenarios over the life of the plant, solar energy will displace over 15 billion cubic feet of gas and 769,000 tons of coal.

SOLAR PLANT TOTAL FOSSIL FUEL DISPLACEMENT

- Gas - 15 Billion Cubic Feet
- Coal - 769,000 Tons
- Savings - $41M (levelized)

The determination of the actual fuel displacement was based on a detailed hour-by-hour analysis of the Southwestern system. General Electric's Electric Utility Systems Engineering Department utilized complex computer simulation codes to model the utility system using Southwestern projections of capacity, demand, and generation mix. The technique is identical to those used by utilities in general for assessing the implications of installing other generation types. The resulting projections of life-time fuel savings are thus quite realistic.

By utilizing several of their own existing computer codes, Southwestern has independently confirmed that the fuel savings calculated by General Electric can be achieved under the given assumptions.

SOLAR PLANT OPERATION AND MAINTENANCE COSTS

Operating and maintenance costs include such items as the costs for operating personnel, spare equipment, and maintenance labor. During the first year of operation, an operating and staff crew of 13 personnel will be required. In subsequent years, however, a much smaller crew (8 personnel) will be needed to operate the plant.

OPERATION AND MAINTENANCE COSTS

(1980 DOLLARS)

	Crew Size	Annual Cost (Thousands)
First Year	13	$892
Subsequent Years	8	$650

BASE CASE VALUE ANALYSIS

A value analysis of the Solar Repowering Demonstration Plant was performed using realistic economic assumptions provided by Southwestern. Coal and natural gas costs were assumed to escalate at 2% above general inflation (which was taken as 8%) over the life of the plant. The discount and fixed charge rates consistent with this general inflation level are 13.2% and 14.9% respectively. Since the Plant X, Unit 3 fossil boiler will probably remain operational throughout the life of the solar plant, the solar portion will not receive a capacity credit. The levelized cost savings for the displaced 15 billion cubic feet of gas and 769,000 tons of coal is $41 M, or $730/kW (in 1980 dollars). Offsetting this substantial savings are the plant operation and maintenance costs, estimated to be $160/kW. The total value of the demonstration project is $570/kW.

ASSUMPTIONS FOR THE VALUE ANALYSIS
(BASE CASE)

Solar Plant Life	- 30 years
Investment Tax Credit	- 10%
Discount Rate	- 13.2%
Fixed Charge Rate	- 14.9%
Fuel Costs (1980$):	
Coal	- $1.90/MBTU
Gas	- $1.95-2.82/MBTU
Fuel Price Escalation Above Inflation	- 2%
Fossil Boiler Availability	- Life of the Solar Plant

Given the assumptions on fuel escalation, load growth, construction, and expansion plans along with the economic parameters utilized, Southwestern agrees that the performance modeling and economic analysis of the base case is accurate and attainable.

ALTERNATIVE CASE

An alternative case was evaluated to examine the impact of changing fuel price escalation relative to inflation (which was constant in base case). Gas prices were assumed to reach oil prices by 1990, and fuel prices were assumed to escalate at 2% above inflation until year 2000, and then increase at a rate equal to inflation. This scenario was selected because it is anticipated that (1) prior to year 2000, the high desirability of gas, coupled with deregulation, will cause the price of gas to escalate faster than other, less attractive, fossil fuels such as coal, and (2) by the year 2000 alternative energy sources will greatly reduce or eliminate excessive fossil fuel cost increases. Under these assumptions, the plant value increases to $750/kW.

IMPACT OF BOILER RETIREMENT

Some utilities may assign a capacity credit to the solar repowering plant after the fossil boiler is retired, since it would contribute some amount toward peak load reliability. An analysis was performed on the Southwestern solar repowering plant to assess the magnitude of this credit, using the same performance and economic assumptions as the base case. If the boiler is retired in 1995, the solar plant capacity credit would be $100/kW (in 1980 dollars) and could be significantly higher with earlier retirement. The total value of the solar plant would then be $850/kW.

SOLAR PLANT VALUE
$/kW, 1980 dollars

Item	Base Case	Alternate Case	Retired Boiler
Capacity Credit	0	0	100
Fuel Savings	730	910	910
O&M	-160	-160	-160
TOTAL	570	750	850

Value Discussion

A number of factors have been identified which have affected the value of the Solar Repowering Plant. The more important factors are summarized below.

