1043

Solar Thermal Repowering

Central Receiver Systems

January 1980

Sandia Laboratories | Livermore

San Francisco Operations Office

INTRODUCTION

After a significant potential market for Solar Thermal Systems was identified by several independent studies[1,2,3] the U. S. Department of Energy issued a solicitation in March 1979 for Utility repowering/Industrial Retrofit system conceptual design studies employing central receiver systems technology. Twenty-two responses were evaluated and twelve were selected for funding. These twelve studies, when completed this year, plus one study already completed[2] and one privately funded will provide the basis for several demonstration projects to be constructed and operational by 1985. Six of the twelve studies are for electric utility repowering of existing oil or natural gas fossil fuel generating plants and the other six are the first site-specific studies of the use of solar central receiver systems to supply energy to a variety of industrial processes. These industrial processes include gypsum board drying, oil refining, enhanced oil recovery, uranium ore processing, natural gas processing, and ammonia production.

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[1] "Solar Thermal Repowering, Utility/Industry Market Potential in the Southwest," Mitre Corporation, MTR-7919, December 1978.

[2] "Technical and Economic Assessment of Solar Hybrid Repowering," Public Service of New Mexico (PNM), SAN/1608-4-1, September 1978.

[3] "Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat," Battelle Columbus Laboratories, TID-27348-1, January 1977.

PROGRAM OBJECTIVE

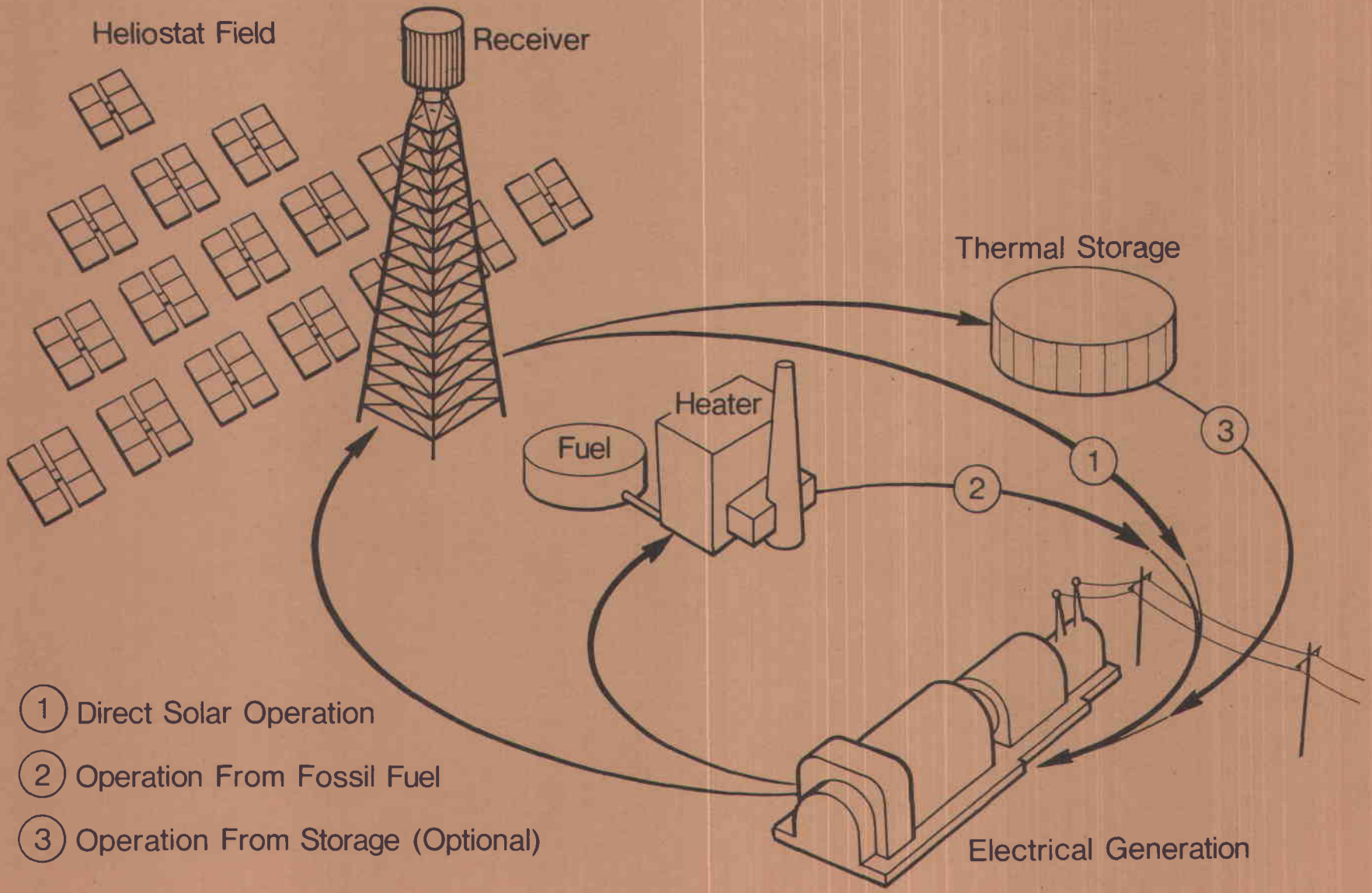
A draft Solar Thermal Central Receiver Repowering Program Plan, released January 1980 and being circulated within industry and government for comment, has as its objective increasing user confidence and experience with central receiver technology to the point that it becomes a probable renewable energy system choice for future private investment. The steps toward commercialization have progressed from design and testing of individual central receiver components at DOE test facilities like the central receiver test facility (CRTF) at Sandia Laboratories in Albuquerque, New Mexico, to design and near-term construction of a cost-shared* technical demonstration of central receivers in an electric utility setting at Barstow, California. The Barstow plant will generate 10 megawatts of electricity to be put on Southern California Edison's power grid system. The next steps toward commercialization are to provide valid demonstrations of central receiver technology in a variety of commercial settings under direct control of the industries involved.

