JIM FISH 8452

DOE/SF/11065-1(Exec.Summ.)

CONCEPTUAL DESIGN OF THE SOLAR REPOWERING SYSTEM FOR WEST TEXAS UTILITIES COMPANY PAINT CREEK POWER STATION UNIT NO. 4

Executive Summary

July 15, 1980

Work Performed Under Contract No. AP03-80SF-11065

Rockwell International
Canoga Park, California

U.S. Department of Energy

Solar Energy

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EXECUTIVE SUMMARY

WTU WEST TEXAS UTILITIES COMPANY
A MEMBER OF THE CENTRAL AND SOUTH WEST SYSTEM

Rockwell International
Energy Systems Group

UNIVERSITY OF HOUSTON Founded 1927

BOEING ENGINEERING & CONSTRUCTION
THE BOEING ENERGY AND ENVIRONMENT DIVISION

SARGENT & LUNDY ENGINEERS
55 EAST MONROE STREET CHICAGO IL 60603

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CONTENTS

CONTENTS

TABLES

FIGURES

1.0 EXECUTIVE SUMMARY

1.1 PROJECT SUMMARY

1.1.1 The Concept

A conceptual design of a sodium-cooled, solar, central-receiver repowering system for West Texas Utilities' Paint Creek Unit 4 was prepared, solely under funds provided by West Texas Utilities (WTU), the Energy Systems Group (ESG) of Rockwell International, and four other support groups.* A central-receiver repowering system is one in which a tower, surrounded by a large field of mirrors, is placed adjacent to an existing electric power plant (Figure 1-1). A receiver, located on top of the tower, absorbs solar energy reflected onto it by the mirrors and converts this solar energy to heat energy. The heat energy is transported by the liquid sodium to a set of sodium-to-steam steam generators (Figure 1-2). The steam generators produce steam at the same temperature and pressure as that produced by the fossil boiler in the existing plant. When solar energy is available, steam is produced by the solar part of the plant, thus displacing steam from the fossil boiler, and reducing the consumption of fossil fuel while maintaining the original plant output. A means for storing the solar energy is usually provided, so that some energy obtained from the solar source can be used to displace natural gas or oil fuels when the sun is not shining.

On this conceptual design study program, a large number of trade studies and optimizations were carried out, in order to derive the most cost-effective design that had the greatest potential for widespread application and commercialization. As a result of these studies, the optimum power level for the solar part of the plant was determined to be 60 MWe, and provisions were made to store enough solar energy, so that the solar part of the plant would produce, on March 21 (equinox), 60 MWe of electric power for a period of 4 h after sunset. The tower in this system is 154 m (505 ft) high to the midpoint of the receiver, and is surrounded by 7882 heliostats (mirrors), each of which is 6.7 m (22 ft) by 7.3 m (24 ft). The mirror field occupies 1.74 x 10^6 m^2 (430 acres), and extends 1040 m (3400 ft)

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*The University of Houston (U of H), Boeing Engineers and Constructors, Sargent & Lundy, and the Texas Energy and Natural Resources Advisory Council.

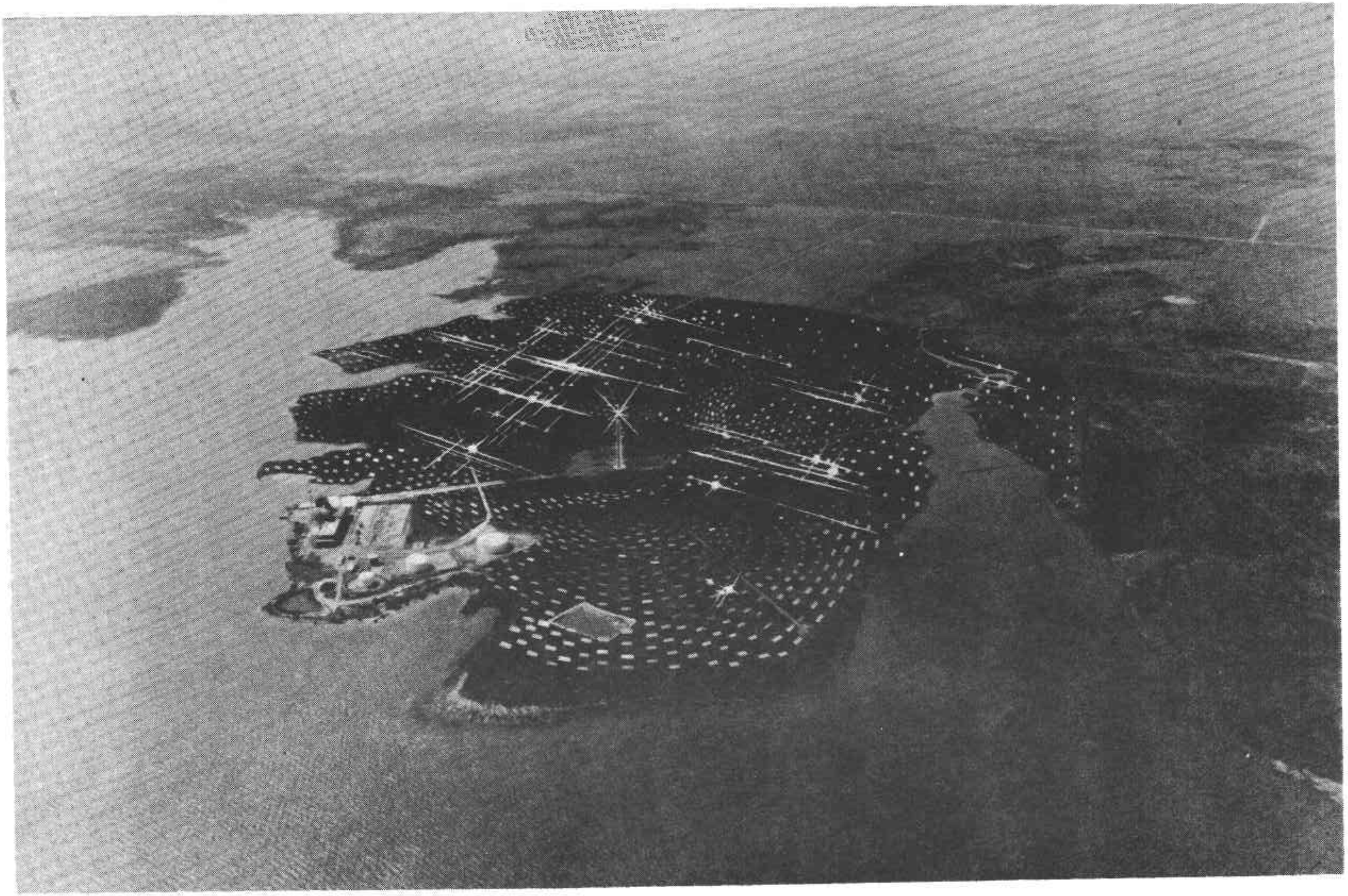

Figure 1-1. Artist's Concept of Collector Field at Paint Creek

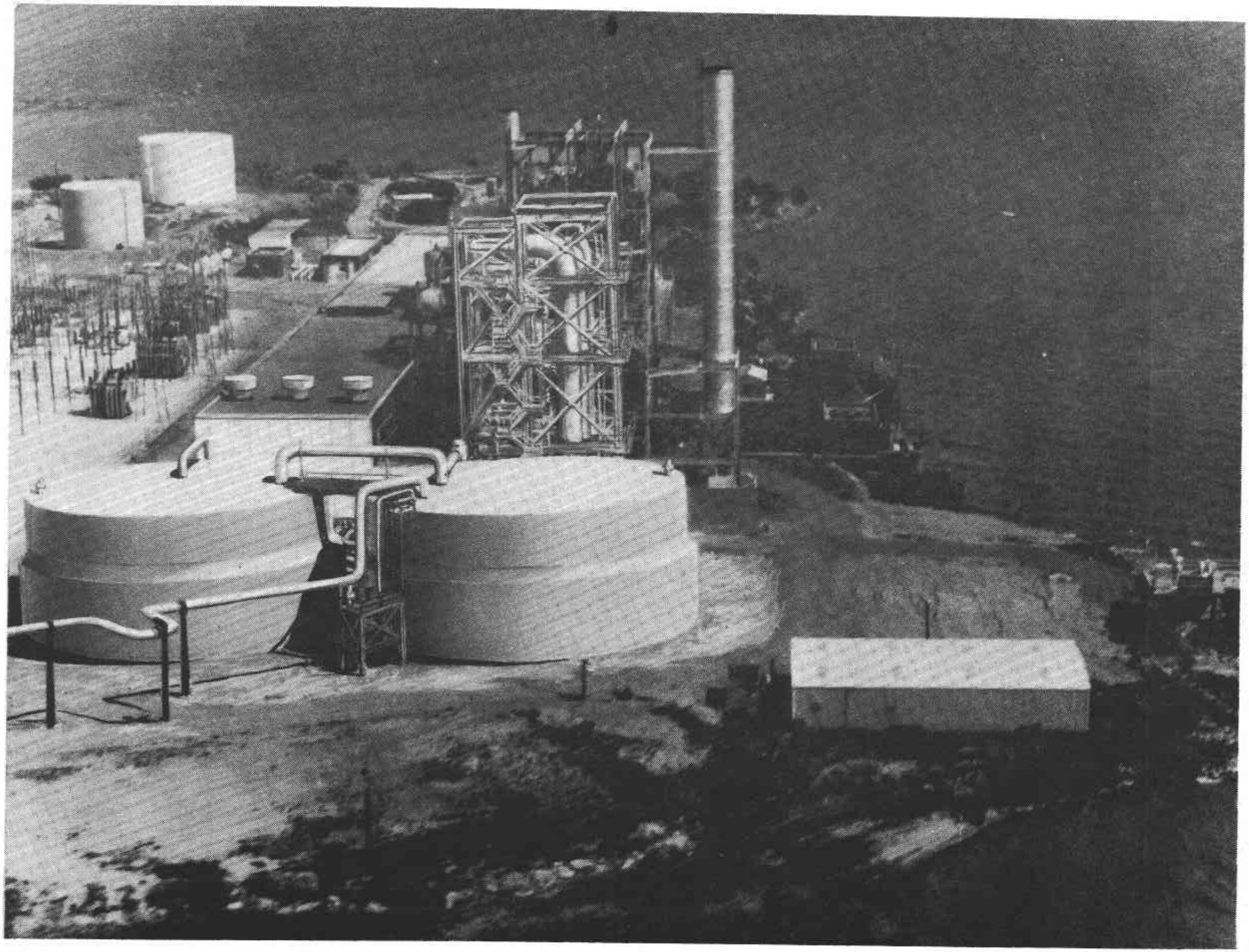

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Figure 1-2. Artist's Concept — Thermal Energy Storage Tanks (Foreground) and Sodium-Heated Steam Generators With Existing Plant to the north of the tower, 550 m (1800 ft) to the south of the tower, and is bounded on the east and west by Lake Stamford. The receiver, which is of the external type, is 15.4 m (50.5 ft) high by 14 m (45.9 ft) in diameter, and is capable of absorbing a maximum of 226 MW of thermal energy. The set of sodium-to-steam generators consists of an evaporator, a superheater, and a reheater, the power ratings of which are 83.2, 43.7, and 18.1 MWt, respectively.

The existing Paint Creek Unit 4 is a natural-gas-fired, baseload unit with a dependable net power output of 110 MWe. It is a reheat unit, has a main steam temperature and pressure of 538°C (1000°F) and 12.41 MPa (1800 psig), respectively, has a reheat temperature of 538°C (1000°F), and was placed in operation in 1972. Cooling water for the plant is provided by Lake Stamford, adjacent to the plant.

