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SOLAR REPOWERING SYSTEM FOR TEXAS ELECTRIC SERVICE COMPANY, PERMIAN BASIN STEAM ELECTRIC STATION UNIT NO. 5, FINAL REPORT

Executive Summary

July 15, 1980

Work Performed Under Contract No. AC03-79SF10607

Rockwell International Corporation
Energy Systems Group
Canoga Park, California

U.S. Department of Energy

Solar Energy

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Price: Paper Copy $6.00
Microfiche $3.50

ESG-80-22

DOE/SF/10607-1/1
Distribution Category UC-62

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FOR
TEXAS ELECTRIC SERVICE COMPANY
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PREFACE

This summary is submitted by the Rockwell International Energy Systems Group to the Department of Energy under Contract DE-AC03-79SF10607 as final documentation. It summarizes the analyses, design, planning, and costing activities performed between September 27, 1979, and July 15, 1980. The full report is available under separate cover, and consists of the following three major sections:

Executive Summary	Section 1
Solar Repowering Conceptual Design	Sections 2-7
Appendices	

The participants supporting Rockwell International's Energy Systems Group in this conceptual design effort and their main areas of responsibility are: Texas Electric Service Company, the utility partner; McDonnell Douglas Aircraft Corporation, responsible for the Collector Subsystem; Stearns-Roger Services, Inc., responsible for the Electric Power Generating Subsystem, Fossil Energy Subsystem, Tower Design, and Civil Engineering; and The University of Houston, responsible for Collector Field Optimization Studies. Personnel contributing to this design program and to the final report included:

Energy Systems Group - T. H. Springer, Project Manager; T. L. Johnson, Project Engineer; W. W. Willcox, System Engineer; J. Ives, Lead Engineer, Steam Generator Components; S. Lee, Lead Engineer, Master Control Subsystem

Texas Electric Service Company - G. A. Clary, Project Coordinator; J. E. Allison, Project Manager

McDonnell Douglas Aircraft Corporation - D. A. Carey, Project Engineer

University of Houston - L. L. Vant-Hull, Associate Director, Solar Energy Laboratory; M. D. Walzel, Collector Field Optimization

Stearns-Roger Services, Inc. - W. R. Lang, Project Manager; A. W. McKenzie, Principal Author

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ABSTRACT

The conceptual design and economic assessment of a sodium-cooled, solar central receiver repowering system for Texas Electric Service Company's Permian Basin Steam Electric Plant Unit No. 5 has been completed. A repowering system is one in which a central receiver tower, surrounded by a field of mirrors, is placed adjacent to an existing electric utility power plant, and supplies steam to the turbine at the same condition as that provided by the existing boiler. When sunshine is available, energy is provided from the solar system, and the amount of fuel consumed is proportionally reduced. Successful construction and operation of a repowered unit during 1985 is projected. Environmental or institutional problems associated with the construction and operation of the Permian Plant Unit No. 5 are minimal. The estimated construction cost of this project is \$111.6 x 10^6 in January 1, 1980 dollars; and the utility company's estimate of its equivalent plant investment is \$12.5 x 10^6 in January 1, 1980 dollars.

As expected, the economic assessment of the specific concept for this site indicates that the cost of energy is greater than that resulting from the burning of natural gas alone in the existing plant (principally, as a result of the current cost of heliostats and the scheduled retirement date of Unit No. 5). Favorable economics for similar types of plants can be projected for the future. The annual fuel savings are equivalent to 236,900 barrels of oil, with a total dollar value of \$21.5 x 10^6 and \$93.6 x 10^6 for a 7-year life and a 25-year life, respectively. However, it has also been found, from separate studies, that favorable interpretations of the Fuel Use Act will be necessary for this economic viability to be reached. In particular, a program to reduce the cost of heliostats to \$100/m^2 will be needed.

All sodium components, except the receiver, are available on the basis of similar-sized or larger components that have been designed, fabricated, tested, and operated in power plants for hundreds of thousands of hours. Liquid sodium has been demonstrated for use as a stable, safe, and easily contained heat transfer fluid, up to temperatures exceeding those required for modern steam plants. Some development work, already planned and underway, for the receiver component is necessary, in order to assure the performance of the receiver.

The in-service date for a repowered plant is very crucial. Utilities must plan for added power generation several years ahead of construction. Since utilities are now planning for replacement of natural-gas-fired generation in the early 1990's, the solar technology must be on-line and proven early, so that the utilities can include solar technology as an option. If the repowering program is delayed, the use of solar as a viable option will be lost.

Texas Electric Service Company has participated actively in this study, and concurs with the findings, relative to the areas of their expertise.

1.0 EXECUTIVE SUMMARY

1.1 PROJECT SUMMARY

A conceptual design study has been completed by the Rockwell International Energy Systems Group (ESG) and Texas Electric Service Company (TESCO) to repower TESCO's Permian Basin Unit No. 5. The objectives of this study are given by the following subheadings.

1.1.1 Provide Practical and Effective Use of Solar Energy

This application is a logical step in developing the solar central receiver concept as a viable alternative thermal energy source for utilities to displace natural gas and oil usage. A nominal thermal power level of 160 MWt (giving 50 MWe gross, plus 1 h of storage) established in this study is a modest scale factor of 4 times the size of the Barstow plant. From this plant to a commercial-sized plant of 100 to 200 MWe would require an additional modest scale factor of 2X to 4X.

The subject 50-MWe size is sufficiently large to give meaningful experience for a solar plant as part of a utility grid. Yet the size is sufficiently small, in comparison with TESCO's grid, so that significant grid instabilities will not result because of weather outages or other operating uncertainties that may be associated with a demonstration plant.

The Permian Basin Unit 5 requires reheat capability, and this capability is readily provided by the subject system, using liquid sodium as the heat transport fluid, at the steam conditions required by the turbine. The sodium system also simplifies the storage concept — the sensible heat storage of sodium in the hot tank feeding through the steam generators to a cold storage tank. An attendant advantage occurs, in that the steam generator system is completely buffered from the receiver, such that temperature transients induced at the receiver (e.g., due to clouds) are prevented by the storage tanks from reaching the steam generators. In addition, operation from a sodium storage system yields the same steam conditions as from direct operation, and increases overall system efficiency.

Repowering Permian Basin Unit 5 has many attractive features: (1) the technical data derived from the proposed concept will apply to a large number of existing power plants that currently use oil and gas and that employ modern steam conditions (1000°F, ~1500 psi, 1000°F reheat), (2) operational and economic data will be representative of a large area of the U.S. where the solar insolation is good, but less than ideal, (3) a good match exists between peak power demand on the utility system and solar energy availability, (4) a significant savings of natural gas and/or fuel oil is expected, (5) TESCO owns 2.5 km^2 (640 acres) of the site, and (6) the site is suitable for the collector field. The location in Texas is also appropriate, because Texas is predicted to have a rapidly growing demand for power over the next several decades.

1.1.2 Potential for Construction and Operation by 1985

The development plan in Section 1.7 shows the steps to be accomplished, leading to the construction and operation of this plant by 1985. Design activities must be initiated by mid 1981. Since the major sodium components are developed items, as identified in the following section, the delivery of these items is consistent with a startup goal of 1985.

The time period for solar repowered plants to be competitive is short. The Fuel Use Act requires, in certain instances, that utilities replace natural gas as a fuel by 1990. For solar repowering to be an option, it must be demonstrated starting in 1985, to allow for planning and construction lead times such that utilities can be confident of operation in the 1990 to 2000 time frame.

1.1.3 Make Maximum Use of Existing Technology

ESG was a prime contractor on Phase I of the DOE-sponsored program, "Conceptual Design of Advanced Central Receiver Power Systems,"[(1-1)] and on a similar program, "Solar Central Receiver Hybrid Power System."[(1-2)] The work on these two programs is directly applicable to the repowering concept, and provides the basis for the repowering conceptual design. The McDonnell Douglas Astronautics Company (MDAC) second-generation heliostat is the reference design for this study. The Barstow Pilot Plant, when completed, will provide operating data for the heliostats, collector field, and receiver.