These repowering/industrial retrofit demonstration projects will provide practical hands-on experience in true industrial settings by interfacing with existing commercial plants. The solar central receiver systems will be used to displace fossil fuels normally used. These projects will provide continued demand for design and fabrication of central receiver components (e.g., receivers and heliostats), and will also supply economic data which could be the basis for some initial, privately funded commercial applications of central receiver technology. These projects are essential steps toward commercialization.

The following pages briefly summarize each of the utility repowering/industrial retrofit conceptual design projects. These summaries include the PNM repowering study already completed and the 13 project studies (including the privately funded study) currently underway. The conceptual designs are representative of actual plants that could be constructed if funding were approved.

*The partners are Southern California Edison, Los Angeles Department of Water and Power, and the State of California Energy Commission.

SOLAR REPOWERING-Electrical Generation



(1) Direct Solar Operation

(2) Operation From Fossil Fuel

(3) Operation From Storage (Optional)

ARIZONA PUBLIC SERVICE–Saguaro Power Plant, Unit 1

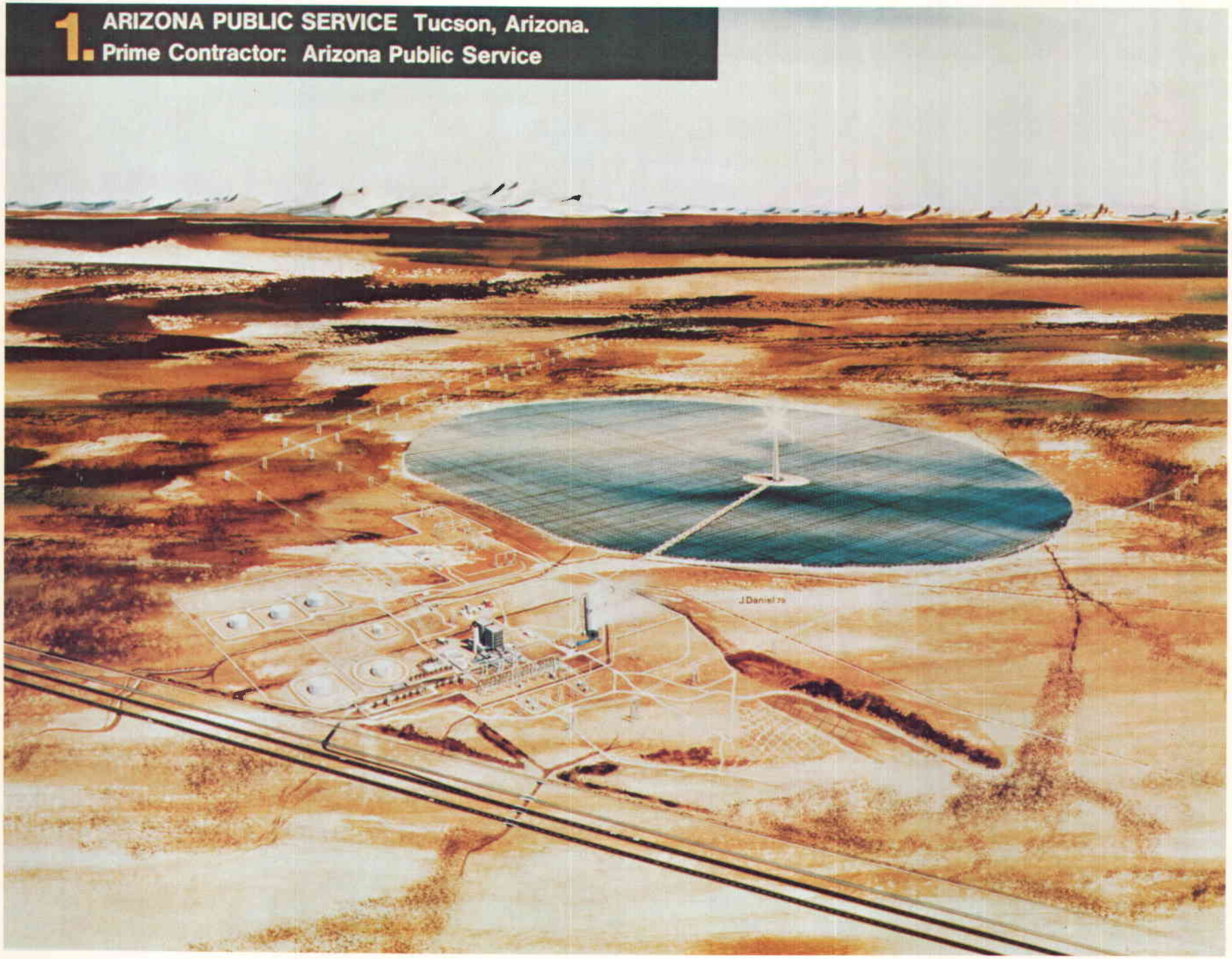
PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
Arizona Public Service Co. P. O. Box 21666 Phoenix, AZ 85036	Eric R. Weber	Martin Marietta Corp. Badger Energy, Inc. Gibbs & Hill, Inc.	September 24, 1979– July 15, 1980