1.1.2 Economic Assessment

As part of the study effort, a site-specific assessment of the value of the conceptually designed repowering system to WTU, as an energy source in its generating system, was carried out and compared to other options, such as providing power from a coal-fired plant. Although, as expected, the cost of energy from the solar plant was greater, at this time, than that which could be derived from the continued burning of natural gas alone at the existing plant, favorable economics for this type of plant were projected for the future. Favorable economics can be achieved by the reduction of the cost of heliostats from the $216/m^2, assumed for this study, to a cost of the order of $150/m^2. For the specific repowering system studied, a busbar energy cost of 82.2 mills/kWh (1980 dollars) was derived, assuming, among other parameters, a start of operation in 1985, a cost of natural gas of $2.19/10^6 Btu, an escalation of 8% on that fuel cost, a general escalation of 8%, and a plant life of 30 years (for this study, the fuel and general escalation were assumed to be equal). The estimated capital cost of the plant is about $139.8 x 10^6 in 1980 dollars, including a contingency, engineering for preliminary and final design, and an A&E fee. For the solar-repowered plant to produce energy at a levelized busbar energy cost equal to that from a replacement coal plant, a subsidy of $26 x 10^6 would be required. This is approximately a measure of the "uneconomic" portion of the plant, since it will be a first-of-a-kind demonstration. These capital cost assumptions and economic parameters resulted in an annualized cost of \$28.7 x 10^6, an annualized benefit of \$10 x 10^6, and a payback period of 31 years.* Inasmuch as the design derived on the project was conceptual in nature, a very rough estimate of ±30% has been assumed in the capital cost.

1.1.3 Benefits

Even though the repowered solar plant was found, during the study program, not to be cost competitive with conventional options at this time, there are several benefits that were identified, and that can be derived from carrying out the construction of a solar system at the Paint Creek site. First and foremost among these benefits, from the standpoint of the current energy crisis, is that, on an annual basis, 1.76 x 10^9 ft^3 of natural gas will be saved, an amount which is equivalent to 3.1 x 10^5 bbl of crude oil. Therefore, over the life of the plant, the amount of natural gas saved will be 53 x 10^9 ft^3 (9.3 x 10^6 bbl of crude oil). Secondly, since the cost of heliostats (the single most important cost item in the solar plant — \$84.6 x 10^6 out of the \$140 x 10^6 total) is expected to decrease substantially as the number of units produced increases, the undertaking of a construction project at Paint Creek will contribute substantially to heliostat cost reductions for future plants. Thirdly, and of the highest importance to the utility industry as a whole, the cost and performance of the solar central-receiver concept can be evaluated on a significant and meaningful scale, thus allowing this concept to become the viable energy option that current studies indicate it can by the early 1990's. It has been shown, for example, that, under certain reasonably realistic economic scenarios, the busbar energy cost derived from a solar central-receiver plant is less than that from a new coal plant† of the same size, at least up to a 35 to 40% capacity factor. Fourthly, solar repowering offers the potential for meeting some of the goals of the National Energy Act without the need to dismantle relatively new, efficient, and useful gas- and oil-fired plants. Completing the useful life of many of these plants will result in considerable cost savings to the energy consumer. Finally, an improvement in overall air quality will be achieved, since there will be a concomitant reduction in the consumption of natural gas.

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*Payback is defined as the capital cost divided by the base year fuel savings.

†"Second Utility Advisory Committee Meeting for Solar Repowering Study," ESG-BD-80-1 (January 22, 1980)
P. J. Eicker, "Comparisons of Projected Electricity Costs for Coal Fired and Central Receiver Power Plants," SAND-79-8073 (November 1979)

1.1.4 Capability of a Start of Operation by 1985

During the course of the design study, a construction schedule for the Paint Creek Unit 4 repowering project was developed. If it is assumed that a total design and construction package, starting in June 1981, is authorized, and that no unnecessary delays and reviews are involved, a start of operation to put electrical power into the WTU grid can be achieved by about April 1985. Confidence that this schedule can be attained is enhanced by the selection of sodium as a heat transport fluid. Except for the receiver, sodium components of design and size similar to those proposed for this plant have been designed, fabricated, and operated for hundreds of thousands of hours, under conditions more severe than those expected in this plant. In addition, the compatibility of liquid sodium with the common materials of construction (stainless steel, carbon steel, and Croloy) has already been demonstrated, not only in test loops, but also in operating systems with large temperature differences, and at temperatures well in excess of those required for the application studied in this project. Over 25 years of experience with sodium systems, some in the production of electrical power up to 1200 MWe, has been and is continuing to be acquired.

Other factors contributing to confidence in this schedule are that ESG has successfully designed, constructed, and put into operation similar types of sodium power systems (the Sodium Reactor Experiment and the Hallam Nuclear Power Plant) in similar time frames. Also, the Rocketdyne Division of Rockwell is currently designing and constructing the receiver and storage systems for the Barstow Solar Pilot Plant, and thus is gaining direct experience in component fabrication in solar systems. ESG has the capability, in many instances, to reassign the fabrication responsibility and undertake completion of a component, itself, if a vendor is unable to meet its fabrication schedule.

Development of the sodium-cooled receivers is already underway, as part of the DOE development program, by both General Electric and Energy Systems Group.* Current schedules on this development should, however, be maintained, in order to support the design and fabrication of a receiver for the Paint Creek Project.

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*The design and fabrication of a receiver test panel, under ESG funding, is being undertaken at this time.

1.1.5 Suitability of the Paint Creek Site

The Paint Creek site is very well suited for the demonstration of the solar central-receiver technology, for both repowering and stand-alone solar electric power generation. An insolation level of 6.4 kWh/m^2-day, which was derived on the study program from weather data obtained over 30 years from Fort Worth, Texas, is typical of the solar energy received over a large area of the southwestern United States. The performance data obtained at the Paint Creek site will apply to areas that include parts of Texas, Oklahoma, Colorado, Nevada, Utah, New Mexico, Arizona, and California. Thus, it demonstrates the capability of the solar power concept outside the so-called ideal solar insolation areas. Of equal importance is the fact that this insolation level coincides with a large part of that area of the United States where natural gas consumption is the greatest.

Other important site and plant considerations that were studied are: (1) the land is typically level, (2) the land is owned in part by WTU, and necessary additional land can be acquired, and (3) the solar plant can be located to the north of and adjacent to the existing fossil unit. The latter feature tends to minimize piping runs and concomitant costs. Furthermore, because of the plant layout, access to Unit 4 is virtually ideal – that end of the turbine building in which the unit is located was designed so that the end wall could be removed and the building extended. Thus, steam generators can be located, with ease, in very close proximity to the turbine and feedwater equipment. In addition, the plant is relatively new, has modern steam conditions typical of a large number of plants that can potentially be repowered* and will not need any modifications in the feedwater treatment equipment. Finally, cooling for the plant is obtained from Lake Stamford, rather than from cooling towers, a fact that eliminates any concern that might arise from drift of water vapor from cooling towers over the mirror field.

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*The demonstration of the reheat feature in solar repowering is extremely important, since it extends the applicability of solar repowering. In the Public Service of New Mexico survey, most of the capacity that was deemed suitable for repowering came from newer reheat units. However, operation of the Paint Creek Unit 4 in the repowering mode will provide all of the necessary information for nonreheat units as well.

1.1.6 Suitability of the Design

The field surrounding the tower (Figure 1-1) occupies ~1.74×10^6 m^2 (~430 acres) adjacent to the existing Paint Creek Unit No. 4. At this site, the lake forms the larger part of the mirror field boundary, except to the north. With the relatively expensive heliostats assumed in this study, and with virtually no field area south of the plant, it is most cost effective to locate the tower at the plant site, and use a "north only" field and a flat-plate receiver. This configuration was not selected in this study because it would yield a special plant design applicable to a very small commercial market, and thus would not satisfy the purpose of demonstrating the viability of commercial solar-repowering stations in general. The commercial plants are expected to use a lower-cost heliostat, and to be relatively free of south field restrictions. Thus, they would use a surrounding field and a cylindrical receiver. The configuration selected for the Paint Creek repowering study utilizes a surround field, and permits the use of a typical receiver with a circumferential power distribution, typical of a commercial plant.

Solar plant components for the Paint Creek Unit 4 repowered system were selected on the basis of conservative, state-of-the-art designs, so that a high probability of successful operation could be achieved. Peak flux levels on the receiver, for example, could probably be somewhat higher; but, since this is the only component that does not have an operating history to draw upon, it was deemed wise to proceed more cautiously. It is noteworthy that, if testing of selected sodium components were required, facilities* that can handle very large components, such as pumps and valves, are available.

In order to minimize thermal cycling of components in the solar plant, a thermal energy storage capacity and a solar multiple that will permit operation of the solar part of the plant 24 h/day on December 21, at reduced power at night was chosen.

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*Energy Technology Engineering Center, operated by Rockwell International for the Department of Energy

No technical problems that would prevent successful construction and operation of the proposed plant during 1985 were identified.

1.1.7 Environmental Assessment

During the course of this study program, consideration was given to the impact on the environment of a repowering project at the Paint Creek site. No significant environmental limitations were identified. Since the solar plant will produce 32% of the total energy generated at the plant on an annual basis, significant reduction in CO_2 production in the fossil boiler will occur. Thus, the air quality will, in fact, be improved.

Although the utilization of 24.3×10^3 to 32.4×10^3 m^2/MWe (6 to 8 acres/MWe) by a solar collector field is often perceived as large for solar plants in general, this value is not large compared to the area required for a coal plant, if the coal mining operation is included over the life of the coal plant.

Considerable attention was given on the project to the prevention of sodium leaks and sodium releases, and to the detection of leaks in their early stages, to limit the extent of the leak. Safety and leak detection systems have been designed into the plant, and are included in the capital cost estimate developed. For example, a secondary tank is located around each storage vessel, in order to contain any spillage, and each storage tank can be used to contain the entire inventory of the other. Also, relief discs are placed in the steam generator system, in order to handle any sodium-to-water reaction that might take place. These relief systems have been tested under full-scale conditions, and found to perform safely and satisfactorily.

Should sodium be released to the environment, calculations were carried out during this study to determine the aerosol concentrations in the vicinity of the plant, and the effect of the aerosols on the environment. Since sodium is non-toxic and, after oxidizing, eventually converts to sodium carbonate (a relatively benign substance), no long-term effects exist. The maximum aerosol concentration calculated outside of the site boundary was 0.3 mg/m^3 at a point 600 m (1969 ft) downwind, under Pasquill A atmospheric conditions. This aerosol level is below the threshold limit value of 2 mg/m^3 of NaOH, and does not take into account the conversion of the sodium oxide to the carbonate as it goes downwind. Actual tests of the characteristics of the aerosols that can potentially be formed and released into the atmosphere were conducted, and were used to substantiate the conclusions that the use of sodium does not pose any undue hazard. It does not, in fact, pose any more of a hazard than other materials with which we deal on an everyday basis. The safety record on sodium systems supports this statement. For example, the overall industrial accident frequency is 10.4 disabling injuries per 10^6 h worked, compared to 0.3 for sodium systems experience, averaged over the same 10-year period.

1.1.8 Regulatory Bodies and Construction Permits

The constraints imposed on the construction and operation of the Paint Creek repowering system were investigated by WTU on the program. No out-of-the-ordinary permit requirements are identified. FAA approval of the tower will be required because of its height, but air and water quality will either be unaffected or improved. Since the plant is located on the shores of Lake Stamford, the Corps of Engineers was also contacted. The selected design concept for the plant and collector field is not expected to present unusual permit problems in this regard.

If DOE proceeds with the development of a generic-type of environmental impact assessment, as currently planned for central receiver plants, the detailed site-specific environmental studies that are to be conducted during the design stage of the project are expected to be sufficient to allow the construction to proceed. The latter procedure will depend, however, on DOE and EPA policies and positions. No requirement for an EIS is expected from the city near which the plant is located, the county in which it is located, nor the State of Texas.