Sodium system technology and components are well developed, due to the considerable investment by the government in the Fast Breeder Reactor Program. Components, such as sodium pumps, steam generators, piping, and valves, have been developed, and tested in size ranges for a 50-MWe plant as well as for commercial-sized plants. The development of the receiver component, being pursued by both DOE-funded programs and by the ESG company-funded efforts, has a high probability of success.

1.1.4 Provide the Best Overall Economics

The use of a reheat steam cycle increases system efficiency, so that the collector field can be reduced in size for a given electrical output. With these increased system efficiencies inherent in a sodium system, capital costs are generally less than for a comparable water-steam system.

The plant capital cost of $111.6 x 10^6, including the design costs, is based on a summation of subsystem cost data. The subsystem cost data is developed from the extensive experience of ESG on sodium systems and nuclear power plants, TESCO and Stearns-Roger on conventional power plants and civil structures, and the McDonnell Douglas Astronautics Company on numerous heliostat production studies. This procedure gives a realistic cost estimate, compatible with a conceptual design effort.

A detailed economic analysis, performed by TESCO, employing normally used techniques, assumptions, and evaluation parameters, resulted in a levelized busbar energy cost (BBEC) of $266 mills/kWh. This cost is based upon a plant life of 7 years, which is the planned remaining life of the plant. Twenty years has been determined to be the optimum economic life for a similar repowered plant. This cost estimate is sensitive to plant startup year, a parameter which has been identified as being critical to the viability of the repowering concept. It is expected that, since this is a demonstration project, economic parity with the available conventional alternatives will not be achieved. However, with an equitable subsidy, such that the plant cost approaches the plant worth, the plant could be economically attractive.

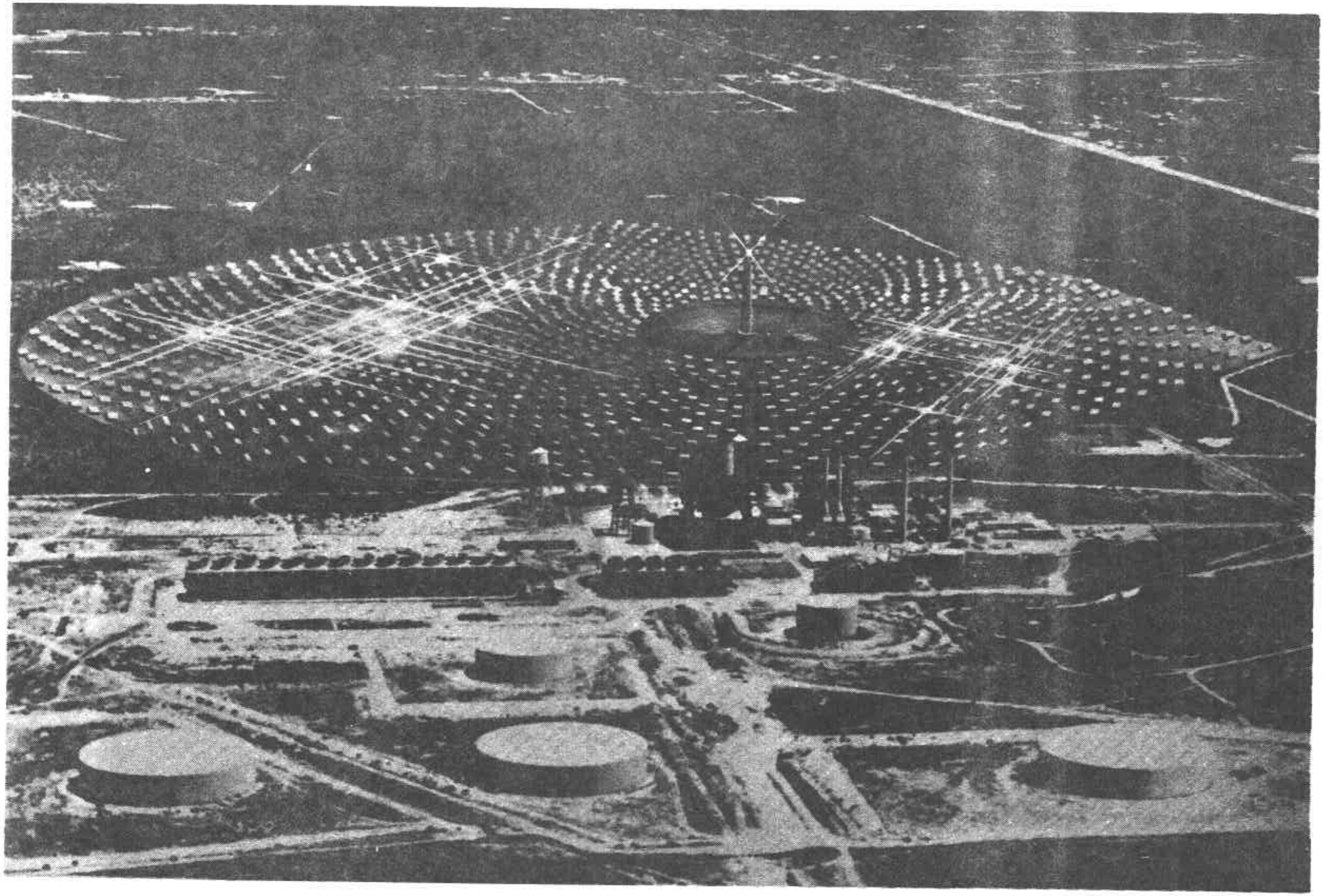

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Figure 1-1. Artist's Concept of Collector Field at Permian Basin

The substantial subsidies currently needed initially for solar repowering will likely decrease with time, as heliostat costs are reduced and fuel costs increase; so that solar plants may be competitive for peaking applications at some time in the future.

1.2 BACKGROUND

The technical approach used in this study consisted of establishing a reference design, and performing trade study variations of that design, to meet cost, performance, site requirements, and objectives as identified in the previous section.

Major trade studies were conducted to select the solar power level, storage capacity, plant layout arrangement, collector field size and configuration, tower height, tower design, and storage tank configuration. These studies resulted in the selection of a solar system with a thermal power level equivalent to 50-MWe gross, and a storage system capacity with 1-h duration at the 50-MWe power level. With solar plant size and storage capacity selected, a conceptual design study was performed in sufficient depth to allow repowered plant performance and cost estimates to be made. These estimates, in turn, provided the basis for the economic evaluations of the repowered plant. A development plan was prepared which shows the design, procurement, and construction activities which must be accomplished in order to have a solar repowered plant in operation by 1985.

The solar central receiver system consists of a receiver absorber surface mounted on a tower which is surrounded by a field of heliostats (mirrors), such as shown in Figure 1-1. As the heliostats track the sun, the solar radiation is reflected by the mirror surfaces to the receiver on the tower. Solar energy, in the form of heat, is absorbed by the liquid sodium flowing through the receiver. Liquid sodium, an excellent heat transfer fluid because of its high thermal conductivity, remains liquid for the temperature range of this application. The sodium technology is well developed. The resulting system advantages from these characteristics of sodium are that: (1) the receiver is smaller and lighter in weight, (2) a single-phase fluid simplifies receiver operation, (3) reheat is readily accomplished, and (4) thermal storage is easily incorporated as tanks