SITE DESCRIPTION–Arizona Public Service Company's Saguaro power station is located between Phoenix and Tucson approximately 75 miles south of Phoenix. The Saguaro station is situated on a triangular-shaped piece of land east of Interstate Highway 10 and the Southern Pacific rail line. The sections immediately surrounding the APS section are state owned. These sections, now devoted to cattle grazing, have been reserved by the State of Arizona for the solar repowering project. The Saguaro Station consists of two oil/gas-fired steam units having electrical outputs of 115 and 99 MWe. Also, the station has two-55 MWe combustion turbines that serve as peaking units. The steam units are used for intermediate power production and were installed in 1954 and 1956. Based upon solar monitoring stations in Tucson and Gila Bend, the Saguaro Station site is projected to have an average direct normal insolation of 7.60 kWh/m^2-day.

PROJECT SUMMARY–The portion of the Saguaro station selected for repowering is the 115-MWe oil/gas-fired steam plant designated as Unit 1. The concept being pursued involves repowering 60 MWe of the 115 MWe unit. Saguaro plant Unit 1 contains a single-admission, non-reheat turbine using 1000°F and 1475 psia steam supplied by an oil/gas-fired steam generator, rejecting waste heat to a forced-draft wet cooling tower. The proposed level of repowering results in a solar capacity factor of 0.4 which corresponds to 72% of the energy obtained from the No. 1 unit in 1977.

CONCEPTUAL DESIGN–Baseline design for solar repowering is the central receiver power tower concept using molten salt (60% sodium nitrate, 40% potassium nitrate) as the receiver heat transport fluid. Tower height is 459 ft with a surrounding collector field of 8985 heliostats. The receiver is a four-aperture cavity-type with dimensions of 59 by 64 and 51 ft high. Hot molten salt is pumped to the thermal storage subsystem. Three hours of thermal storage at 60 MWe is provided by a storage subsystem comprised of an internally insulated hot salt tank and an externally insulated cold salt tank. Hot molten salt, at 1050 F, is pumped from the hot tank to a salt/steam heat exchanger subsystem made up of a preheater, boiler, evaporater, and superheater supplying 1000°F, 1475 psia steam to the Saguaro Unit 1 steam turbine. The solar plant interfaces with the Saguaro Unit 1 main steam line to the turbine inlet and at the feedwater line to the fossil steam generator.