1. Displaced Fuel

The Plant X, Unit 3 solar facility displaces a high percentage of coal over the plant life. If Southwestern's program for replacing gas capacity with coal is delayed, the solar plant will displace more gas and less coal resulting in higher value. The same value increase would occur on a utility system with a less ambitious coal capacity addition program.

Only two areas affecting possible fuel displacement accuracy have not been addressed in the analysis. First, no contractual factors regarding natural gas have been included in the model. Under current contracts, Southwestern is required to pay for a certain amount of gas whether or not it is used. This "take or pay" system can adversely affect a strict economic dispatch approach to analysis. The potential effect of this factor is not considered significant since several gas contracts will be renewed before the solar plant goes on line, thus making contract adjustments possible.

A second factor not included in the analysis was the impact of the Fuel Use Act which requires curtailment of natural gas use. Omission of this factor was justified under the assumption that synfuel will be available as a replacement fuel for the gas-fired units.

2. Fuel Escalation

The plant value is sensitive to the difference in fuel inflation rate and general inflation rate. The faster fuel costs escalate relative to general inflation the higher the solar plant value will be.

The plant value is not significantly affected by the general inflation level since the levelizing factors used to predict both the lifetime fuel savings and the fixed charge rate used to capitalize the fuel savings are similarly affected by the general inflation rate.

3. Insolation Level

The solar plant output is proportional to the hours and intensity of solar insolation. Areas with higher insolation will have higher plant values assuming the same economic and utility system parameters.

4. Investment Tax Credit

Investor-owned utilities are limited to a 10% investment tax credit for solar installations. An increase in investment tax credit to the level available to industry (25%) would significantly reduce the fixed charge rate, thus increasing plant value.

5. Scheduled Maintenance

The value analysis conducted for this program assumed a one-month scheduled maintenance period. Although the maintenance was scheduled for the poorest insolation month (January), it still had the effect of reducing plant capacity factor (and value) by 6%. The assumed month-long shutdown was based primarily on boiler and turbine considerations. If maintenance operations show the solar plant will not require a four-week shutdown, future plants could realize increased value by providing tie-ins to other existing turbines to recover part or all of this lost value.

6. Part Load Turbine Efficiency

The amount of energy displaced by the solar plant is directly related to the turbine efficiency. During hybrid operation the turbine will be operating at, or near, full load. During solar-alone operation, the turbine will be operating at greatly reduced load and efficiency. Since the cost of natural gas is high, and Unit No. 3 plant efficiency is relatively low compared to other power plants in the Southwestern System, economic dispatch of the plant output will result in infrequent fossil boiler operation and frequent solar-alone operation. This situation has the effect of lowering the value of the solar plant.

In future applications, consideration should be given to the solar repowering of power plants which have a high ranking in the utility system dispatch scheme. This will result in more frequent operation in the hybrid mode and an increase in solar plant value. As an upper limit, if the fossil portion of the output was dispatched whenever the solar plant is in operation the turbine would always be operating at peak efficiency, and a 10% increase in capacity factor and plant value could be expected over the values reported in this report.

Approximately four and one-half years will be required to complete the construction of the solar repowering plant. No further component development work is required to support the remainder of the program, which greatly reduces schedule risk. Assuming a go-ahead by June 1981, the plant will be on line by the end of 1985. Procurement of the steam generators will pace construction, and orders must be placed by early 1982. Because of the emphasis placed on the evaluation and analysis of these components during conceptual design, detailed specifications will be available to support the procurement when required.

The final selection of heliostats for the project must be made and the order placed, by early 1982. Southwestern has already initiated discussions with possible heliostat vendors and evaluations are in progress. The selection of heliostats by early 1982 presents no problems.