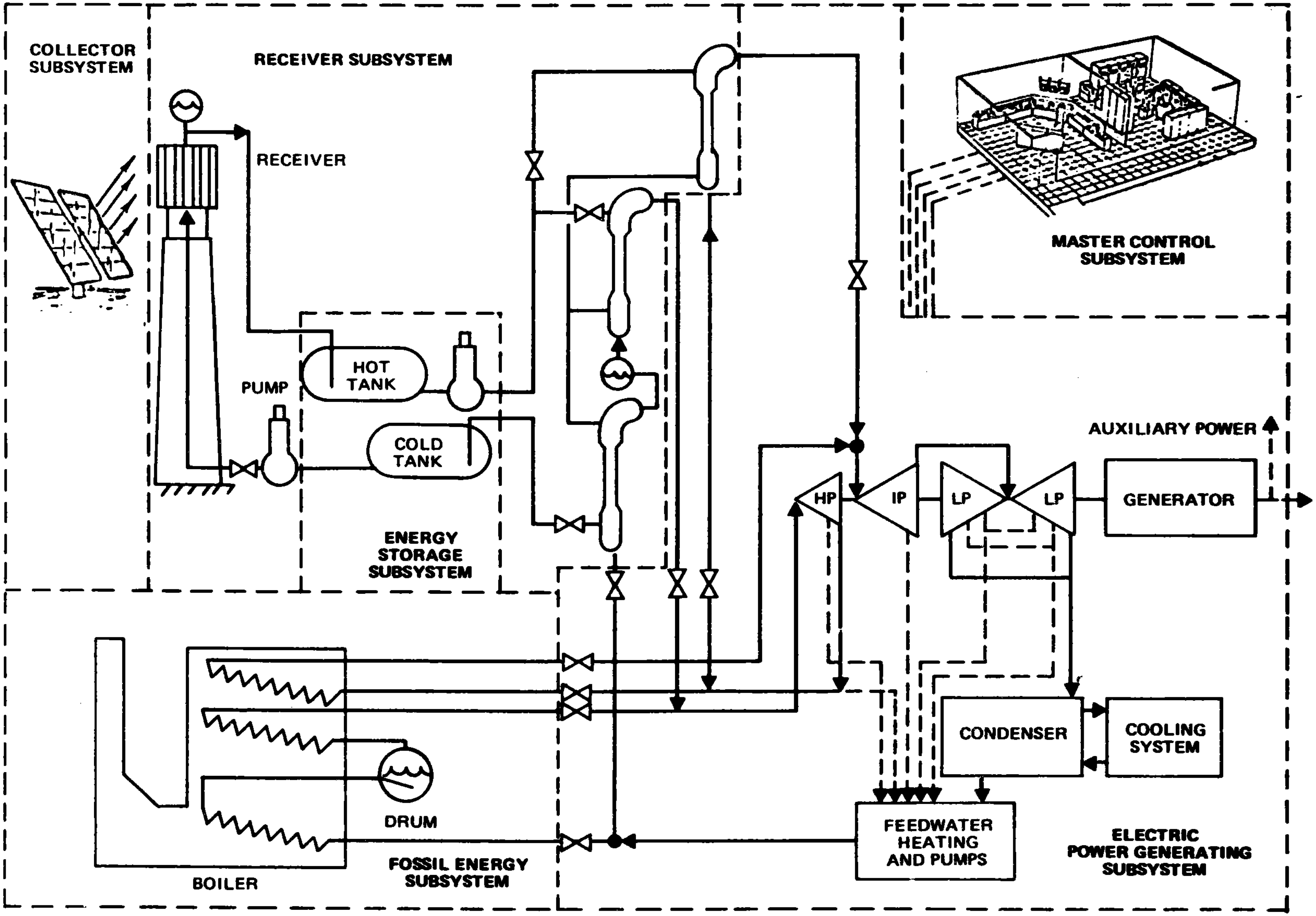

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Figure 1-2. Subsystem Integration and Process Flow Diagram containing liquid sodium. With this thermal storage concept, complete thermal buffering between the receiver and steam generator is accomplished. This condition minimizes the effects of receiver thermal transients on the steam turbine.

The solar part of the plant is integrated (Figure 1-2) into the existing plant by inserting a tee in the feedwater line, so that flow can be split between the fossil boiler and the sodium-to-water evaporator unit. The existing feedwater pumps are expected to be adequate, insofar as capacity and discharge pressure are concerned. The steam lines from the superheater and reheater are also to be cut and mixing tees installed, so that the sodium-to-steam superheater and sodium-to-steam reheater are in parallel with the comparable units in the boiler. Under full-load conditions, steam flow from the existing fossil boiler is decreased as the insolation increases, and there is a commensurate reduction in the amount of fuel being burned. A master control system is provided to integrate the instrumentation and control elements of the solar and the fossil energy systems.

A summary of the major results of this study are included in Section 1.0. Details of the study, with extensive discussion and analysis, are presented in Sections 2 through 7. Appendices A, B, and C include the System Requirements Specification for the Repowered Permian Basin Plant, Design Data Sheets, the cost details, and solar insolation data collected at the Permian Basin site. The team members assisting in this study are identified in the preface.

1.3 SITE DESCRIPTION

The Permian Basin Steam Electric Station is located 6.5 km (4 miles) west of Monahans, Texas, in Ward County. Of the section of land [2.5 km^2 (640 acres)] owned by the Texas Electric Service Company, ~0.65 km^2 (160 acres) are occupied by the current facility, and 1.63 km^2 (400 acres) are brush-covered and unused, except for several oil wells (Figure 1-3). The property is at an elevation of 808.8 m (2653.5 ft) with a gentle slope to the southeast. The neighboring property is also brush-covered and unused, except for occasional oil or gas wells. The station consists of six units. Unit 5, which is a candidate for repowering, is a 115-MWe intermediate-load power plant with reheat, using natural gas with fuel