1. ARIZONA PUBLIC SERVICE Tucson, Arizona.
Prime Contractor: Arizona Public Service



EL PASO ELECTRIC COMPANY–Newman Unit 1

PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
El Paso Electric Company P. O. Box 982 El Paso, TX 79960	James E. Brown	Stone & Webster Westinghouse	September 30, 1970– July 15, 1980

SITE DESCRIPTION–Newman Station is located in a rural area at the north end of the City of El Paso, 15 miles northeast of the downtown area, and 12 miles from the El Paso SOLMET weather station. Newman Station consists of four electric power generating units rated at a combined total of 498 MWe. Newman Unit 1, the unit selected for solar repowering, is an 82.3-MWe (net) gas/oil-fired reheat steam turbine, built in 1960. The Newman 3,500-acre site is nearly flat. The land is owned by El Paso Water Utilities Public Service Board, and the Board agreed in a public meeting held April 25, 1979, in El Paso, to make the land available for Solar Repowering. The average direct normal insolation is estimated to be 7.26 kWh/m^2-day.

PROJECT SUMMARY–The baseline design utilizes water/steam central receiver technology to provide main and reheat steam to the turbine-generator. Fossil energy supplements solar-generated steam for intermittent cloudy day operation when solar energy is not available. Steam generated by the solar subsystem will be mixed with that from the existing fossil steam generator before entering the turbine.

CONCEPTUAL DESIGN–The external central receiver concepts (primary and reheat) for the baseline are based on the improved water/steam-pumped recirculation central receiver boiler technology being developed by DOE that is familiar throughout the utility industry. Primary receiver length is 92 ft and the diameter is 60 ft. The reheat receiver is 16.5 ft long with a diameter of 90 ft. This technology was selected on the basis of utilizing commercial/utility boiler design approaches, using conventional boiler materials with known properties and demonstrated lifetimes. Thermal energy storage systems will be considered in the proposed study. The heliostat field consists of 4735 heliostats and provides 225 MW(t) at the receivers located on a 560-ft tower.

2. EL PASO ELECTRIC El Paso, Texas.
Prime Contractor: El Paso Electric

PUBLIC SERVICE COMPANY OF OKLAHOMA–Northeastern Station Unit 1

PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
Black & Veatch Consulting Engineers 1500 Meadow Lake Parkway P. O. Box 8405 Kansas City, MO 64114	Sheldon Levy	Public Service Co. of Oklahoma Babcock & Wilcox Co. Bailey Controls Co.	September 13, 1979– July 15, 1980

SITE DESCRIPTION–Northeastern Station at Oologah, Oklahoma, is the study site for this DOE solar repowering project. Owned by Public Service Company of Oklahoma (PSO), the station has four operating units. Northeastern Station Unit 1 (NES 1), gas/oil fired, has a rated net output of 150 MW; steam conditions are 1800 psi, 1000/1000°F. Unit 2 has a net output of 450 MWe. The other two units, 3 and 4, are located on the same site about one-half mile south of Units 1 and 2. They are supercritical units rated at 450 MW, have steam conditions of 3500 psi, 1000/1000°F reheat, and are fueled by western coal. The 1400-acre Northeastern Station site is located 30 miles northeast of Tulsa, Oklahoma. The site includes sufficient open land to supply 30-40 MWe solar repowering for Unit 1. Average direct normal insolation at the site is estimated to be 5.5 kWh/m^2-day. NES 1, designed by B&V and completed in 1961, has a B&W fossil boiler.

PROJECT SUMMARY–The solar repowering for NES 1 uses the central receiver concept where heliostats redirect the sunlight to a solar receiver. The solar and fossil steam generators will operate in parallel, i.e., as a solar hybrid plant. In this operating mode, solar steam generation for NES 1 is expected to displace the equivalent of at least 100,000 barrels of oil per year. Solar repowering offers the potential for improving the contribution which Unit 1 will make to the PSO electric grid by increasing the projected load factor and extending the plant's operating life. Without repowering, Unit 1's annual output is projected to drop from about 28% capacity in 1985 to about 1% in 1989 and remain at that level until its retirement in 1994. The unit is being cut back to conserve high-cost fossil fuel.

CONCEPTUAL DESIGN–The baseline design includes a water/steam receiver located on a 340-ft receiver tower surrounded by 2,600 heliostats covering 140 acres. The receiver generates steam which is then piped to the existing plant where it is mixed with steam being generated by the fossil boiler. No storage is proposed for this demonstration project.