One area of concern is the position of the Public Utility Commission of Texas, insofar as solar-thermal electricity generation is concerned. As a minimum, it will be necessary for the PUC to permit WTU's capital investment in the plant to be included in the rate base.

1.1.9 Federal Government Involvement

In addition to the needs identified previously for funding sources to cover the uneconomic portion of this first-of-a-kind demonstration project, for expeditious handling of environmental impact assessments, and for favorable PUC rulings, several institutional concerns that involve the Federal Government were inferred during the evaluation of the degree of success to be expected in the conduct of a demonstration project at Paint Creek. One of these is a favorable interpretation of the permanent exemption clause in the Fuel Use Act. It is essential that the plant be allowed to burn natural gas in the repowered system beyond the year 1990, since more than 20% of the plant's energy needs will be derived from solar. It is also of considerable importance, in terms of the long-term viability and widespread application of the solar-thermal electric concept, that consideration be given by the Economic Regulatory Administration to allowing utilities to repower other existing power plants, if the Paint Creek demonstration project is successful, and the economics and performance are as favorable as currently expected.

A definitive commitment on the part of DOE to complete the project, once started, is of considerable importance from the standpoint of meeting the construction schedule and technical goals for repowering Paint Creek Unit 4. The schedule that has been developed on this study program assumes that the design and construction project will be carried out in the manner normally followed by a utility (i.e., some site preparation and ordering of long-lead time items are initiated before the design is complete). Also, design reviews must not cause project delays, and must be limited to demonstration that the design meets the overall functional plant requirements.

1.2 OBJECTIVE

The objective of this study is to provide a conceptual design of a cost-effective solar-repowering system for the West Texas Utilities Company Paint Creek Power Station Unit No. 4, for operation in 1985, which will allow continued station operation under the Fuel Use Act, and which will satisfy the purpose of demonstrating the viability of commercial solar-repowering stations.

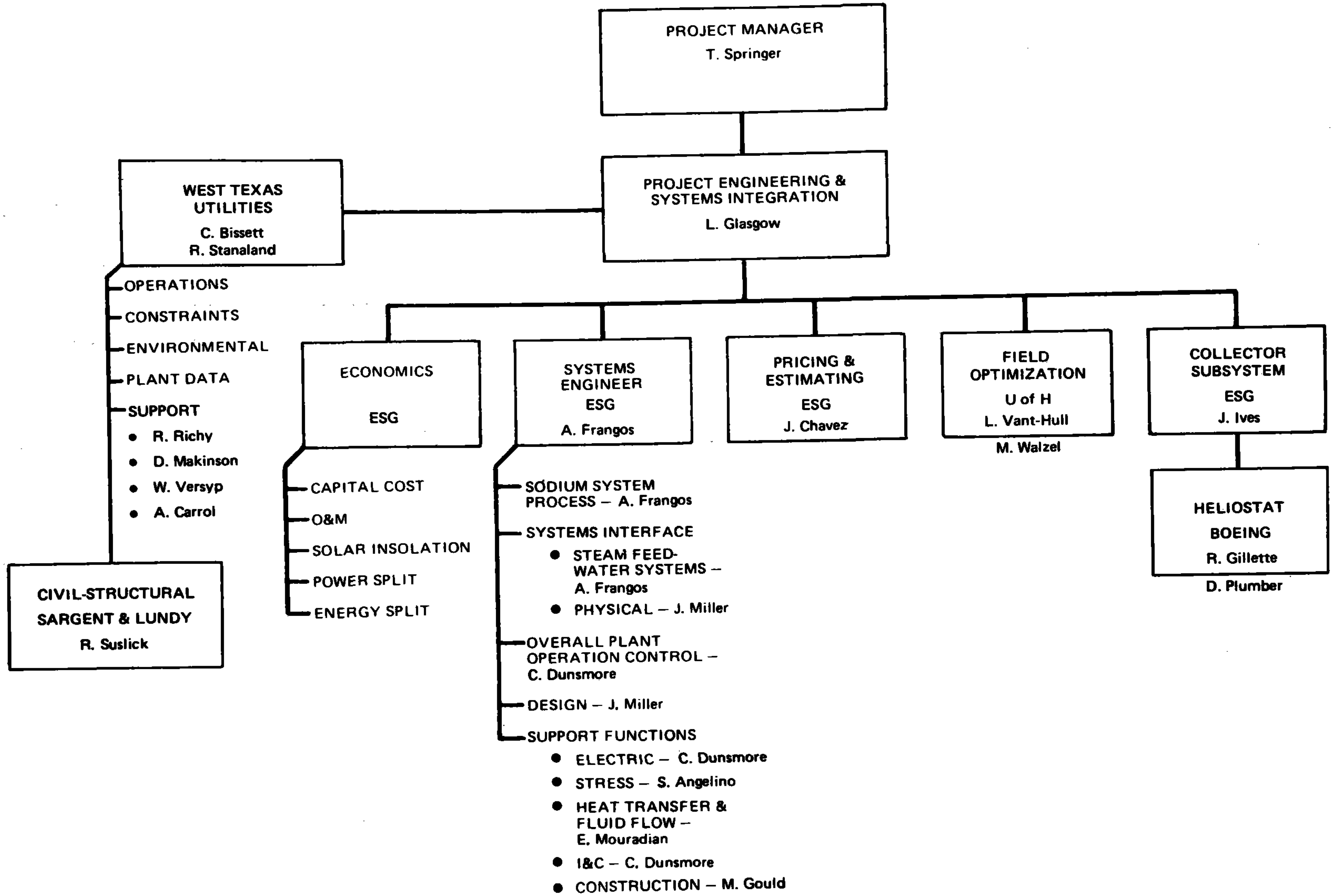


Figure 1-3. Project Organization

The technical approach that was adopted on this program was to establish a reference design meeting the specific site requirements, and then to perform system and subsystem trade studies to select the most cost-effective design consistent with demonstrating the viability of the central-receiver repowering concept. The requirements were identified by studying previous reports and the site conditions, and by consulting with the study team management. The general top-level requirements are: (1) solar power fraction >50%, (2) annualized solar energy >20%, (3) reliability and ease of operation to remain about the same as they are on the existing plant, and (4) capability of solar-only, fossil-only, and combined solar-fossil operation.

The specific top-level requirements are a solar maximum power level of 60 MWe, ability to operate at 10% on solar energy during the longest night of the year, a plant availability of >90%, and a plant life of 30 years. The detailed requirements are given in the SRS.* Appendix A.

The study team is shown on the organization chart, Figure 1-3. The organizational responsibilities are shown in Table 1-1. The artist concept of the plant is shown in Figure 1-1. The overall system layout is shown in Figure 1-4.

1.3 SITE DESCRIPTION

The plant chosen for this study is the West Texas Utilities Company Paint Creek Unit No. 4. The existing fossil plant employs a Rankine steam cycle with a Riley Stoker drum boiler that provides 538°C (1000°F), 13.1 MPa (1900 psia) main steam and 538°C (1000°F), 3.5 MPa (507 psia) plant. The turbine is a General Electric tandem-compound, two-flow unit with 23-in. last-stage blades. It has a gross turbine heat rate of 8258 Btu/kWh. The condensate is cooled by water from adjacent Lake Stamford. Five feedwater heaters and two feedwater pumps (each rated at 60% of full-power capacity) are used. The plant net heat rate is 10,200 Btu/kWh at full load.

*SRS — System Requirements Specification

TABLE 1-1

PROJECT ORGANIZATIONAL RESPONSIBILITIES

Organization	Relationship	Responsibility
ESG	Prime (Solar Plant Supplier)	Overall project direction, systems integration and interface, collector, receiver, thermal storage, steam generating, master control, heat transport, and EPG's subsystems
WTU	Prime (Owner-Customer)	Plant Owner, basic plant requirements, performance, operating, maintenance data for EPG's and nonsolar subsystems, site constraints, environmental concerns, requirements, and plant economics
Boeing	Subcontractor	Heliostat design, cost, and performance data
U of H*	Subcontractor to ESG	Collector field optimization and performance verification, receiver power distribution, and annual performance curves
Sargent & Lundy	Subcontractor to Owner	Civil and structural design, construction cost data

*A portion of the funding for this work was provided by The Texas Energy and Natural Resources Advisory Council and the Energy Systems Group of Rockwell International.

Paint Creek Power Station is located in the northwestern part of Texas, in Haskell County, on Lake Stamford. The largest nearby population center is Abilene, which is 77.2 km (48 miles) south of the plant.

Most of the area surrounding the plant is used for farming and ranching, and is therefore rurally populated. The plant is isolated from other population areas, since the only access road deadends at the plant. The access road is a 3.22-km (2-mile) north-south road, off Texas FM 2082.

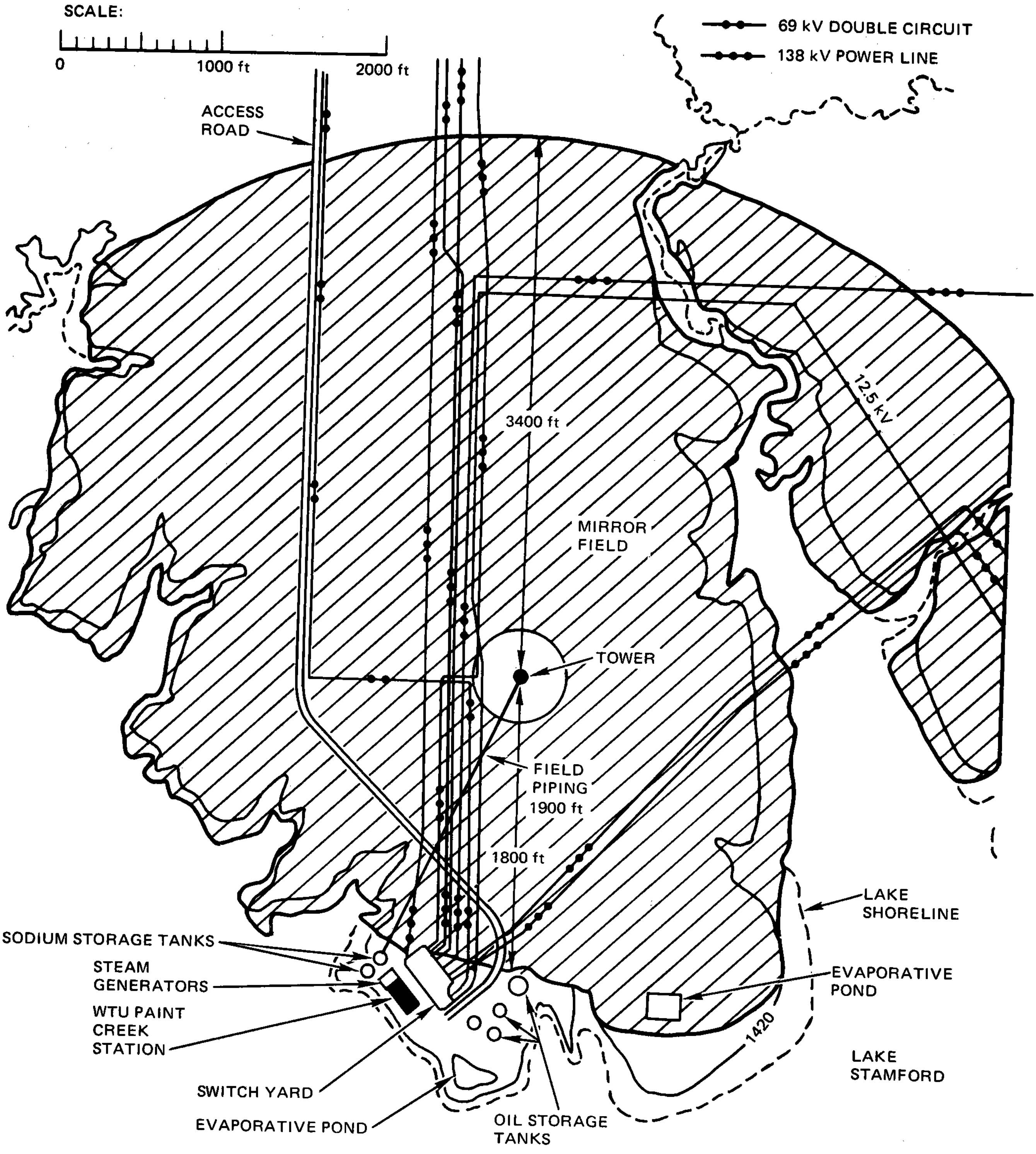


Figure 1-4. Collector Field Layout

The plant is located on a wide peninsula on the north shore of the lake. One of the main branches of the lake is on the west side of the plant, and a large inlet of the lake is on the east side of the plant. There are some other small inlets, along the lake shore, that follow small ravines. The slope of the land around the lake shore is 5 to 10% grade, but becomes very gently sloping inward from the shore, with the highest elevation in the area 440.72 m (1446 ft). The plant grade elevation is 434.32 m (1425 ft).