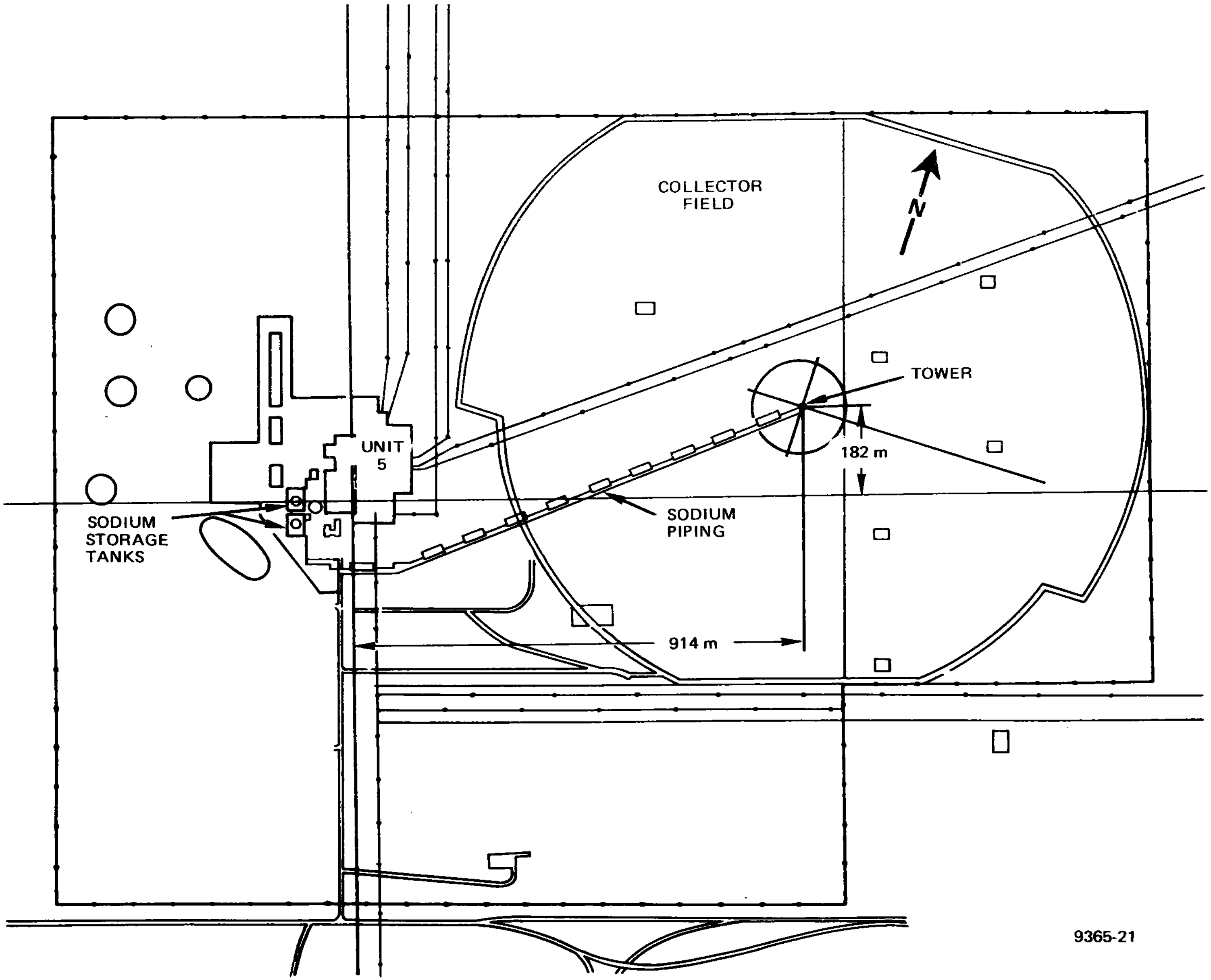

Figure 1-3. Site Plan Solar Repowering Conceptual Design

oil as a backup. Unit 5 went into operation in 1958. Units 1 through 4 are older, small 12-MWe plants available for peaking loads. Unit 6 is a 550-MWe baseload plant. The nearest official weather station is at the Midland-Odessa Airport, ~80.5 km (50 miles) to the east of the plant site. Percent possible sunshine at the site is 77%. Annual solar insolation is indicated to be 2520 kWh/m^2. Average yearly precipitation is 0.34 m (13.5 in.), which includes 0.09 m (3.5 in.) of snowfall. The temperature range over the year is from -22.7°C (-8°F) to 42.8°C (109°F). The wind speed is between 1.79 m/s (4 mph) and 8.05 m/s (18 mph), 86% of the time.

1.4 CONCEPTUAL DESIGN DESCRIPTION

In this conceptual design, the Permian Basin Steam Electric Power Station Unit 5 is repowered with a solar system with thermal capacity to provide 50-MW gross electric energy and a storage capacity with energy for 1 h of operation at 50-MWe gross. This power level is ~43% of the gross rated power of 115 MWe of the existing steam boiler. A conceptual design summary is presented in Table 1-1.

The flow configuration is shown in Figure 1-4. Sodium is pumped at 550°F to the top of the tower and through the receiver, from which it exits at a temperature of ~1100°F. The receiver is of the external type, 10.6 m (34.8 ft) in diameter by 13.5 m (44.3 ft) high, and is located on top of a 110 m (360.9 ft) tower. The hot sodium coming from the receiver is allowed to flow through a pressure-reducing device and then into a hot storage tank, which contains 1.2×10^6 kg (2.6×10^6 lb) of sodium when fully charged -- enough sodium to permit operation for a period of 1 h with no solar insolation. The sodium is pumped from the hot storage tank through a set of three steam generator units (an evaporator, a superheater, and a reheater), and then into a cold storage tank. From this tank, which is the same size as the hot tank, the sodium is again pumped to the top of the tower, thus completing the circuit. With this configuration, the hot storage tank provides complete buffering between the receiver and the steam generator units, so that transients at the receiver due to clouds are isolated from the steam generator units. This simplifies the design of the steam generator units.

TABLE 1-1

CONCEPTUAL DESIGN SUMMARY

Prime Contractor:	Rockwell International Corporation Energy Systems Group 8900 DeSoto Avenue Canoga Park, California 91304	Total Cost:	$\$111.6 \times 10^6$ $\$106 \times 10^6$ with heliostats at $\$230/m^2$
		Construction Time:	4 years
Uility Partner:	Texas Electric Service Company Post Office Box 970 Fort Worth, Texas 76101	Solar Plant Power Contribution at Design Point:	50-MWe gross
Subcontractors:	Stearns-Roger Service, Inc., Electric Power Generator System, Tower and Storage Tanks; McDonnell Douglas Astronautics Company, Collector Field Studies; University of Houston, Collector Field Optimization	Solar Fraction Annual:	28% (49% Capacity Factor)
		Annual Energy Produced:	355.5×10^3 MWh(t)
		Annual Fossil Energy Saved:	236,900 bbl equivalent (5.8×10^6 Btu/bbl)
Site Process:	Solar-generated and/or fossil-generated steam supplied to turbine at 538°C (1000°F), main steam at 10,100 kPa (1465 psig) and 538°C (1000°F), reheat steam at 3100 kPa (450 psig). The Westinghouse turbine is a tandem-compound, double-side exhaust, 3600 rpm, reheat condensing type, manufactured in 1958.	Annual Cost Savings:	$\$3.178 \times 10^6$, based on 7-year service life
		Type of Fuel Displaced:	Natural gas
		Ratio of $\frac{\text{Annual Energy Produced}}{\text{Total Heliostat Field Area}} = \frac{355.5 \times 10^3 \text{ MWh(t)}}{264 \times 10^3} = 1346 \text{ MWh(t)/m}^2$	
Site Location:	Permian Basin Steam Electric Station is located 6.5 km (4 miles) west of Monahans, Texas, at 31° 35' N, 102° 58' W.	Ratio of $\frac{\text{Capital Cost}}{\text{Annual Fuel Displaced}} = \frac{111.6 \times 10^6}{355.5 \times 10^3} = \$313.9/\text{MWh(t)}$	
Design Point:	Equinox noon. Receiver absorbed power of 158.5 MWt, steam generator power of 123.6 MWt, equivalent to 50-MWe gross.	Site Insolation (direct normal)	
		Annual Average:	2520 kWh/m^2
		Source:	University of Houston analysis with weather data from Climate Atlas for Abilene, Amarillo, Midlands, and Roswell
Receiver:	Fluid: liquid sodium Configuration: external Type: forced circulation, single pass Elements: 18-panel heater Outlet temperature: 593°C (1100°F) Outlet pressure: 69.0 kPa (10 psig)	Site Measurement:	Epply pyrheliometer, April 1980 to June 1980
Heliostats:	Number: 4742 Mirror area: 56.42 m^2/heliostat Cost: $\$260/m^2$ Type: MDAC second generation, modified Field configuration: surround		
Storage:	Duration: 1 h Media: liquid sodium		

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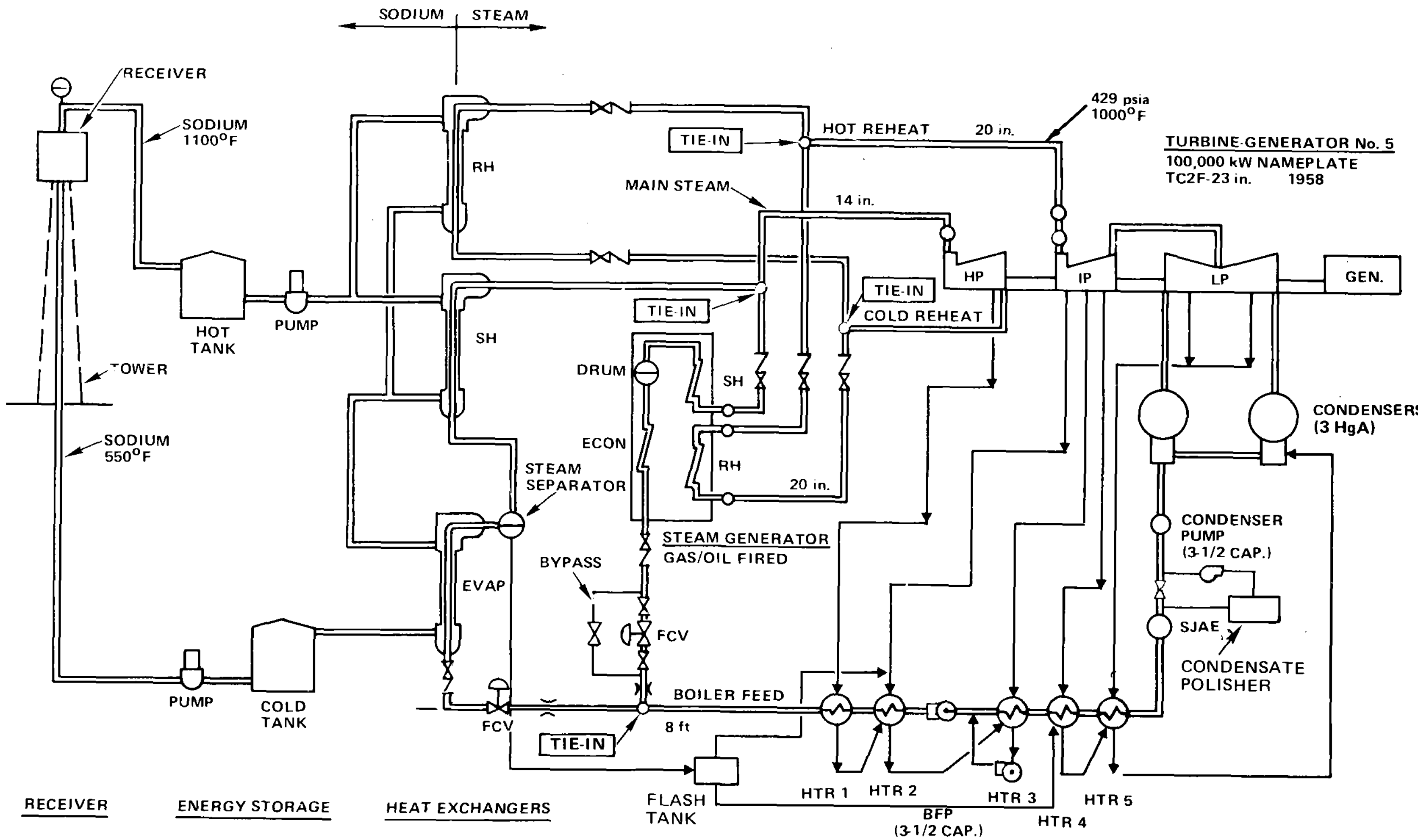