3. PUBLIC SERVICE OF OKLAHOMA Oologah, Oklahoma.
Prime Contractor: Black and Veatch

SIERRA PACIFIC POWER UTILITY–Ft. Churchill Plant, Unit No. 1

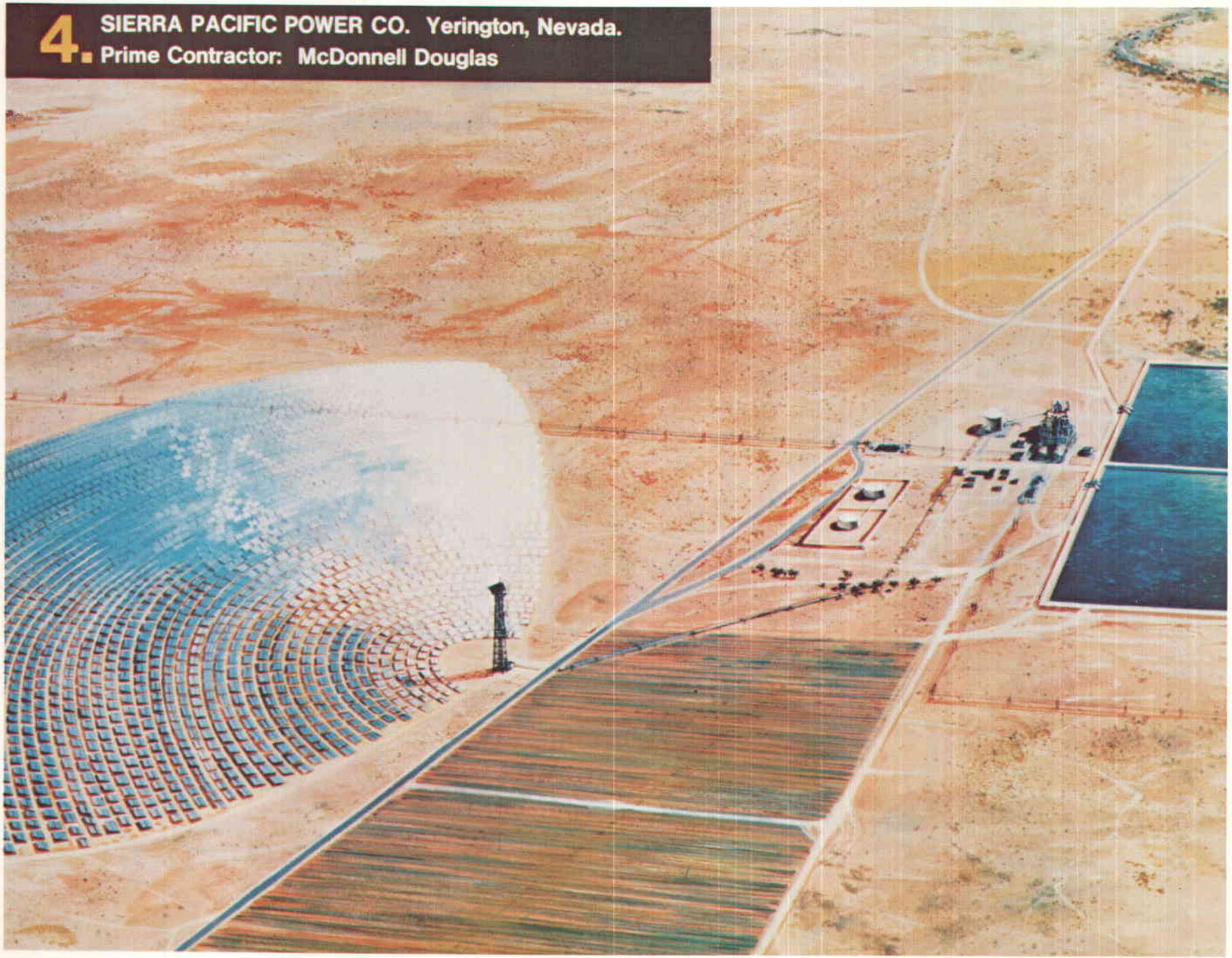
PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
McDonnell Douglas 5301 Bolsa Avenue Huntington Beach, CA 92647	Robert Easton	Sierra Pacific Stearns-Roger Services Desert Research Inst. Foster Wheeler University of Houston Westinghouse	October 24, 1979– June 23, 1980

SITE DESCRIPTION–The site being studied for repowering is Sierra Pacific Power Company's (SPPCo.) Ft. Churchill plant, located 47 miles southeast of Reno, Nevada. The plant has two identical oil/gas-fired reheat units rated at 115 MWe. Unit No. 1, completed in 1962, was selected for this study. SPPCo. owns approximately 10 square miles of land surrounding the plant. The land is high desert (4300 ft) with a surface composition of silty sand. The average direct normal insolation is about 7.1 kWh/m^2-day.