West Texas Utilities owns 5.5848 x 10^5 m^2 (138 acres) of land at the Paint Creek site, with the present plant facilities covering ~2.438 x 10^5 m^2 (~60 acres). This includes: (1) the plant building, containing four steam turbine-generator units and their auxiliaries, (2) four steam generators, (3) three circulating water crib houses, (4) a treated water plant, (5) a 138-kV, 69-kV, and 12.5-kV switchyard, (6) four fuel oil storage tanks, (7) two evaporation ponds, (8) one settling basin, (9) one warehouse, and (10) two company houses. The substations are located on the opposite side of the plant from the lake. The fuel oil storage tanks, water treatment plant, evaporation ponds, settling basin, and Lone Star Gas Company meters are located on the south side of the plant. The warehouse is on the north end of the site, near the lake shore.

Paint Creek has seven 138-kV power lines, two 69-kV power lines, and one 12.5-kV power line. All the power lines depart the plant to the north to get around the lake.

Haskell County has a subhumid, warm-temperature, continental climate. Summers are hot and winters are moderate, but severe cold spells sometimes occur. Average annual precipitation is low, and is irregularly distributed throughout the season. Rainfall is also erratic from year to year, and many of the rains are of high intensity. Figure 1-5 is a site-specific diurnal insolation model for equinox, summer solstice, and winter solstice, developed by the University of Houston for the Paint Creek Station site.

Gentle breezes usually blow in the summer, and gusty winds can sometimes be expected from December through May.

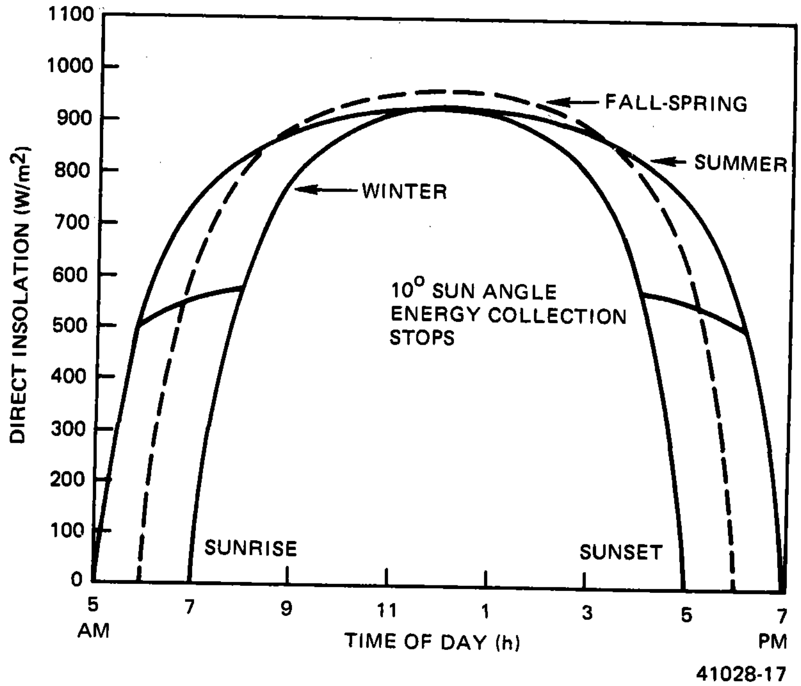


Figure 1-5. Clear Day Solar Insolation

The Paint Creek plant is the second largest plant in the West Texas Utilities system. There are four steam turbine generators at Paint Creek, all built by General Electric. The No. 1 unit was installed in 1953, No. 2 in 1955, No. 3 in 1959, and are used primarily for peaking and emergency service. Unit No. 3 is rated at 53,000 kW net dependable output, and is used during high-load periods in the summer and during scheduled maintenance of the other system units in the winter. At other times, it is on hot standby, for use during forced outages of the other system units. These three units burn natural gas as a primary fuel, and No. 2 fuel oil as a backup emergency fuel.

Unit No. 4 is rated at 110,000 kW net dependable output, and is one of the primary units on the West Texas Utilities generating system. It burns natural gas as a primary fuel, and No. 2 fuel oil as a backup emergency fuel. The load point for No. 4 unit is set by the economic dispatch control in Abilene during normal operation. The combustion controls automatically follow the turbine loading, to insure the proper amount of steam is supplied for the desired turbine-generator output.

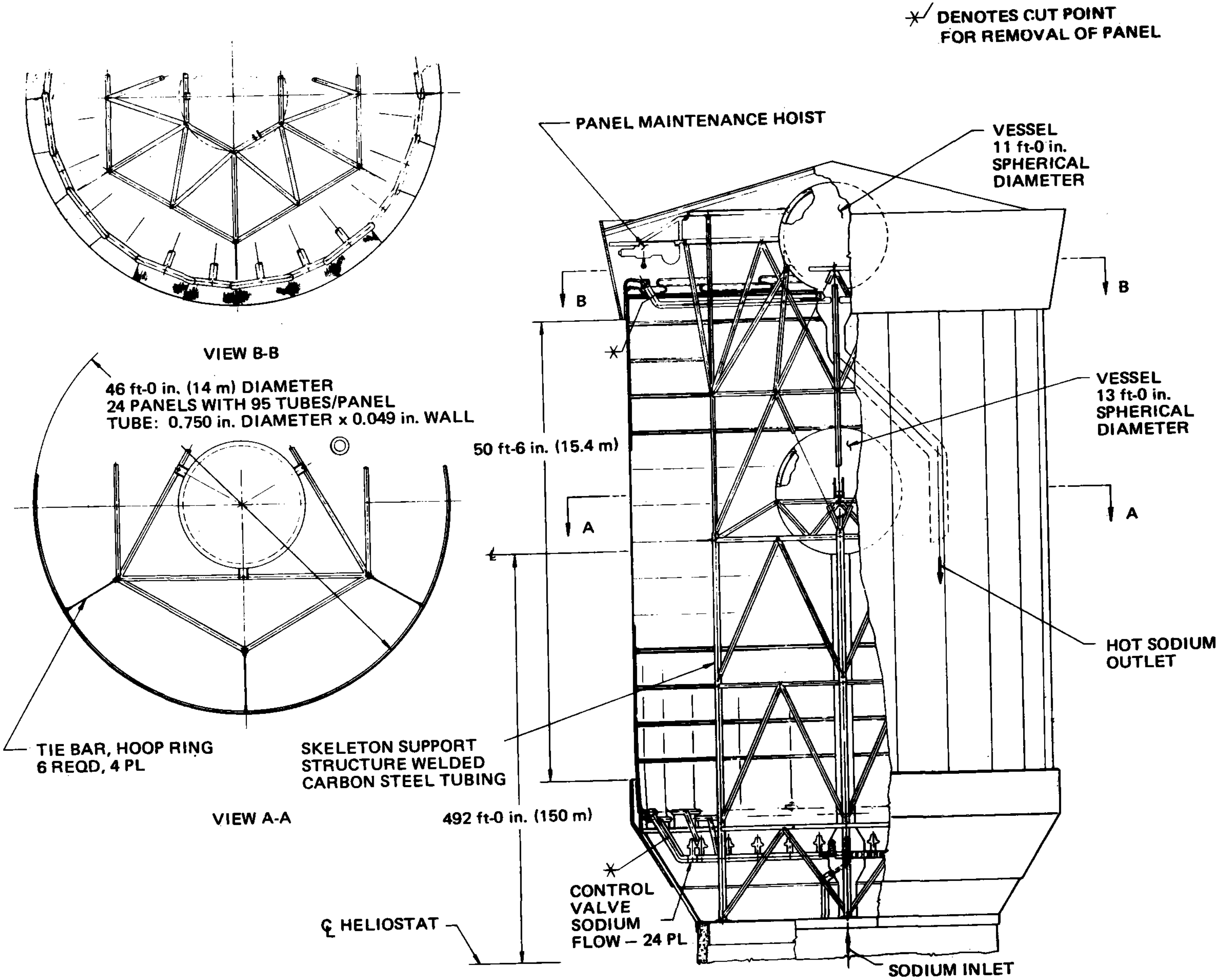


Figure 1-6. WTU Solar Receiver

The steam flow from the boiler passes through the high-pressure turbine and back to the boiler for reheating. The reheated steam passes through the intermediate-pressure turbine to the low-pressure turbine and into the condenser. The condensate is pumped through two low-pressure, closed, feedwater heaters to the deaerating heater. The water leaving the deaerating heater is called boiler feedwater, and is pumped through a feedwater control valve, two high-pressure, closed, feedwater heaters, and through the economizer section of the boiler to the boiler steam drum.