Figure 1-4. Flow Configuration — Solar Repowering Conceptual Design

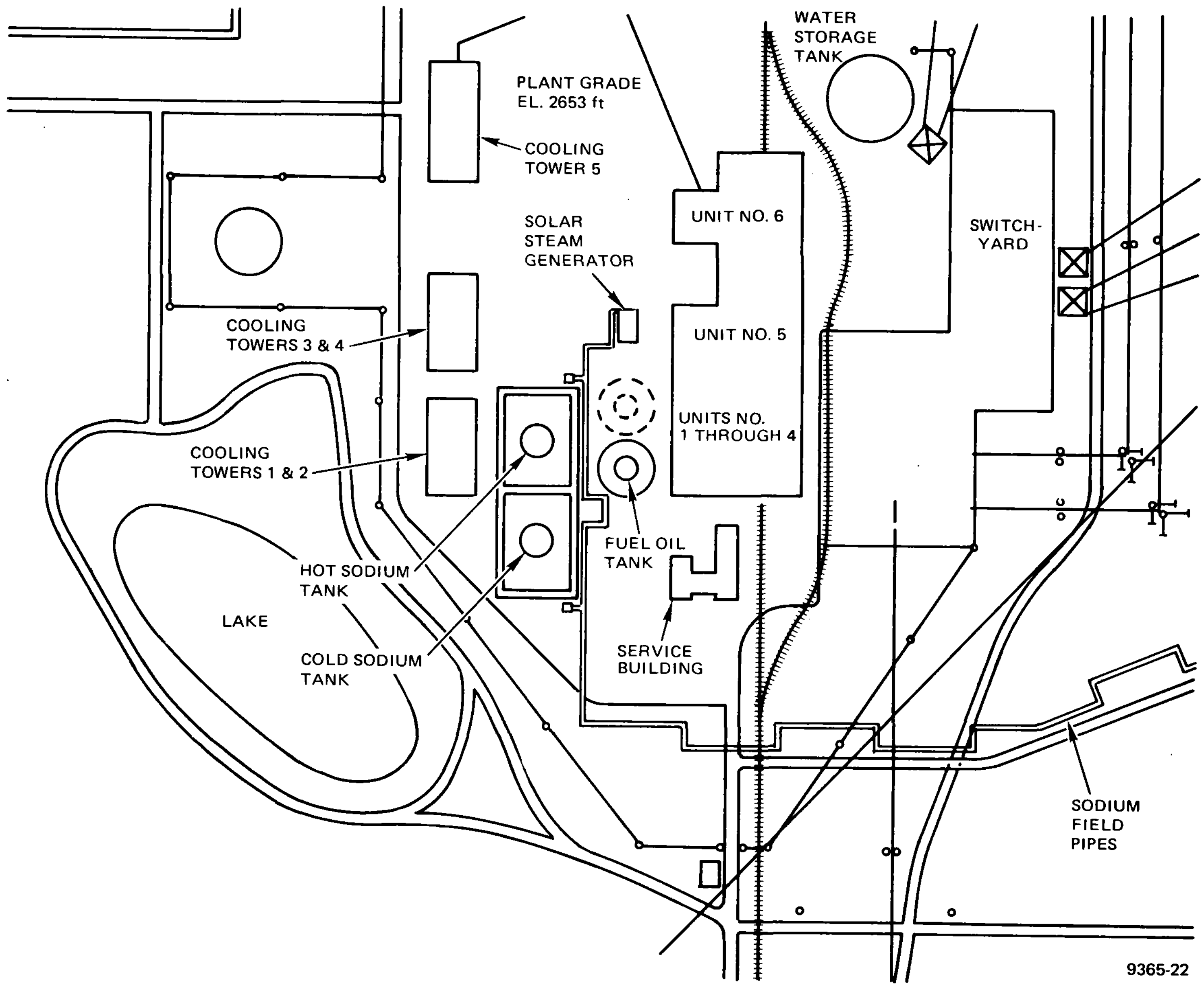

Figure 1-5. Plant Layout

The collector subsystem consists of a surround field containing 4742 heliostats on an area of 1.3 km^2 (322 acres). The collector field is sized for a solar multiple* of 1.23. This design was selected to give a significant solar fraction of 28% and a solar power level such that the power level for the fossil system, including a small control margin, would not be <30%. The solar system will be operated to maximize the use of solar energy. Load-following variations will be provided either by the fossil system or by other units on the grid.

The plant design characteristics are shown by the plant layout, Figure 1-5. The layout shows the steam generators located directly to the west of Unit 5, and the hot and cold storage tanks located to the southwest of Unit 5. This arrangement shows an economic advantage over other arrangements, and also enhances solar steam generator control by coupling the hot storage tank and pump closely to the steam generators.

The main advantage in locating two sodium storage tanks near each other is to reduce the length of the argon cover gas vent between the tanks. This 25.4-cm (10-in.) line permits the interchange of a large quantity of cover gas as the tanks are filled and drained daily.

1.5 SYSTEM PERFORMANCE

A summary of repowered plant parameters is given in Table 1-2.

System power and energy output are summarized in Table 1-3 for the solar-only and for combined modes of operation, for both the design point operation and the annual average.

The net power output for the solar-only mode is reduced to 44,400 kWe, since the entire house electric load is supplied by the solar system, rather than sharing the house load, as for the combined mode. During solar-only operation, the turbine heat rate is increased, due to operation at 43% of the turbine design point which reduces the annual output for this mode.

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*Solar multiple is defined as the thermal power from the receiver, after downcomer ans piping losses, divided by solar thermal power input to the turbine.