PROJECT SUMMARY–The Sierra Pacific Power Company presently has an installed capacity of 480 MWe of oil/gas-fired generation plants. The proposed repowered Ft. Churchill Unit No. 1 is expected to be used at a 0.72 plant capacity factor, with a solar fraction of 0.46. The solar energy operation will displace oil and gas. The estimated displacement is 550,000 bbl oil equivalent per year. Turbine-rated conditions are 1800 psi inlet pressure at 1000 F with 1000°F reheat at 422 psia. Heat is rejected to cooling ponds located to the south of the plant. The plant rate at the design condition is 9467 Btu/kWh net.

CONCEPTUAL DESIGN–The solar system baseline design uses a molten salt receiver fluid. The fluid is heated in the receiver to 1050-1100°F. The hot molten salt flows to the thermal storage where a storage capacity of approximately six hours is provided. Salt is withdrawn from storage to generate steam at rates up to 80 MWe gross equivalent. Depending on the choice of heliostat design, 9,800 to 11,000 heliostats will be required. The collector field will deliver approximately 330 MWth to the receiver fluid at the design point. Dual medium thermocline and two tank thermal storage units are both being considered. Plant operation from solar energy can be initiated as soon as 100 MWh is accumulated in the thermal storage unit. Electric power from solar can continue to be generated as long as 100 MWh remains in storage. Transition to shut down or to fossil operation will occur when thermal storage is depleted.

4. SIERRA PACIFIC POWER CO. Yerington, Nevada.
Prime Contractor: McDonnell Douglas



SOUTHWESTERN PUBLIC SERVICE COMPANY–Plant X, Unit 3

PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
General Electric Company Energy Systems Programs Department 1 River Road Schenectady, NY 12345	James A. Elsner	Southwestern Public Service Kaiser Engineers	September 28, 1979– July 15, 1980

SITE DESCRIPTION–The site selected for the Southwestern Public Service Company (SPS) Solar Repowering Program study is Plant X located approximately five miles south of Earth, Texas (near Lubbock). SPS owns approximately 1700 acres of unused land, generally flat and semi-arid, surrounding Plant X. No plans for other use of this land are under consideration by SPS. The Plant X facility has four generating units, all of which are gas fired, although each can be fired by oil as a backup. Unit 3 is a 100-MWe reheat plant typical of other repowerable facilities in the Southwest.

PROJECT SUMMARY–The SPS repowering system is to be operated in parallel with Unit 3 and to provide 60 MWe. The remaining 40 MWe will be generated by the existing fossil plant. The 40 MWe of fossil generation was chosen because it is the minimum boiler operating level under automatic control. The sodium-cooled receiver proposed for repowering will reflect General Electric's design and test experience gained from the Advanced Central Receiver Phase II program now being conducted for DOE. The project has been tailored to ensure that reliable plant electrical output will be available at all times with a significant amount of natural gas being displaced by solar whenever adequate insolation is available.

CONCEPTUAL DESIGN–The baseline conceptual design is a sodium-cooled solar central receiver heated by about 5176 heliostats. The storage provided for the plant will be limited to approximately 10 minutes, a level sufficient to buffer the total plant output from solar transients. The 10-minute system will function identically to a three-hour storage system and thus will adequately demonstrate the storage concept for future plants.

5. SOUTH WESTERN PUBLIC SERVICE CO. Earth, Texas.
Prime Contractor: General Electric

TEXAS ELECTRIC SERVICE COMPANY*–Permian Basin Unit 5

PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERFORMANCE PERIOD
Rockwell International Energy Systems Group 8900 De Soto Avenue Canoga Park, CA 91304	Tom H. Springer	Stearns-Roger Services McDonnell Douglas University of Houston	September 27, 1979– July 15, 1980

SITE DESCRIPTION–The Permian Basin Steam Electric Station is located four miles west of Monahans, Texas, in Ward County. Of the section of land (640 acres) owned by the Texas Electric Service Company, approximately 240 acres are occupied by the current facility and 400 acres are brush covered and unused except for several oil wells. The property is at an elevation of 2650 feet with a gentle slope to the southeast. The Station consists of six units. Unit 5, which is a candidate for repowering, is a 115-MWe gas/oil-fired intermediate-load reheat system. The fossil boiler supplies 1005°F superheat steam at 1516 psia and 1005°F reheat steam at 471 psia. The turbine is a tandem compound, double-side exhaust, 3600-rpm, condensing type and has a gross heat rate of 8457 Btu/kWh. The condenser is cooled by water from the cooling tower which is located west of the power plant. Average direct normal insolation is indicated to be 6.0 kWh/m^2-day.