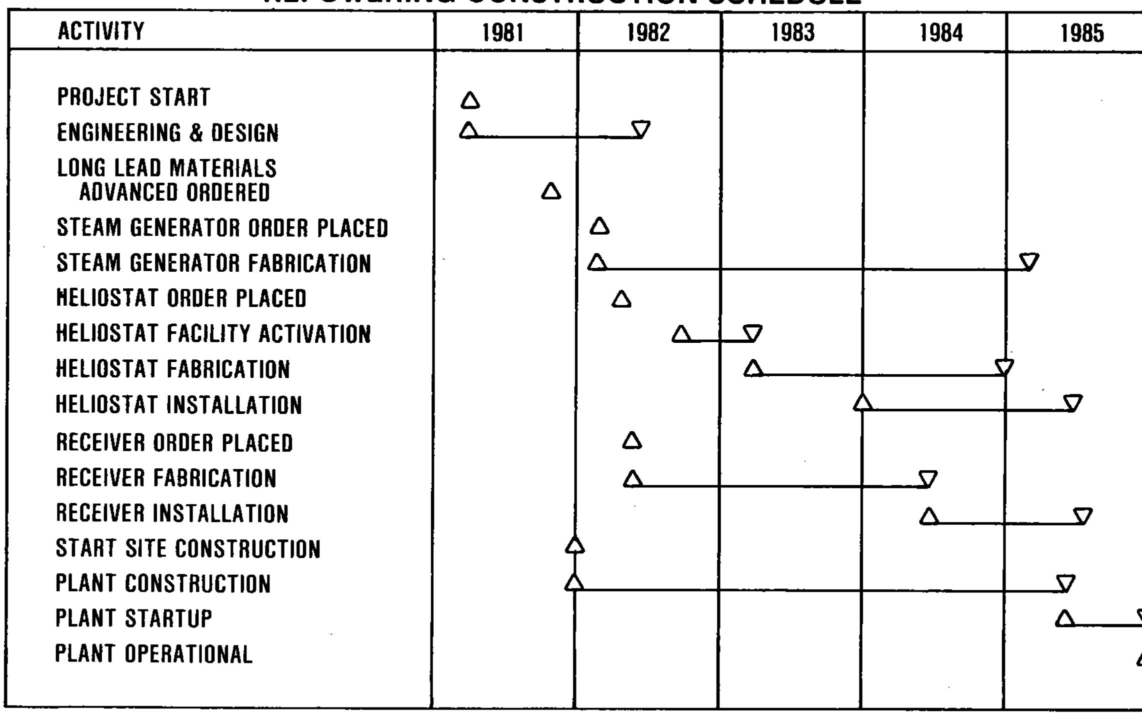
Southwestern will lead the final design and construction efforts of the program, with support from the General Electric Company in the area of solar plant engineering. Southwestern plans to perform the program with the same design and construction techniques they use for building coal-fired electric generating plants, plants which they install at costs less than the current national average. The principal cost-effective techniques Southwestern employs in the design and construction of plants include:

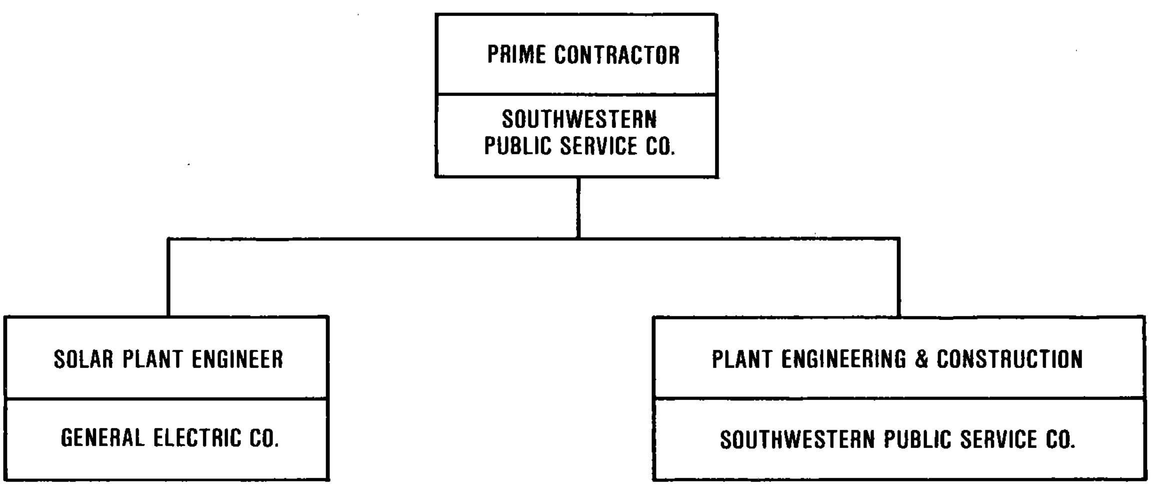
- Design, procurement, and construction in parallel when appropriate to support the schedule
- Use of their own standardized and proven procurement procedures
- Construction management by Southwestern rather than by an architect-engineer

This approach will provide DOE with a solar repowering plant at the lowest possible cost for a plant of this size.