TABLE 1-2

BASELINE SOLAR SYSTEM

SUMMARY OF PLANT PARAMETERS

System	Parameter	Selected Design Parameter
Electric	Gross Power (MWe)	50
	Cycle Efficiency (%)	40.0
Receiver	Solar Multiplier (SM)	1.23
	Thermal Power (MWt)	
	Nominal	129.6
	Maximum (Design Goal)	160.0
	Receiver Fluid Temperature [^{o}C (^{o}F)]	
	In	288 (550)
	Out	593 (1100)
	Receiver Midpoint Elevation [m (ft)]	124 (407)
Storage	Operating Time (h)	1.0
	Energy [MWh(t)]	128.3
	Quantity [10^6 kg (10^6 lb)]	1.18 (2.6)
Electric Power Generation	Turbine Inlet Pressure [kPa (psia)]	10,100 (1465)
	Superheater Temperature [^{o}C (^{o}F)]	540 (1005)
	Reheat Temperature [^{o}C (^{o}F)]	540 (1005)
Collector	Mirror Area [km^2 (10^6 ft^2)]	0.268 (2.88)
	Heliostat Area (56.4 m^2/heliostat) (m^2)	4742
	Exclusion Area [km^2 (acre)]	0.1721 (42.5)
	Total Land Area [km^2 (acre)]	1.305 (322.5)

TABLE 1-3

SOLAR REPOWERED CONFIGURATION PERFORMANCE SUMMARY

Parameter	Combined Mode	Solar-Only Mode
Design Point		
Gross Plant Output (kWe)	115,000	50,000
Gross Solar Output (kWe)	50,000	50,000
Net Solar Output (kWe)	46,700	44,400
Overall Efficiency (%)	22.01	20.52
Annual Average		
Net Output [GWh(e)]	127.8	118.9
Capacity Factor (%) (115-MWe nameplate)	12.06	11.80
Natural Gas Saved (10^6 ft^3)	1,333	1,239
Fuel Oil Saved (bbl Bunker C)	218,500	203,300

The solar fraction is given in Table 1-4 for two plant-capacity (C_F) factors. While Unit 5 has, in recent years, been operating at a capacity factor of ~49%, the projected operation by TESCO is for 5% factor on fossil fuel and ~12.0% capacity factor on solar. The solar fraction increases as the capacity fraction of the fossil system decreases; and, of course, becomes 1.0 for solar-only operation. The goal of achieving a minimum solar fraction of 0.20 is reached under all expected operating conditions.

TABLE 1-4

SOLAR FRACTION - SELECTED DESIGN

	Solar Hours/Day	Solar Fraction	
		C_F = 49%	C_F = 18.5%
Winter Solstice	6.51	0.254	0.675
Equinox	9.30	0.347	0.931
Summer Solstice	11.32	0.429	1.135
Annual Average	9.27	0.278	0.736

When built, the plant will be operated such that solar energy usage will be maximized — a signal will be generated to inform the load dispatcher of solar availability. In order to maximize solar energy usage, output from other plants will be reduced, as required, to allow maximum available solar output. The following operating modes will be used:

1) Combined mode
   a) Fossil as base, solar as available
   b) Fossil and solar share load changes
2) Fossil only
3) Solar stand-alone

Daily startup of the solar portion of the plant is planned for Unit 5. The overall control philosophy adapted for this repowering application is:

1) The Master Control Subsystem integrates the operation of the combined fossil and solar system. The heliostat field and the sodium storage facilities are controlled by subsystem controllers.
2) Analog controls are utilized to control various steam and feedwater flow regulator valves.
3) The plant will be as automated as practical.
4) The plant operator is provided a manual override for control of all fossil and solar steam generating valves.

1.6 ECONOMIC FINDINGS

The repowering capital cost estimate is shown in Table 1-5 by top level subaccounts. This estimate includes design costs, as well as fabrication and construction costs.

The economic analysis of the repowered unit has been made with the techniques, assumptions, and evaluation parameters normally used by TESCO. An alternate analysis has been made utilizing the JPL methodology with a set of economic parameters specified by the technical monitor for this study, Sandia National

TABLE 1-5

TESCO PERMIAN BASIN UNIT 5 SOLAR REPOWERING CAPITAL COST

Subaccount	Description	Cost (1980 10^6\$)
5100	Site Improvements	2473
5200	Administrative Areas	0.044
5300	Collector Subsystem	69.576
5400	Receiver Subsystem	22.802
5500	Master Control Subsystem	1.206
5600	Non-Solar Energy Subsystem	0
5700	Energy Storage Subsystem	7.936
5800	Electric Power Generating Subsystem	7.574
	Total	111.611

Laboratories, Livermore (SNLL). Tables 1-6 through 1-8 contain results of calculations utilizing three different sets of economic parameters; these results are discussed in the following paragraphs. All of the various calculations are based upon an annual average net generation of 118,900 MWh. This estimate is derived from an assumed annual operating period of 2,678 h equivalent at 44,400 kW net output. The operating hours estimate includes an annual planned maintenance of 20 days and an annual unplanned downtime of 4% of available operating hours. The annual fuel savings resulting from the preceding assumptions is 1,374 x 10^9 Btu, which is equivalent to 1,239 x 10^6 ft^3 of natural gas, or 221,180 bbl of crude oil.

All dollar values shown in the tables are expressed in 1980 dollars; these dollars are obtained by discounting the estimated annual costs at the composite cost of capital rate.

The approved retirement date for Permian Basin Unit 5 is December 31, 1991, which results in a 7-year service life for the repowered unit. Other service lives are included in the tables, so that economic comparisons can be made for several different service lives.

TABLE 1-6

TESCO ECONOMIC ANALYSIS — GENERAL INFLATION = 8%

Service Life (years)	Fuel Savings ($10^3$$)	Equivalent Plant Investment ($10^3$$)	$\overline{\text{BBEC}}$ (mills/kWh)
7	18,546	10,473	263
10	26,419	14,623	224
15	38,898	20,943	192
20	50,354	26,678	189
25	60,866	31,858	187
30	70,496	36,601	189

Economic Parameters:

Capital Cost ($10^6$$)	111.6
Start of Operation	1985
Capital Investment (%/year)	25
Cost of Capital (%)	11.9
Income Tax Rate (%)	46
Revenue Related Tax Rate (%)	3.5
Investment Tax Credit Rate (%)	10
O&M Cost (1985)(% of Plant Investment)	1
Property Taxes and Insurance Rate (%)	2.25
AFUDC Rate (during construction) (%/year)	8
General, Capital, O&M Escalation Rate (%/year)	8

Annual Fuel Escalation Rate (%):

1980-1984	9.5
1985-1989	10.0
1990-1994	12.3
1995-2014	10.0

Notes:

1. All costs as of January 1, 1980
2. 1980 fuel cost: $2.50/$10^6$ Btu — supplied by Sandia National Laboratories, Livermore
3. The fuel escalation rates were obtained from The Annual Report to Congress — 1978: Volume 3 — Forecasts, prepared by the Energy Information Administration of the United States Department of Energy. The fuel escalation rates were obtained by adding the fuel inflation ratio obtained from Table 4.3, "U.S. Energy Prices: Projection Series C, 1962-1995," to the assumed general escalation rate.

TABLE 1-7

TESCO ECONOMIC ANALYSIS — GENERAL INFLATION = 10%

Service Life (years)	Fuel Savings (10^3\$)	Equivalent Plant Investment (10^3\$)	$\overline{\text{BBEC}}$ (mills/kWh)
7	21,448	12,451	266
10	32,550	18,841	226
15	49,491	27,584	202
20	66,502	36,280	194
25	93,591	44,991	193
30	104,204	56,099	192

Economic Parameters:

Capital Cost (10^6\$)	111.6
Start of Operation	1985
Capital Investment (%/year)	25
Cost of Capital (%)	11.9
Income Tax Rate (%)	46
Revenue Related Tax Rate (%)	3.5
Investment Tax Credit Rate (%)	10
O&M Cost (1985)(% of Plant Investment)	1
Property Taxes and Insurance Rate (%)	2.25
AFUDC Rate (during construction) (%/year)	8
General, Capital, O&M Escalation Rate (%/year)	10

Annual Fuel Escalation Rate (%):

1980-1984	11.5
1985-1989	12.0
1990-1994	14.3
1995-2014	12.0

Notes:

1. All costs as of January 1, 1980
2. 1980 fuel cost: \$2.50/10^6 Btu — supplied by Sandia National Laboratories, Livermore
3. The fuel escalation rates were obtained from The Annual Report to Congress — 1978: Volume 3 — Forecasts, prepared by the Energy Information Administration of the United States Department of Energy. The fuel escalation rates were obtained by adding the fuel inflation ratio obtained from Table 4.3, "U.S. Energy Prices: Projection Series C, 1962-1995," to the assumed general escalation rate.