PROJECT SUMMARY–A liquid sodium-cooled central receiver was chosen to repower the existing fossil-fueled Permian Basin Unit 5 because the receiver is smaller and lighter in weight, a single-phase fluid simplifies receiver operation, reheat is readily accomplished, and thermal storage is easily incorporated. The solar system has a thermal power input equivalent to 60 MWe or about 50% of the gross rated power of 120.8 MWe on the existing steam boiler. A storage system is provided to permit operation of the plant from storage alone at 60 MWe for three hours. On an annual basis, the energy provided by solar, including the three-hour storage capability, will be about 41% of the total energy supply for Unit 5 in its current mode of operation.

CONCEPTUAL DESIGN–The solar system is configured to permit operation of the plant from storage alone at 60 MWe for three hours. The receiver is of the external type, approximately 40 ft in diameter by 40 ft high and is located on top of a 40-ft tower. The hot sodium coming from the receiver flows into a hot storage tank; then the sodium is pumped by a second pump from the hot storage tank through a set of three steam generator units (an evaporator, a superheater, and a reheater) into a cold storage tank. From this tank the sodium is again pumped to the top of the tower and into the receiver. The central receiver system is integrated with the fossil plant by inserting a tee in the feedwater line. Feedwater is sent to the solar steam generators and steam is returned to the main steamline to be mixed with steam generated by the fossil-fueled boiler. The solar receiver is heated from sunlight reflected by 6531 heliostats.

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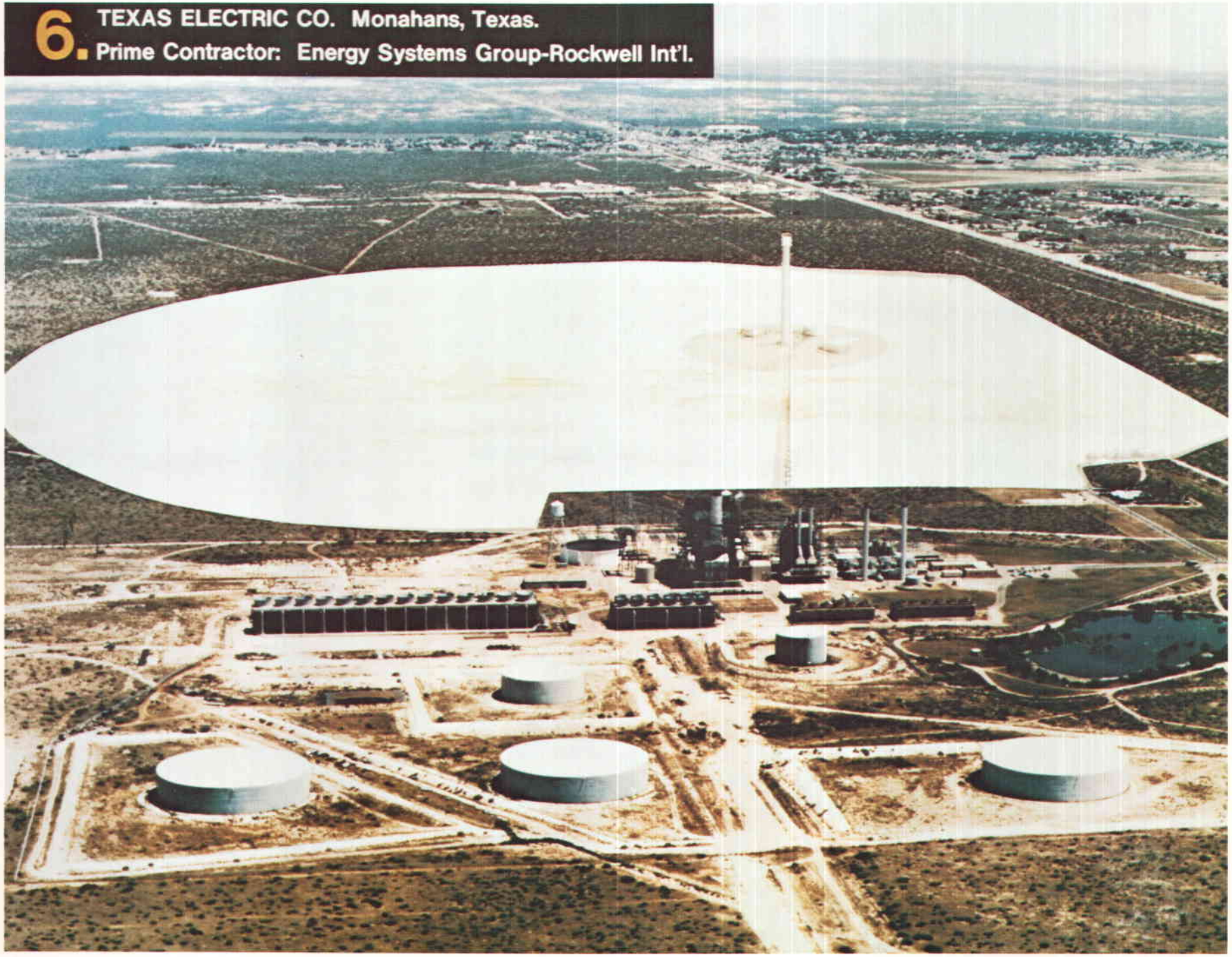
*Texas Electric Service Company is a significant contributor to this study at its own expense.