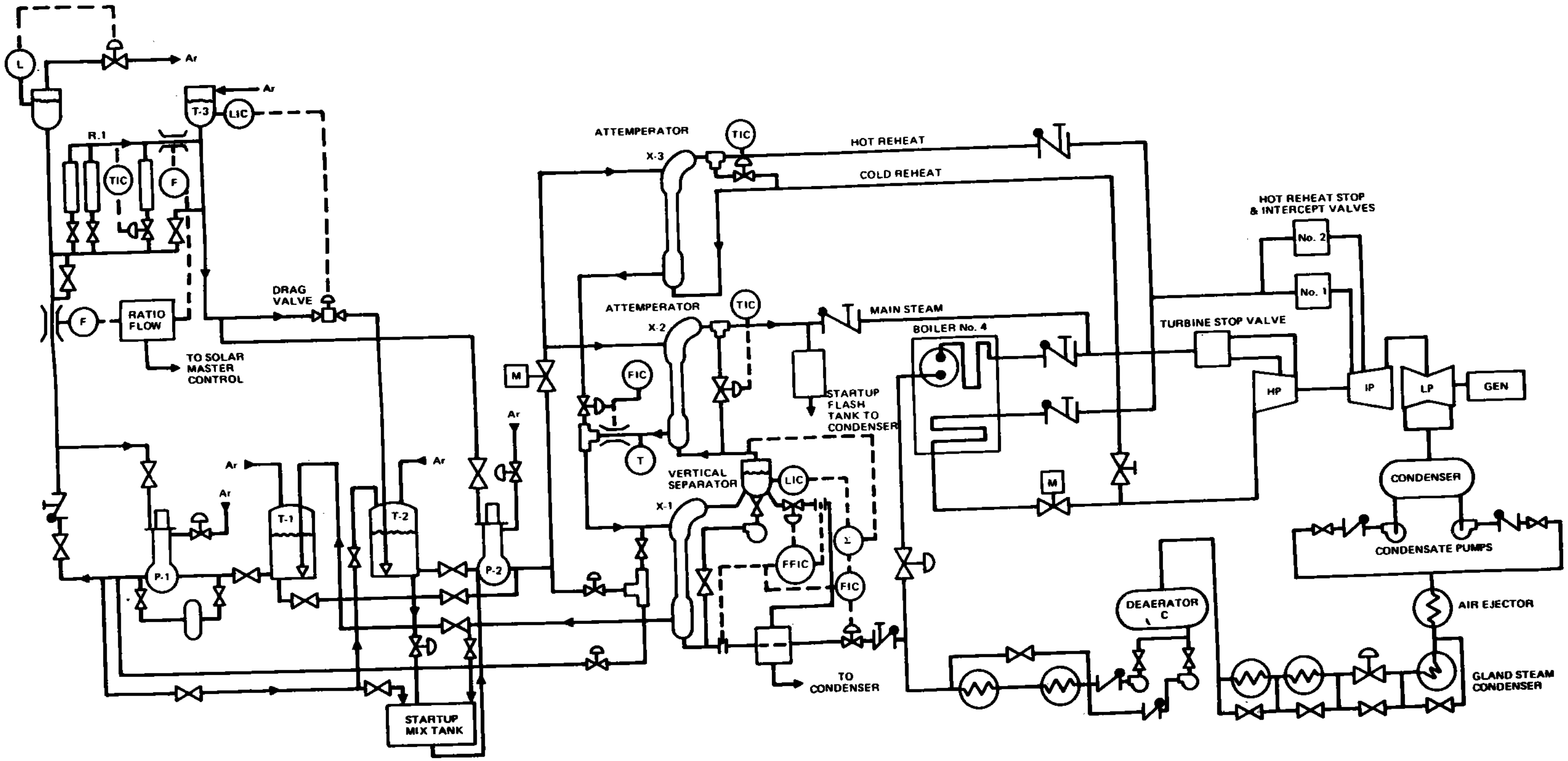
The electric power generated from the Paint Creek Power Station enters the WTU transmission and distribution system, which serves 53 counties and over 85,300 km^2 (53,000 square miles) from the Red River to the Rio Grande. The WTU system has a total generation capability of 1054 MW, with the Paint Creek plant providing 22% of the total.

1.4 CONCEPTUAL DESIGN DESCRIPTION

1.4.1 Solar Plant

A nominal reference repowering level of 60 MWe has been chosen for Unit No. 4, and the collector field has been sized for a solar multiple of 1.56, which provides 3.8 h storage capability at equinox. The plant uses liquid sodium for both the heat transport and thermal energy storage systems.

The solar energy collection part of the plant consists of a field of mirrors surrounding a tall tower which supports a sodium-cooled central receiver (Figures 1-1 and 1-4). The distance from the base of the central receiver tower to the midpoint of the receiver is 154 m (505 ft). The tower is a jump-form reinforced-concrete type. The receiver will be of the external type [a right circular cylinder ~14 m (45.9 ft) in diameter by 15.4 m (50.5 ft) in height], and will weigh ~336 tonne (~370 tons) (Figure 1-6). This configuration is similar to that being designed for the 10-MWe Barstow plant, and being tested at the CRTF, in Albuquerque, New Mexico. The single, surround-field tower will minimize piping runs between the fossil plant and the solar plant systems. Towers of this height, carrying loads of the magnitude of the receiver weight, are well within the present state of the art for reinforced-concrete structures.



80-MA30-1-58A

Figure 1-7. Paint Creek Station Unit 4 Process Flow Diagram

Sodium is used as the heat transport fluid, and is pumped to the top of the tower by a 0.69 m^3/s (11,000 gpm) pump (see Figure 1-7). The sodium enters the receiver at 288°C (550°F) through a riser, and exits at 593°C (1100°F) into a downcomer. The hot sodium from the receiver flows through a drag valve, and then into a hot storage tank which is located at ground level. The hot storage tank is sized to contain enough sodium to permit operation at full power for 4.0 h without sunshine. The sodium is pumped by a second 0.50 m^3/s (8000 gpm) pump from the hot tank through a set of three sodium-to-steam steam generator units (an evaporator, a superheater, and a reheater) that are located in a structure to be constructed on the west side of the existing turbine building. From the steam generators, the sodium flows into a "cold" [288°C (550°F)] storage tank, which is approximately the same size as the hot tank, and then is pumped to the top of the tower, thus completing the sodium flow circuit. The steam produced by the steam generators is sent to the existing steam turbine through pipes that are connected to existing main steam and reheat lines. Steam conditions produced by the sodium-to-steam steam generators are compatible with those produced by the existing fossil-fired boiler. As designed, this system separates the energy-collecting function from the electric-power-generating function, and the two functions operate nearly independently of each other. Thus, the electric power generation is not disturbed by a broken cloud cover sky condition. In fact, with prior planning, the plant can operate at reduced power for 2 days without sunshine, and normally operates overnight with ~10% of the plant power taken from stored solar energy. A summary of the conceptual design is given in Table 1-2.

1.5 SYSTEM PERFORMANCE

On clear days, it is planned to operate the solar plant at full power (60 MWe) from about 7 a.m. until about 5 p.m. in the summer, and from about 9 a.m. until 3 p.m. in the winter (see Figure 1-5).

At night, the solar plant will be operated from storage, at ~10% of full power (6 MWe). Operating in this manner, and allowing for actual weather conditions at the site, plant outages, and using the design value for the plant capacity factor (65%), the annual solar contribution will amount to 32% of the plant

TABLE 1-2

CONCEPTUAL DESIGN SUMMARY

Prime Contractors

West Texas Utilities Company

Energy Systems Group of Rockwell International Corporation

Major Subcontractors

University of Houston

Sargent & Lundy

Boeing Company

Site Process

Electric Power Generation

Turbine: General Electric 12.4 MPa (1800 psig), 538°C (1000°F), 538°C (1000°F) reheat tandem-compound double-flow reheat steam turbine

Site Location

North shore of Lake Stamford, Haskell County, Texas, 77.2 km (48 miles) north of Abilene, Texas

Design Point

Vernal Equinox Noon

Receiver

Receiver Fluid: Sodium

Configuration: External

Type: Forced circulation

Elements: Single-pass sodium heater

Output Fluid Temperature: 593°C (1100°F)

Output Fluid Pressure: Atmospheric

Heliostats

Number: 7882

Individual Mirror Area: 49 m^2

Cost: $216/$m^2$

Type: Boeing

Field Configuration: Surround

Storage

Duration: 4.0 full-power hours

Media: Sodium

Cost

Total Project Cost (including all capital and startup and checkout costs, but excluding O&M): $140 x 10^6

Total Project Cost (at heliostat price of $230/$m^2$): $145 x 10^6

Construction Time

4 years (from start of preliminary design to start of operations)

Solar Plant Contribution at Design Point

226 MWt at Vernal Equinox Noon

Solar Fraction — Annual

32% (at 65% plant capacity factor)

Annual Fossil Energy Saved

351,000 bbl (equivalent at 5.800 x 10^6 Btu/barrel)

Type of Fuel Displaced

Natural gas

Annual Energy Produced

482,500 MWh(t)

Ratio of $\frac{\text{Annual Energy Produced}}{\text{Total Heliostat Mirror Area}}$ = 1.249 MWh(t)/m^2

Ratio of $\frac{\text{Capital Cost}}{\text{Annual Fuel Displaced}}$ = $234.6/MWh(t)

Site Insolation (Direct Normal)

Annual Average: 2346 MWh/m^2

Source: University of Houston

Site Measurements

Pyrheliometer readings at the Paint Creek site were started March 31, 1980, and will continue at least through the summer. Values are being recorded every 10 min, and tabulated on a daily basis.

energy output. At full solar power, the solar contribution is 55%. The overall solar plant efficiency, from direct solar insolation to gross electrical energy, is 21.4%. The EPGS net conversion efficiency is 41%. The annualized energy absorption systems performance characteristics are shown in Figure 1-8.

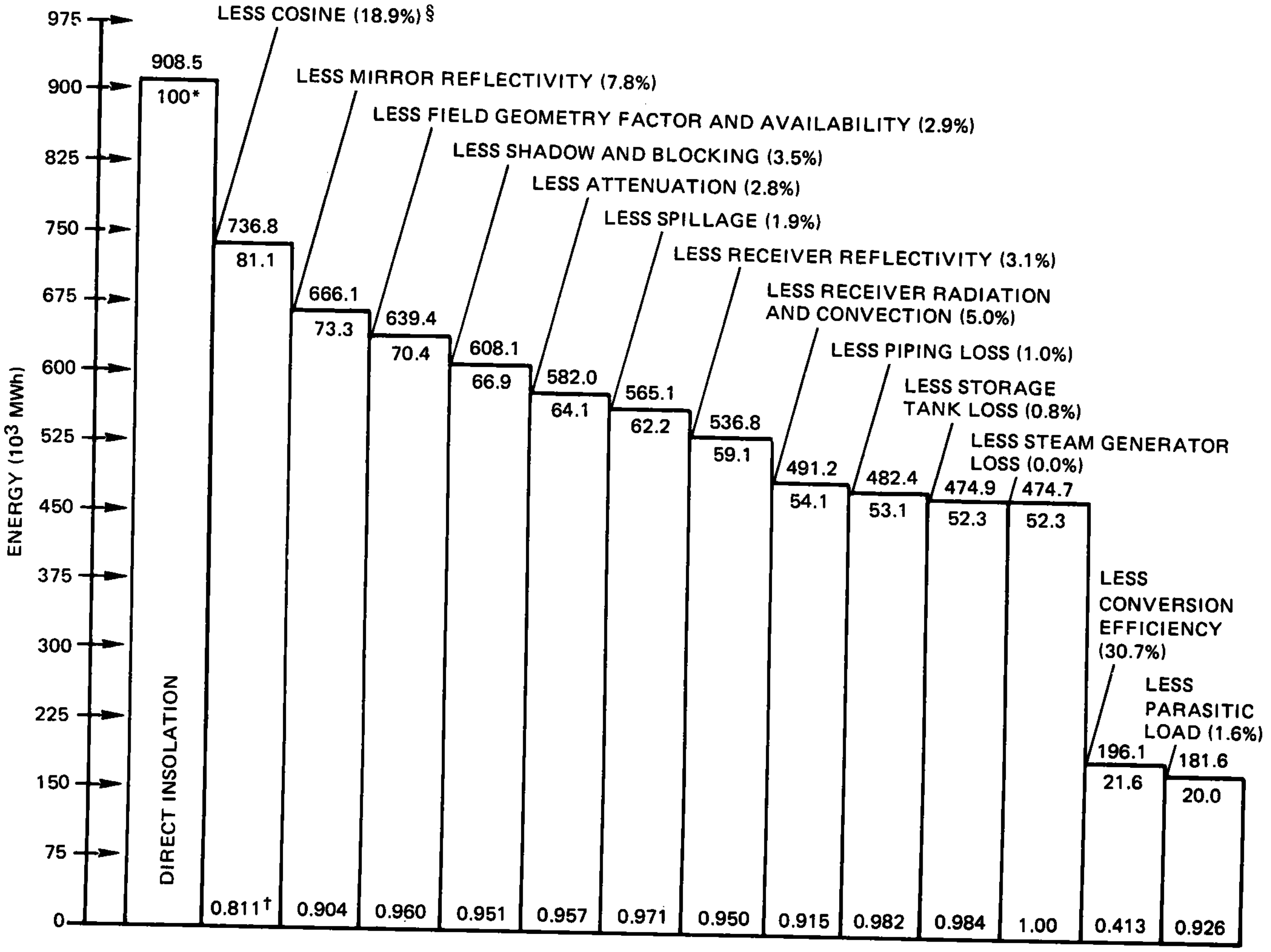
The numbers in parentheses give the efficiency of each process, and the numbers along the bottom of the chart give the cumulative efficiency through the indicated process. Figure 1-8 summarizes the performance characteristics for the entire solar plant. The collector field performance characteristics are given in Table 1-3.