TABLE 1-8

TESCO ECONOMIC ANALYSIS PER SNLL ECONOMIC SCENARIO — GENERAL INFLATION = 8%

Service Life (years)	Fuel Savings (10^3\$)	Equivalent Plant Investment (10^3\$)	$\overline{BBEC}$ (mills/kWh)
7	20,143	11,767	263
10	28,442	16,229	224
15	41,825	23,161	197
20	54,671	29,761	189
25	67,010	36,129	187
30	78,868	42,302	189

Economic Parameters:

Capital Cost (10^6\$)	111.6
Start of Operation	1985
Capital Investment (%/year)	25
Cost of Capital (%)	11.9
Income Tax Rate (%)	46
Revenue Related Tax Rate (%)	3.5
Investment Tax Credit Rate (%)	10
O&M Cost (1985)(% of Plant Investment)	1
Property Taxes and Insurance Rate (%)	2.25
AFUDC Rate (during construction) (%/year)	8
General, Capital, O&M Escalation Rate (%/year)	8
Annual Fuel Escalation Rate (%)	11

Notes:

1. All costs as of January 1, 1980
2. 1980 fuel cost: \$2.50/10^6 Btu — supplied by Sandia National Laboratories, Livermore (SNLL)
3. Fuel escalation rate supplied by SNLL.

Table 1-6 contains the results of calculations based upon a general escalation rate of 8%.

Table 1-7 contains the results of calculations based upon a general escalation rate of 10%.

Table 1-8 contains the results of calculations based upon economic parameters supplied by SNLL. The general, capital, and O&M escalation rates are 8% annually.

The fuel equivalent plant investment shown in the tables is a representative estimate of the value of the repowered plant to a utility. The present value of fuel savings is reduced by the present value of the O&M costs. This value is then multiplied by a ratio obtained by dividing the 1980 estimated cost of repowering the unit by the present value of the unit's revenue requirements. If a capital investment is made, income taxes, property taxes, etc must be included in the total cost of the project; thus, the capital investment of an equivalent plant addition is less than the expected fuel savings obtained by that plant addition.

The busbar energy costs (BBEC) for service lives of 7 and 25 years can be compared, and the comparison can be extended to results obtained using the JPL methodology of Reference 1-3. The BBEC obtained when using a general escalation rate of 8% is 263 mills/kWh and 187 mills/kWh, for service lives of 7 and 25 years, when using the TESCO methodology. The BBEC obtained when using a general escalation rate of 10% is 266 mills/kWh and 193 mills/kWh, for service lives of 7 and 25 years, when using the TESCO methodology. The BBEC obtained when using a general escalation rate of 8% is 196 mills/kWh for a service life of 25 years, utilizing the JPL methodology. The difference between the TESCO method and JPL method primarily results from the difference in cost of capital — before tax for the TESCO method, and after tax for the JPL method.

Tables 1-6 through 1-8 show the importance of plant life in evaluating the repowering concept, particularly with regard to fuel savings and Equivalent Plant Investment. The latter value is an indication of the capital investment that would have to be made to obtain the fuel savings, over the life of the plant, resulting from the use of solar energy. The uneconomic part of a solar repowered plant is the difference between the capital cost (of Table 1-5) and the equivalent plant investment shown in Tables 1-6 through 1-8.

1.7 DEVELOPMENT PLAN

The development plan schedule shown in Figure 1-6 shows the sequence of design, procurement, and construction activities required to have the repowered Permian Basin Unit 5 checked out and in operation during 1985. The design phase has a duration of 18 months. In order to accomplish the start of plant operation in 1985, long-lead procurement must be initiated near the midpoint of the design phase, early 1982. The construction phase is also scheduled for 18 months. During this period, the fossil plant would be down a maximum of 3 months to permit the solar system to be integrated with the existing plant.

A plant checkout phase of 7 months would lead into the system performance validation phase of ~2-months duration. Successful completion of these phases would allow the joint User-DOE phase of ~2 years to start. The checkout and system performance phases would include operational and performance tests and checks of components and subsystems prior to acceptance by the User. The joint user phase would allow long-term evaluation of the operational, performance, and economic characteristics of a solar repowered plant. This joint user phase refers to the sharing of plant performance data and of cost data to the extent that such data is normally made public.

Operation of the plant would be completely the responsibility of TESCO.

Although the subject study is for a site-specific application, the design constitutes a basic product that can then be used in other solar repowering applications. A preliminary market assessment indicates substantial application potential for this product, with excellent potential for fossil fuel replacement. Preliminary economic studies indicate that the cost-to-benefit ratio for a repowered plant could be attractive for a 1990 or later start date, due to the reduced heliostat cost attendant with increased production quantity.

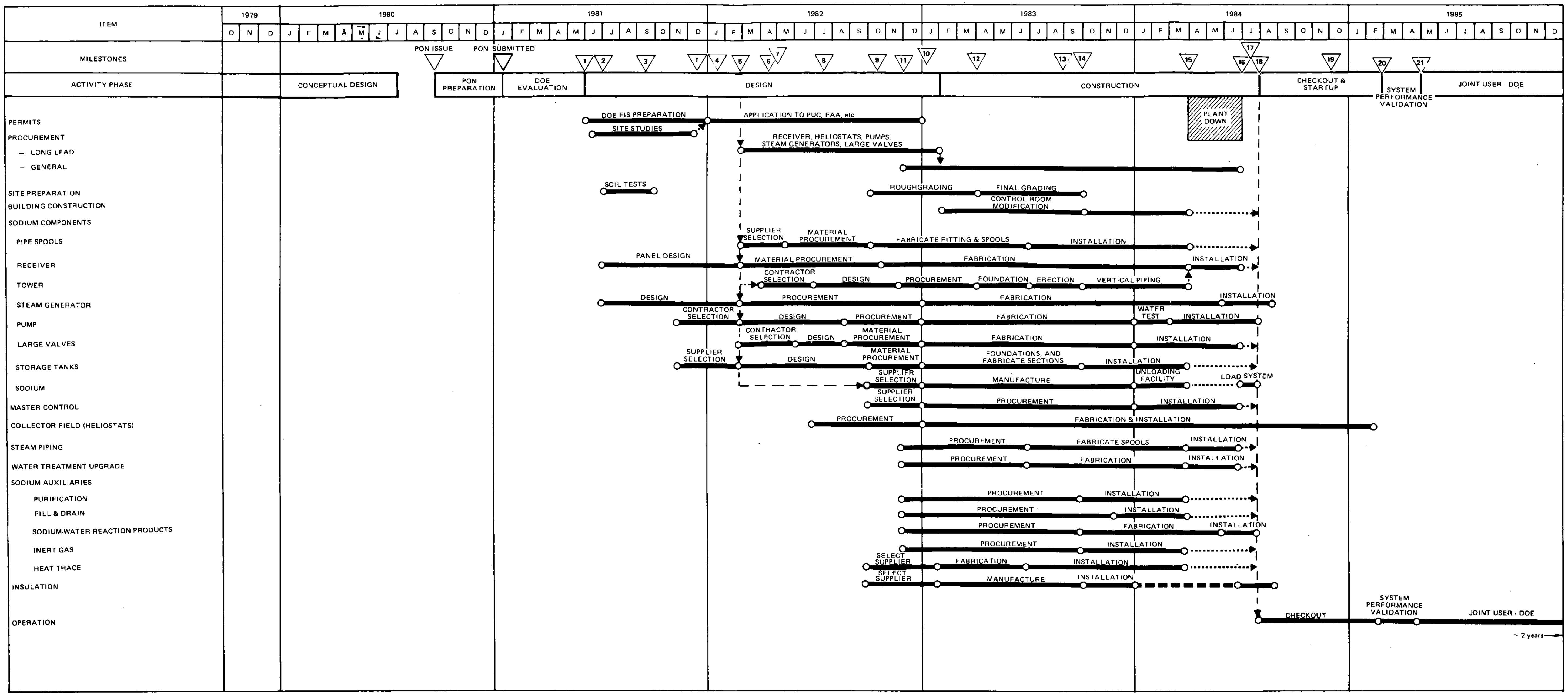

Figure 1-6. Development Plan Schedule

1.8 SITE OWNER'S ASSESSMENT

1.8.1 Economic Considerations

In order to assess the worth of this project, several factors must be considered. One factor which has been present from the inception of this program was to determine the dollar value of a repowering system, from the viewpoint of the benefit of potential fuel savings. The immediate thought would be to determine the projected quantity of fuel saved, estimate the value of this quantity of fuel, and make a present-worth calculation of the dollar value. This exercise is contained in Section 6 of the report, Economic Analysis. However, it must be considered that this present-worth value of fuel is only an approximate number. No matter how much effort and thought enter into this exercise, there are several reasons why it will still be subject to significant variation. The major reasons for this condition are summarized here.