DEVELOPMENT PLAN

REPOWERING CONSTRUCTION SCHEDULE





- RECEIVER DESIGN AND FABRICATION
- SOLAR PLANT DESIGN & SPECIFICATION
- SODIUM ENGINEERING

- PLANT CONTROLS
- COMPONENT PROCUREMENT
- PLANT ENGINEERING
- CONSTRUCTION MANAGEMENT
- OPERATIONS

Southwestern is perhaps in a better position than most utilities to review and critique the proposed design. The company is among the few electric utilities in the nation that design and supervise construction of their own generating facilities; in effect, Southwestern is its own architect and engineer consultant. Southwestern, therefore, assumed a much more active part in the actual design than most utilities would.

1. Endorsement of the Conceptual Design

Southwestern endorses the Plant X repowering study as a comprehensive conceptual design influenced by the company's engineering standards and design practices. The company considers the proposed design technically achievable requiring only engineering effort to produce a functional solar-electric generation facility.

2. Plant Cost Estimate

Southwestern participated in the development of the conceptual design cost estimate. The company believes the cost estimate presented in the repowering study is valid. Southwestern's productivity on numerous construction projects is significantly greater than the standard architect engineer productivity figures used in the cost estimate. Use of the lower productivity figure indicates the conservative approach General Electric and Southwestern applied in estimating construction cost.

3. System Performance and Economics

Southwestern used its existing computer codes and estimation methods to verify GE's system performance and economic analysis. Uncertainties such as government regulations and economic variables may affect a definitive cost estimate.

4. Value of Project to Industry

The real value of the proposed project is to demonstrate to the utility industry that solar repowering technology can be applied successfully on a commercial scale.

5. Solar Repowering Potential at Southwestern

Southwestern conducted a survey of other existing generating units in its service territory and determined it has a maximum solar repowering potential of approximately 50 percent of existing natural gas-fired capacity.

6. Safety

Southwestern does not foresee any extraordinary safety hazards associated with sodium central receiver technology. It is Southwestern's opinion that adequate safety practices and procedures exist or can be developed that would reduce hazards inherent to solar thermal facilities. The conceptual design has selected and located proper equipment to augment these safety procedures.

7. Environmental Impact

The positive benefits of new jobs and the resultant boost to the local economy outweigh the minimal adverse environmental impact of the solar installation.

8. Project Implementation

Southwestern would design and construct the solar facility in the same manner as it does any of its power plants. The company's objective is to conduct a turnkey project and meet the proposed 1985 start-up date.

9. Advantage of Repowering

The principal advantage of repowering is replacement of fossil fuel, while maintaining the capacity credit of the existing unit to overcome rising fuel costs, government regulations, and the conversion to coal-fired generation.

10. Role of Solar Repowering in Corporate Planning

Southwestern cannot at this time consider repowering as being an economically viable option because of economic and regulatory uncertainties. Southwestern's present strategy is to build coal-fired plants and utilize existing gas-fired facilities. However, if in the future solar repowering becomes economically attractive, it would be considered in Southwestern's corporate planning activities.

11. Permits

There is no significant environmental or regulatory permit requirement for repowering an existing facility. There is no local or state agency permitting or approval problem.

12. Acceptability of Central Receiver Technology for Repowering

Southwestern believes the central receiver design is particularly acceptable to repowering. The major constraint is the high cost of heliostats, which must be decreased before commercial implementation is practical.

For further information contact James A. Elsner, Manager - Central Solar Receiver Systems, General Electric Company, Building 6, Room 331, 1 River Road, Schenectady, N. Y. 12345; Area Code 518-385-9599.