TABLE 1-3

COLLECTOR SYSTEM PERFORMANCE CHARACTERISTICS

Insolation	
Design Point (W/m^2)	982, March 21, Noon
Annual, Clear Day (kWh/m^2)	3197
Annual, Average (kWh/m^2)	2346
Performance*	
Design Point Power (MWt/m^2)	226, March 21, Noon
Annual Receiver Energy [$MWh(t)/m^2$-year]	482,500
Hours at Nominal Power (h)	3327
Annual Average Efficiency	0.528
Flux Distribution	
Max Heat Flux (MWt/m^2)	1.23
Average Heat Flux (MWt/m^2)	0.334, Design Point
Max Panel Power (MWt/panel)	20.2 MWt
Max/Min Panel Power	4.56, Design Point
	6.0, Worst Time, Dec. 21, 4:00 p.m.

*Power level is based on MWt absorbed by the sodium and delivered to the storage tanks. This includes receiver system losses of 0.95 receiver absorptivity, and 18- and 1-MWt heat losses from receiver and piping, respectively.



*NET CYCLE EFFICIENCY (%)

†EFFICIENCY OF EACH CONVERSION STEP $\left(\text{FRACTION OF } \frac{\text{ENERGY OUT}}{\text{ENERGY IN}}\right)$

§THE PARENTHETICAL QUANTITY IS THE LOSS IN EACH STEP, AS A PERCENT OF THE INITIAL POWER

41028-18

Figure 1-8. Annual Average Energy Efficiency
(The overall conversion efficiency from insolation energy to net electric energy out is 20%)

1.6 ECONOMIC FINDINGS

1.6.1 Economic Analysis Results

Table 1-4 shows nominal values of economic factors used in the economic analysis of repowering the Paint Creek Station Unit 4 to the 60-MWe level. Tables 1-5 and 1-6 show the input data and results for the computer run made at 8% fuel escalation rate. The net capital cost for the solar-repowered Paint Creek Station is $139.8 million. The levelized busbar energy cost (BBEC) of 82.2 mills/kWh is based on an annual 199,620 MWh of electrical energy delivered from the solar plant with the plant operating at an annual plant capacity factor of 65% (reference design point). The 31-year payback period is based on the reference year (1980) value of fuel saved.

1.6.2 Thermal Storage Economics

The 1.56 solar multiple selected for solar repowering of the Paint Creek Station provides a winter solstice storage level of 1.73 h at 60 MWe (or 17 h at 6 MWe), and is sufficient to operate the plant at 6-MWe solar contribution on a limited continuous basis. This 1.73 h at winter solstice corresponds to available full-power energy storage of 3.8 h at equinox, and 4.4 h at summer solstice. The selection of design storage capacity after the solar multiple has been established is based on minimizing the annualized BBEC for a given set of economic parameters. As storage capacity is added, the solar operating hours and capital cost are increased. As long as the percentage change in solar operating hours increases faster than the percentage change in capital cost, it is cost effective to increase the design storage capacity. Because there is a limit on filling capability (maximum of 4.4 h at summer solstice), however, the return on capital investment in increased storage capacity goes to zero beyond 4.4 h. This indicates that there is an optimum value for design storage capacity which results in a minimum BBEC. This analysis was completed using incremental plant capital costs derived from thermal storage costs for various values of design storage capacity. The results are shown in Figure 1-9, which indicates minimum BBEC at 4.0-h design storage capacity. The trade study indicated that it was economic to increase the storage capacity from 1.73 to 4.0 h, after the solar multiple and mirror field size had been selected.

TABLE 1-4

NOMINAL VALUES OF ECONOMIC FACTORS

Symbol	Economic Factor	Nominal Value	WTU Value*
	Nominal Inputs		
	Utility Description Data		
N	System Operating Lifetime (from SDD)	30 years	30/22†
β_1	Annual "Other Taxes" as a Fraction of CI_{pv} §	0.02	0.0095
β_2	Annual Insurance Premiums as a Fraction of CI_{pv}	0.0025	0.0011
τ	Effective Income Tax Rate	0.40	0.45
D/V	Ratio of Debt to Total Capitalization	0.50	0.48
C/V	Ratio of Common Stock to Total Capitalization	0.40	0.44
P/V	Ratio of Preferred Stock to Total Capitalization	0.10	0.08
k_d	Annual Rate of Return on Debt	0.08	0.12
k_p	Annual Rate of Return on Preferred Stock	0.08	0.12
	General Economic Conditions		
g	Rate of General Inflation	0.05	0.08
g_c	Escalation Rate for Capital Costs	0.05	0.08
g_o	Escalation Rate for Operating Costs	0.06	0.08
g_m	Escalation Rate for Maintenance Costs	0.06	0.08
y_b	Base Year for Constant Dollars	1975	1980
	Nominal Intermediate Outputs		
k	Cost of Capital to (and internal rate of return in) a "Typical" Utility	0.08	0.1095
$CRF_{k,N}$	Capital Recovery Factor (8%, 30 years)	0.0888	0.1146**
FCR	"Typical" Annualized Fixed Charge Rate	14.83%	17.22%

*Reference telecon dated May 12, 1980, L. Glasgow to R. Stanaland, "Economic Factors"

†WTU uses straightline depreciation for book value; SDD for tax purposes.

**10.95% for 30 years

§Present value capital investment

TABLE 1-5

WTU PAINT CREEK ECONOMICS
INPUT DATA

```
***RUN DATE IS 25 JUNE 1980 ECONO4 SOYD= 22.000 YRS,ST LINE= 30.000 YRS
FUEL IS NATURAL GAS STANDBY TURNDOWN =  45.455 %

SYSTEM LIFE =  30.000 YEARS
QUOTE YEAR             1980.000
INITIAL OPERATION =  1985.000  CONSTRUCTION PERIOD= 4.000 YR
TOTAL OPERATING HOURS= 5694.000 H  SOLAR HOURS= 3327.000 H
CF SOLAR= .380   CF TOTAL= .650
FUEL COST= 2454.936 $/HR,  BASED ON 2.188 $/MBTU
SAVINGS $= 4.455 $M/YR,  YEARLY FUEL $= 9.800 $M/YR
NET STATION SIZE= 110.000 MWe   SOLAR POWER= 60.000 MWe
NET STATION HEAT RATE= 10200.000  TD HEAT RATE= 10958.678 BTU/KWHe
CAPITAL COST =  139.800 M  CAPACITY CREDIT= 0.000 M
 NET CAPITAL COST 139.800 M
INITIAL ANNUAL O&M COST =  1.566 MILLION
CRF(k,N)= .115  ESCALATION= .681  GEN.INTEREST= 10.948 %
PV FACTOR-O&M= 29.833 -FUEL= 29.833
FIXED CHARGE RATE =  17.220 %
ANNUAL CAPITAL ESCALATION RATE =  8.000 %
ANNUAL O&M ESCALATION RATE =  8.000 %
FUEL ESCALATION= 8.000 %  GEN. INFLATION= 8.000 %
FUEL O&M= 0.000 %
DISCOUNT RATE,k=  10.948 %
INVESTMENT TAX CREDIT, Alpha =  0.000 %
CORPORATE INCOME TAX RATE, Tau =  45.000 %
(Beta 1 + Beta 2), Beta =  1.060 %
```