Several variables affect the first step of estimating the quantity of fuel savings. One of these is determining the insolation, in order to calculate the available energy. Since no historical weather data is available in this locale, an estimation is necessary. Using data from the nearest points, an interpolation has been made. The actual value of insolation of the site may be affected by some local condition which has not been indentified, and, indeed, will vary from year to year. However, the insolation levels measured by the pyrheliometer at the Permian site for the last 4 months are consistent with those that have been assumed, in this study, to apply to the Permian site.

In addition, the efficiency of use of solar insolation is unknown. Several factors contribute to this efficiency. The efficiency of converting solar insolation into heat stored in liquid sodium has not been demonstrated on a large scale. However, the completion of the Barstow pilot plant will help resolve this uncertainty, as will the completion of the sodium panel tests currently planned by Energy Systems Group and DOE-funded programs. It is believed the estimates of efficiency are, in all probability, close to what will be experienced in actual operation. However, the confidence required to commit investment of the required capital, based on these estimates, may still be somewhat lacking.

Also, the exercise of determining the value of the quantity of fuel saved is probably subject to greater unknowns than those already discussed. TESCO has historically had a good record of predicting future fuel costs, as evidenced by early emphasis on switching from dependence on natural gas to lignite. However, this study invokes slightly different methods of using fuel costs. That is, the investment of an amount of money, based on the value of fuel saved, is required some years before the saving is realized. Obviously, this further complicates the job of estimating future fuel costs, which is becoming much more difficult than it has been in past years, for other reasons as well. All of the preceding factors make the determination of quantities of fuel saved uncertain.

Perhaps the largest difficulty in this project is the necessity for capital expenditures on the part of the utility, with the possibility that the plant may never be completed, or the possibility that the plant may be subjected to delays which are severe enough to limit the usefulness of the repowered plant. The timing of this project is extremely important, from the utility standpoint. Utilities must decide 5 to 10 years in advance which plants will be replaced or repowered. Due to the requirements of the Fuel Use Act, most of the natural-gas-fired generation must be replaced in the 1990 to 2000 time frame. For solar repowering to be a viable option, the repowering project must be placed in service by 1985, so that some operating experience can be obtained prior to 1990. The year 1990 is probably the last date when a utility can consider repowering a plant with solar energy, rather than replacement of the natural-gas-fired generation. Unless the repowering demonstration projects are forthcoming in a timely manner, the solar repowering option will be lost. This may have a significant impact upon the viability of the solar stand-alone option.

As of this writing, the funding for the Barstow solar pilot plant is not assured. The project may or may not be finished on schedule, if at all. A utility cannot include the solar option in its future planning schedule unless the option has been shown to be viable. The Department of Energy must be committed to the repowering concept, and must show that commitment through a positive encouragement of the concept. Delays, whether for financial or technical reasons, add immensely to the final cost of the project.

For these reasons, and the need for minimizing the risks to the utility due to uncertainties in capital costs, O&M costs, unit service life, and unit performance, a specific dollar value of the worth of this project is subject to discussion. There is the need for assumption of these risks by other parties. A viable method of risk assumption, from the utility viewpoint, would involve a third party operating the solar plant and selling the steam to the utility at a fair value.

1.8.2 Additional Site Considerations

When considering other sites on the TESCO system for repowering, all of the problems listed previously would be applicable at this time. Another problem affecting repowering at sites in Fort Worth and Graham is severe land restrictions. Thus, the following units are the only ones of sufficient size to be worth considering. All are located at Permian Basin or Morgan Creek generating stations. Even at these locations, some land problems may be encountered, particularly when considering 200- to 400-MW levels of repowering.

Unit	Size (MW)	Installation Date	Retirement Date
Permian Unit 5	115	1958	1991
Permian Unit 6	540	1973	1998
Morgan Creek Unit 5	175	1959	1992
Morgan Creek Unit 6	500	1966	1994

A notable fact about this list is the age of the units. Only one candidate was constructed as late as the early 70's, and only one candidate was constructed in the 60's. The effect of TESCO's lignite conversion program is obvious, when looking at the age of the units on this list. The two newest units are also the largest. Therefore, they may not be considered to be candidates at this time, since there is the need for demonstrating the repowering concept in the 50- to 100-MW range before moving into the 200- to 400-MW range. By the time this early demonstration work is completed, the age of these two larger plants would then be in the "doubtful" area. All of this assumes that the Fuel Use Act places no additional restrictions on system units.

A possible alternative to repowering is the construction of coal-fired units, which have the economic edge at this point in time.

1.8.3 Institutional Considerations

The company would apply for a Certificate of Convenience and Necessity from the Public Utilities Commission of Texas, prior to construction.

1.8.4 Operational Considerations

The present approved retirement date for Permian Basin Unit No. 5 is December 31, 1991. However, there are some technical risks which may limit the service life of the repowered unit. Most of these unknowns are in the mechanical area. Such items as the cycling abilities of the sodium steam generators, the steam turbine, and the central receiver may limit the operating capabilities of the unit. The study does consider these potential problem areas, and proper allowance has been made. However, the possibility of some of the system placing a severe restriction on the operation of the total system remains.

Operating procedures, from a personnel viewpoint, are also covered in the report. Much thought has been given to personnel safety. Some concern will always be present when operating a sodium system. However, these potential hazards can probably be dealt with in a reasonable manner, based on experience within the sodium industry. If the cost, performance, and risk factors discussed here can be resolved to TESCO's satisfaction, TESCO would not hesitate to use liquid sodium as a heat transport fluid. The use of liquid sodium does not represent any unmanageable problem, with respect to environmental concerns.

1.8.5 Schedule Considerations

Project development plans are presented in Section 1.7. Past experience with developmental projects has been that unexpected difficulties and problems are always numerous. However, these have been anticipated, to some degree, in the schedule; and can be handled in a reasonable manner, assuming no overall delays from causes other than of a mechanical or technical nature.

1.8.6 Energy Considerations

At the present time, reliance upon coal for future units would seem to be the best course of action, in view of the current uncertainties in the interpretation and application of the Fuel Use Act. As mentioned previously, the repowering concept would appear to have limited application on the TESCO system. However, as experience is gained with the central tower receiver concept, it would appear that solar stand-alone units with storage would have to be considered for new unit installations. This would be particularly true after the economics of the system are proven. The solar stand-alone plant with storage could be used advantageously for summer peaking loads. Some question still remains about the winter peaking needs, even with storage. Since the highest winter peaks could occur during days of little or no solar insolation, careful planning would be necessary.

The Department of Energy involvement in the project, if any, should be kept to the minimum possible level. Utilities are continually involved in long-term projects, and have the management expertise to oversee a project of this type.

REFERENCES

1-1 "Conceptual Design of Solar Central Receiver Power Systems Sodium Cooled Receiver Concept Final Report," SAN 11483-1, U.S. Department of Energy, San Francisco Operations Office (March 1979)

1-2 "Solar Central Receiver Hybrid Power Systems Sodium Cooled Receiver Concept Final Report," DOE/ET/20567-1, U.S. Department of Energy, San Francisco Operations Office (January 1980)

1-3 J. W. Doane et al., "The Cost of Energy From Utility-Owned Solar Electric Power Systems . . . .," ERDA/JPL-1012-76/3, NTIS (June 1976)