TABLE 1-6

WTU PAINT CREEK ECONOMICS
ECONOMIC FINDINGS

```
AC= .179 CIT+ 2.326 OMT+ 2.326 FLT+ 0.000 FLT
CONSTRUCTION COST FACTOR                    1.042
ACcap= 25.078    ACom= 3.642    ACfuel= 22.792    ACFLOM= 0.000
ACfuel saved= 10.362
COST= 28.719    BENEFIT= 10.362
PAYBACK PERIOD= 31.380 YR    PLANT VALUE=$ 50.439 MILLION
BBECcap= 40.038  BBECom= 5.814  BBECfl= 36.390  BBECTOT= 82.242 MILLS/KwH
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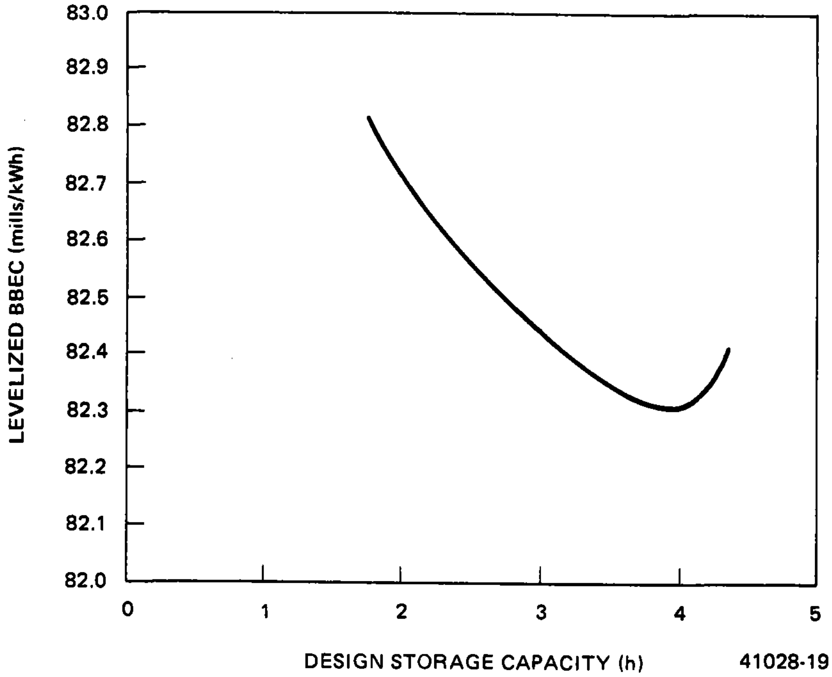

Figure 1-9. Design Storage Capacity Optimization

Appendix C of the full report provides a detailed analysis for the design storage capacity selection.

1.6.3 Collector Field Economics

A north-only collector field using a flat plate receiver was compared to a surround field with a more conventional cylindrical receiver. Table 1-7 lists the major component sizes and costs, and shows that the north-only field concept was slightly less in unit cost than the surround field [$0.248/kWh(t) vs $0.259/kWh(t)]. This was basically due to the presence of the lake south of the WTU site. For the condition of no land restraints, the costs were equal at this power level. However, larger commercial-type units have economics which favor the surround field, and it is for this reason that the surround field concept was selected.

The finding here is that a flat-plate receiver is economically beneficial for this small plant with a south field restriction. For larger plants (>70 MWe), or plants with a south field availability, there is no economic benefit.

TABLE 1-7

FLAT-PLATE vs CYLINDER RECEIVER

Parameter	Cylinder		Flat-Plate	
	No Land Restraints	WTU Site	No Land Restraints	WTU Site
Thermal Power Rating (MWt)	226	226	226	226
Receiver Focal Height (m)	140	150	170	180
Receiver Diameter or Width (m)	13	14	19	19
Receiver Height (m)	14.3	15.4	28.5	28.5
Number of Heliostats	7830	7882	7586	7593
Land Area (acre)	408	430	474	507
Pipe Run (m)	-	434	-	213
Max. Heat Flux (MWt/m^2)	1.55	1.43	1.51	1.54
Max. Flux/Avg. Flux	4.0	4.3	3.62	3.69
Total Costs (10^6 $)	104.16	115.82	103.35	109.99
Heliostats + Wiring + Land	90.40	91.28	88.18	88.43
Receiver	5.72	6.24	5.46	5.46
Tower*	3.53	4.18	4.67	5.97
Pump	0.74	0.80	0.95	1.02
Piping	1.16	1.30	1.47	1.67
Fixed	2.62	2.62	2.62	2.62
Pipe Run	-	4.70	-	2.31
Pipe Thermal Loss	-	4.04	-	1.98
Land Fill	-	0.38	-	0.60
Reliability (Valves)	-	-	-	-0.34
Power Line Relocation	-	0.28	-	+0.27
Energy Absorbed [MWh(t)/year]	447,000	447,000	442,000	442,000
Figure of Merit [$/kWh(t)]	0.233	0.259	0.234	0.248

*Includes a portion of fixed costs $0.47\ (FL/116)^2$

1.7 DEVELOPMENT PLANS

1.7.1 Design and Construction Schedule

The overall system planning for the WTU Paint Creek Station Unit No. 4 Repowering Program has been approached from the standpoint of organizing the work into logical major contract elements. These work packages will be handled by separate general contractors, since each consists of more than a single trade or discipline. The major elements have been identified as follows:

1) Site preparation
2) Foundations, steel structures, and receiver tower
3) Receiver
4) Collector system
5) Steam generator system
6) Storage tanks
7) Heat transport system (HTS).

The construction schedule and development plan shown in Figure 1-10 indicates that initial construction activity is work associated with site preparation. Soil tests and a site survey will be conducted in parallel with the environmental assessment study. Necessary grading, road construction, and other ground surface operations will be performed in advance of U.S. Government (DOE) construction authorization.

Work during the preliminary design phase (after contract award) is directed toward preparation of specifications for the various components and systems. As final design work is initiated, many of these specifications are developed into procurement packages, and go into the bid and award cycle. Installation of foundations and the structural steel work are combined under a single contractor, because of the close interrelations between the two activites. The steel work will precede any component or piping installation, since much of the steel provides support for these items.

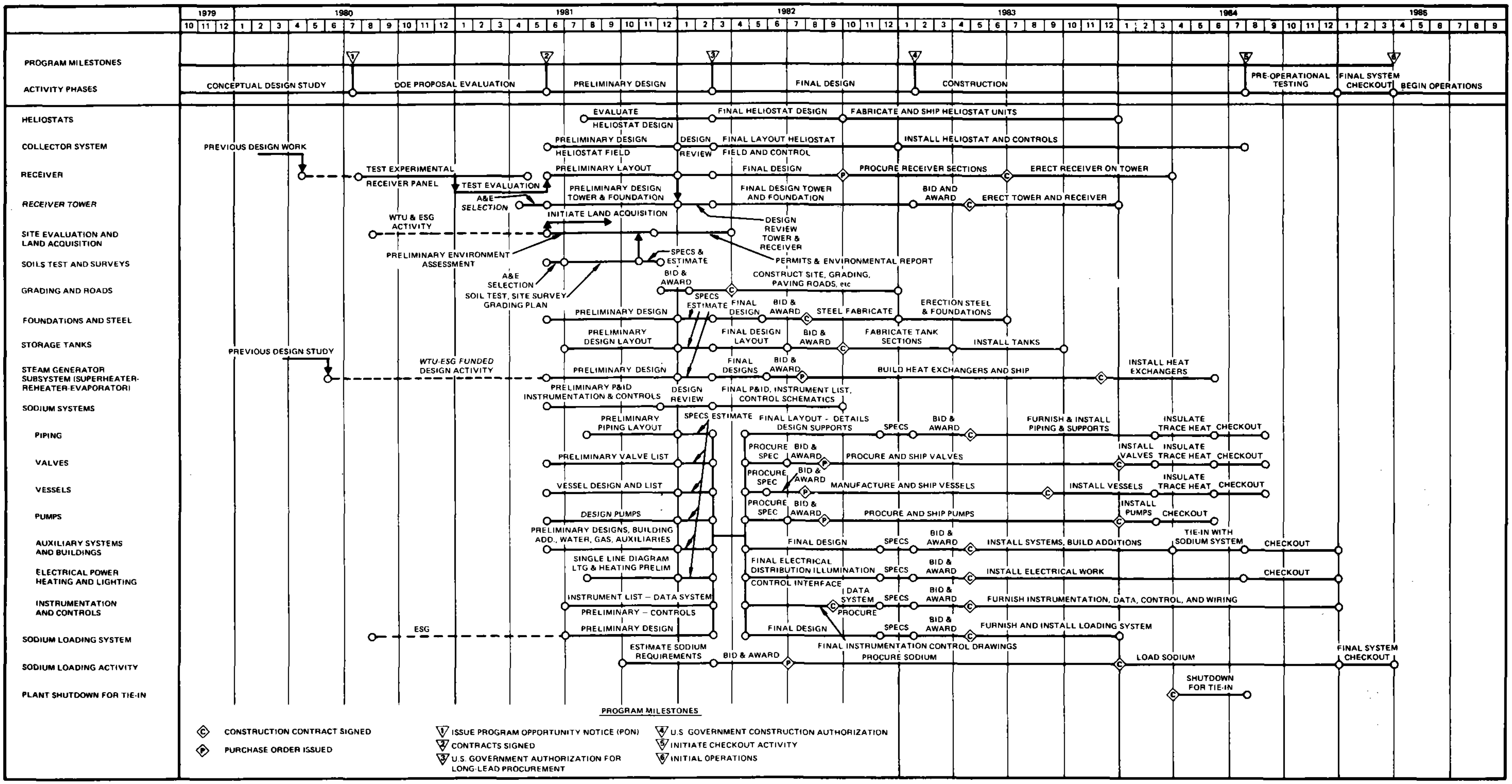

Figure 1-10. Construction Schedule and Development Plan

The concrete receiver support tower and the receiver assembly are primarily structural, and will be handled by a structural contractor. The receiver system, consisting of large prefabricated heat exchanger panels, buffer tanks, and riser and downcomer piping, will be installed following the structural work completion. Construction aids, such as hoists and elevators, are part of the equipment included in this installation.

The concrete tower is considered standard state of the art for jump-form concrete construction, and presents no anticipated problems. The receiver conceptual design is presently under test at the CRTF, Albuquerque, New Mexico. The test and evaluation of the receiver design is scheduled for completion by mid-1981, and will support the WTU Paint Creek Repowering Program schedule.

The collector system and the heliostats will be designed, fabricated, and installed by the Boeing Engineering & Construction Company. This system includes all of the controls and instrumentation required to operate and control the heliostats. Boeing will also perform a final checkout of the collector system, after the installation has been completed. The schedule shown for this system is consistent with that provided by Boeing, and accommodates the overall DOE plan for implementing the repowering program.

The steam generator system consists of a steam generator, superheater, and reheater. Each is of a different physical size, but the design of each is based on the Rockwell-developed and -tested high-temperature modular steam generator. Final design and fabrication will be performed by Rockwell. These components require a substantial leadtime for fabrication, because of the high level of quality assurance involved and the many inspections performed between successive production steps. The schedule shown for the steam generator system is success oriented, and can be considered to be the critical path for the installation program.

Extensive design work has already been performed on the steam generators, both in the Clinch River Breeder Reactor Program (CRBRP) and under Rockwell-funded in-house programs. This effort is ongoing at the present time, and will continue during the latter part of 1980 and into 1981, while DOE is evaluating the PON response. This work and existing designs will be utilized to the fullest extent, to minimize the procurement cycle and to develop steam generator systems which will provide a high level of confidence.

The two sodium storage tanks (nearly 2 x 10^6-gal. capacity each) are major items, and are considered a procurement sufficiently large and unique to warrant handling as separate items. The designer and fabricator will also be the erector and installer. These tanks are considered to be within the state of the art, and will be fabricated in accordance with API Standard 650.

The sodium heat transport system is considered to be a single contract group. Most of the sodium-wetted components are special-order items; consequently, a long procurement leadtime is allowed for these devices.

WTU

WEST TEXAS UTILITIES COMPANY

GENERAL OFFICE: P.O. BOX 841 / ABILENE, TEXAS 79604 / (915) 672-3251

Randal G. Meador
Vice-President
Director of Engineering

July 15, 1980

"To Whom It May Concern"

As a result of scoping-type design and cost studies that were performed prior to the issuance by DOE of RFP DE-79SF-10506 in March, 1979 and as a result of studies performed in the process of preparing the proposal that the Energy System Group of Rockwell International and West Texas Utilities Company submitted to DOE in May, 1979, WTU concluded that the solar central receiver concept had considerable potential as a viable energy option for electric power production. In particular, the central receiver system provided a potentially effective means for reducing the consumption of natural gas, meeting some of the requirements of the National Energy Act, and extending the life of some of WTU's existing power plants which might otherwise have to be replaced before their normal retirement dates at considerable cost to the utility customer.

Since the concept appeared to merit further evaluation, specifically in a repowering application, WTU and ESG embarked upon a more detailed conceptual design and economic assessment of a sodium-cooled, solar central receiver concept for Paint Creek Unit No. 4 using private funding. This study was initiated in November, 1979 and has now been completed. The depth of detail achieved during the study corresponded, in a general way, to that called for in the above referenced RFP. However, because there was concern about the reliability of operation of the existing plant and the solar plant under a wide range of operating modes a special effort was made to design the control system to meet all of the requirements imposed by the operating staff at Paint Creek and by the engineering staff at WTU. Having completed the conceptual design and obtained revised cost estimates on the basis of that design, WTU had undertaken a separate evaluation and assessment of the repowering concept for Paint Creek Unit No. 4. This assessment has included, among other considerations, the technical feasibility, the state of the art of the technology (including components) for meeting a 1985 start operation, the acceptability of the use of sodium as a heat transfer fluid, environmental impacts, the potential for becoming economically viable, and the potential for reliable operation. This assessment, which was carried out by WTU and represents the WTU position at this time, is included in the following Section 1.8.

Sincerely yours,

Randal G. Meador

A MEMBER OF THE CENTRAL AND SOUTH WEST SYSTEM

Central Power and Light *Corpus Christi, Texas* | Public Service Company of Oklahoma *Tulsa, Oklahoma* | Southwestern Electric Power *Shreveport, Louisiana* | West Texas Utilities *Abilene, Texas*

1.8 SITE OWNER'S ASSESSMENT

1.8.1 Project Worth

In terms of the monetary worth of repowering Paint Creek Unit No. 4, the cost and benefits, as presented in this report, have been determined, based on numerous economic variables. This benefit is very sensitive to fuel escalation. Therefore, the determination and selection of the proper fuel escalation is very important in accurately determining the dollar value of the plant to WTU. Prior to 1973, the average annual escalation for fuel to WTU was ~2%. After the Arab oil embargo, natural gas prices rose at a rate of ~49%/year until 1978. Since then, natural gas has only escalated at 5% per annum. To determine future prices based on past performance would be difficult indeed. Since an error on the high side of the fuel escalation estimate would cause their customers to pay a higher rate for electricity than would have otherwise been experienced, WTU feels that it is necessary to assume a rather conservative figure. For the purpose of this study, as well as other ongoing West Texas Utilities and Central & Southwest fuel studies, an escalation factor of 8% is currently being utilized. With this assumption, a plant benefit will be derived.

The repowering project also has other benefits to WTU. The installation of a solar plant will initiate a plan to diversify energy sources. Currently, WTU is dependent only on natural gas as a fuel supply. Although fuel oil is utilized as an emergency fuel supply, most units are not capable of burning the oil on an extended basis. Current governmental regulatory requirements to stop the burning of natural gas as a boiler fuel will cause financial problems, if WTU is forced into a complete system conversion. Diversified fuel sources would prevent the necessity of a complete fuel changeover in the future. The solar repowering would also allow WTU to extend the life of Paint Creek, if a permanent exemption for a fuel mix is granted under the Fuel Use Act. Early retirement and replacement of Paint Creek Unit No. 4 with coal-fired generation would be wasteful and expensive. It should be noted, however, that the time frame for repowering existing units is limited. If the repowering program is delayed too long, many of the candidate units from our company and other companies would become unavailable for repowering, due to their age.

The solar repowering of Paint Creek also has value to WTU in terms of public relations. The construction of a solar-repowered plant at Paint Creek would be a demonstration to our customers that WTU is serious about reducing future costs of power and developing new energy sources.

1.8.2 Other Repowering Opportunities

Several other WTU power plants were considered for repowering. The other plants examined were:* Lake Pauline Power Station, located near Quanah, Texas; Rio Pecos Power Station, located near Girvin, Texas; Oak Creek Power Station, located near Blackwell, Texas; and Fort Phantom Power Station, located near Abilene, Texas. The candidate plants were then evaluated, based on the age and size of the generating units, the adaptability of the plant site and surrounding area to the repowering concept, and the availability of operating resources, such as manpower, water, and effects on the surrounding area. This analysis lead to the selection of Paint Creek Unit No. 4, and possibly Paint Creek Unit No. 3.

Lake Pauline Power Station has sufficient land adjacent to the plant for utilization of a mirror field. The lake supplying cooling water to the power plant has been so low that it was necessary to limit output, in order to conserve water, at several times in the past. It was considered that this lake could be questionable as a dependable source of cooling water in a repowered plant, considering the investment. The two units at Lake Pauline are 19 MW and 29 MW, with the 19-MW unit constructed in 1928 and the 29-MW unit constructed in 1952. These units are not of sufficient size to provide an adequate scale-up from the Barstow unit, and are too old to have sufficient life left in them to adequately demonstrate the repowering concept. For these reasons, Lake Pauline was not selected as a repowering unit.

Rio Pecos Power Station has three units. Unit No. 4, a 4-MW General Electric gas turbine, runs in combined cycle with Unit No. 5, a 35-MW steam turbine generator. Rio Pecos Unit No. 6 is a 95-MW steam turbine generator. Units No. 4 and 5 were built in the early 1950's, and Unit No. 6 was completed in 1969. Cooling water is supplied to the plant from a well field, located ~6.4 km (~4 miles) from

*See inside back cover.

the plant site. This well field will only provide a marginal supply of water to the plant. Sufficient land is available adjacent to the plant site for construction of a heliostat field. Unit No. 6 is considered to be of optimum size for demonstration of repowering, and its age is sufficient to adequately demonstrate a reasonable life for repowering. However, current fuel costs for this plant are considerably lower than for other plants, thereby reducing its worth at this time for solar repowering. Considering this economic reasoning, Rio Pecos No. 6 was not selected for repowering at this time.

Fort Phantom Power Station has two units, a 155-MW steam turbine generator and a 200-MW steam turbine generator. The plant site is located on a peninsula extending into Lake Fort Phantom Hill, and the topography of the area would make it difficult to construct a heliostat field close to the existing plant. Adequate water for cooling is available at this site. Both Unit No. 1 and Unit No. 2 were considered to be too large to be repowered, at this time, with sufficient percentage of the power to the unit being supplied by solar boilers. Unit size and land restrictions were the reasons this plant site was not selected for the repowering project.

Paint Creek Power Station seemed to provide the optimum power station in the WTU system for consideration of repowering. Unit No. 3, a 53-MW steam turbine generator, and Unit No. 4, a 110-MW steam turbine generator, were considered for the repowering project. Unit No. 3 was constructed in 1959, and Unit No. 4 was constructed in 1970. Careful study indicated that Unit No. 4 would provide the best candidate for repowering. Consideration was also given to utilizing the repowering system to repower Unit No. 3 at some time in the future. The Paint Creek site offers sufficient land of suitable topography adjacent to the plant site, and an adequate supply of water, labor, and other operational resources.

WTU feels that the sodium central receiver repowering technology being developed in this conceptual design study is applicable to most, if not all, of the other units on the WTU system. This application can be made with minimum redesigning, due to the versatility of the sodium system. Although the technology is presently well developed, its acceptability by the utility industry will be dependent upon a demonstration unit of sufficient size, typical of a number of operating units currently in service.

This demonstration will provide the proof to make solar energy a reasonable, proven, and cost-effective answer to repowering existing units in the future.

1.8.3 Operational Impacts

Repowering Paint Creek No. 4 with solar power will impact the operations of the Paint Creek Power Station. Completion of this project will require an increase in the plant work force. Additional maintenance personnel and operational personnel will be required to operate the repowered plant. It is expected that this program will have a decidedly good effect on plant morale. The increase of the work force will create new positions, which will allow advancement for certain personnel in the existing work force. Additionally, the opportunity to work with a new and important technological advance is always a challenge to any good worker, and would have a decidedly good effect on the morale of all people working with this project. Most important to the company operations would be the effect the repowering plant would have on the fuel cost. The solar repowering would decrease the amount of scarce natural gas used by WTU in its system, and would reduce the fuel cost charges WTU assesses its customers.

1.8.4 Safety Considerations

Utilities have historically had good safety records for employees in power plants, and WTU is no exception. When WTU became involved in this study for solar repowering, using liquid sodium as a heat transfer medium, care was taken to investigate the employee and environmental safety considerations. It was evident that, with the combination of a safely designed plant, employee education about the characteristics of sodium, and the utilization of safety equipment, the sodium system could be operated as safely as existing fossil-fired plants. Past industrial experience reinforces this opinion. The handling of potentially dangerous material is not new to the utility industry, and includes the handling of the following materials:

1) Hydrogen
2) Compressed air and gas
3) Natural gas
4) Polychlorinated biphenyls
5) Chemicals that are highly caustic or acidic
6) Superheated steam.

With the built-in safeguard of proper design and safety commitment by employees, we do not foresee any hazards which would prevent the construction and operation of a solar plant utilizing liquid sodium as a heat transfer medium.

1.8.5 Environmental Impacts

The construction of a repowering system at Paint Creek Power Station would have a beneficial effect on the environment at that location. Repowering with solar would reduce the amount of exhaust products produced by the plant and admitted into the atmosphere. This reduction of air pollution would be the largest environmental advantage of the project. Some environmental problems could be expected from the construction of the 1.74 x 10^6 m^2 (430-acre) heliostat field north of the existing plant. However, it is expected that these impacts will be minimal, in that they will not be creating an appreciable impact on area agricultural production nor will they cause a displacement of area wildlife. The advantages accruing to the area by the conversion of land use from agricultural to industrial will far outweigh any environmental problems created by destruction of agricultural production. Operation of the repowered plant will have no effect on water quality at or near the plant site. Analysis of accident contingencies does not indicate any adverse environmental effects that might result from a massive loss of sodium into the air. This particular problem has been examined extensively by the Environmental Monitoring and Services Center and by Research & Engineering, both of which are a part of the Energy Systems Group of Rockwell International.

Some stabilization of stream beds and lake shore may be necessary in the construction of the heliostat field. This work is not expected to impact water quality in Lake Stamford, or to cause any change in runoff produced by the land adjacent to Lake Stamford. Stabilization work will be conducted in an environmentally acceptable manner, and will not result in any areas that are not useable.

1.8.6 Development Plan and Schedule

The only major component which will require development for the solar repowering of Paint Creek Unit No. 4 is the receiver. WTU believes that the plan and schedule time for the development of this item is adequate, considering the design work that has been done in this area. The program and construction schedule, as provided in this report, is somewhat tight in places; but the plant can no doubt be designed and constructed within this time frame, assuming there are no unusual delays in critical items and regulatory and environmental permits, and DOE programmatic approvals.

1.8.7 Alternatives to Repowering

There are various alternatives available to WTU, other than repowering with solar power. Consideration has been given to conversion of Paint Creek Unit No. 4 to coal. Such a conversion would have problems associated with the water supply, plant site configuration, the lack of rail facilities serving the plant, adverse asthetic impact on the recreational community surrounding the lake shore, and extreme expense of such a conversion. Converting Paint Creek Power Plant to coal would require the construction of 24.1 km (15 miles) of rail line to Haskell, connection with the Fort Worth and Denver spur at Haskell, and upgrading of the Fort Worth and Denver line back to Wichita Falls, Texas. Site configuration would also present a problem, because the existing plant severely restricts the amount of space available to construct a boiler between the plant and the lake shore without filling in a large portion of the lake shore. The other side of the plant is severely restricted by the construction of a large substation immediately adjacent to the plant. The use of coal would require an increase in the water consumption of the plant per megawatt of electrical power generated, and this increase in water use would place a severe strain on the water supply of Lake Stamford. There is recreational housing around the shores of Lake Stamford, south and west of the plant site. The conversion of the plant to coal could possibly create asthetic problems to these neighboring residents.

Provisions of the Fuel Use Act require that WTU convert its existing gas- and oil-fired plants to coal, nuclear, or some alternative fuel by 1990. Although there is a possibility of obtaining exemptions for certain of WTU's plants under the Fuel Use Act, it is not clear at this time whether WTU will be able to qualify for any of these exemptions. WTU is hopeful that exemptions may be obtained in the future, or that changes can be effected in laws that will allow our gas-fired power plants to be used to the benefit of their customers for their full designed life. If this possibility does not develop, then WTU will be forced to seek alternative uses for their power plants, or abandonment of these power plants by the year 1990.

The development of a cost-effective and demonstrated operational technology of repowering would have an advantage to WTU, in that there would be an alternative to coal and nuclear conversion of our system. A cost-effective solar-energy repowering program would be applicable to nearly all of the units in the WTU system.

1.8.8 Central Receiver Technology

The technology that is currently being utilized in the conceptual design of Paint Creek requires little or no development. Many of the sodium components, such as pumps, valves, heat exchangers, and piping used in solar plants, are taken from the nuclear industry. The heliostats have and will continue to be demonstrated to be technically sound. WTU believes that the technology is currently available and feasible for central-receiver solar repowering by the year 1985. The only serious question about the future of solar plants is whether the cost, principally that associated with heliostats, can be lowered to the expected levels to make solar power economically feasible.

1.8.9 Institutional and Regulatory Considerations

Completion of the solar repowering of Paint Creek Unit No. 4 will require support from the institutional and regulatory community. A number of permits will be required from various regulators, and contact and support will be necessary from various institutions. The ultimate success of the repowering program will be largely dependent upon the favorable considerations given to it by the regulatory community. WTU hopes that the regulatory community will aid the project by allowing inclusion of the funds necessary to repower Paint Creek No. 4 into WTU's rate base, and allowance of the additional operational charges into WTU's operational budget. It is also hoped that the Department of Energy will be able to grant Fuel Use Exemptions to allow plants that have been repowered to effectively utilize natural gas for production of power to supplement solar insolation, and to supply our customers during times when solar insolation is not available. WTU also realizes that construction of the first repowering units will be possible only through financial support from the Department of Energy, as well as aid from the regulatory community, as stated previously.

It is anticipated that the environmental regulatory community will support solar repowering, because of the less adverse impact of solar than is available with either coal or nuclear energy. WTU's contacts with various regulatory agencies dealing with environmental matters have indicated that most regulators realize the advantages of solar power. We hope that this realization extends to the granting of permits for construction of a repowered project.

WTU has received good public support in this conceptual design project, and believes that public area support would be available to us for the construction of the repowering program. Our contacts with local congressmen and civic leaders have indicated their firm support for the project.

1.8.10 Land Availability

The two property owners on whose land the collector field would be partly located have been approached and told of the purpose of the study, and that there was a possibility of WTU purchasing the land needed for completion of this repowering project. The landowners indicate that they would be willing to discuss this when we were in the position of being ready to buy the land. WTU believes that the land will be available when necessary, based on the contacts made on this occasion and from previous dealings on other matters.

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