6. TEXAS ELECTRIC CO. Monahans, Texas.
Prime Contractor: Energy Systems Group-Rockwell Int'l.



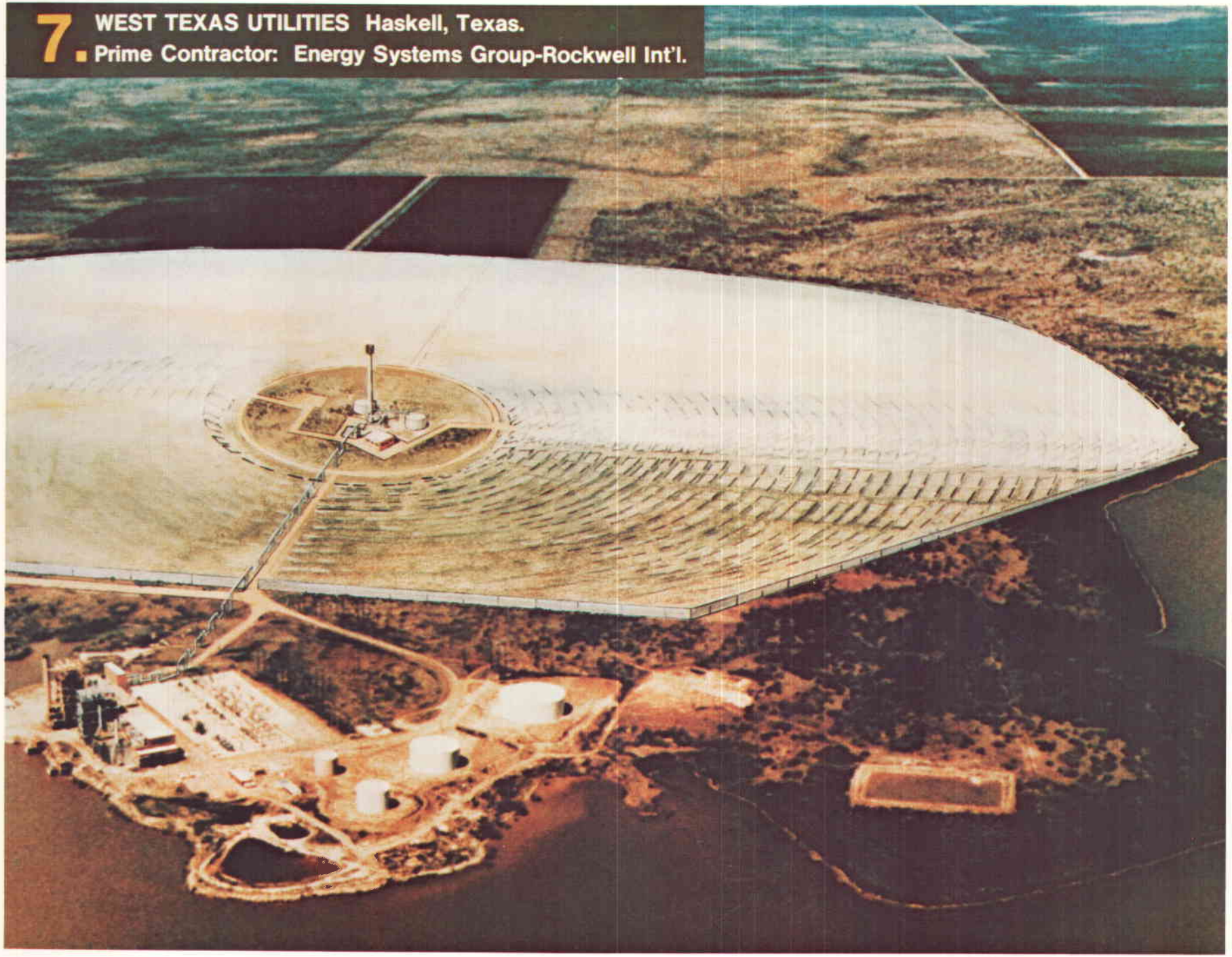
WEST TEXAS UTILITIES COMPANY–Point Creek Power Station Unit No. 4

PARTICIPANTS (Privately Funded)	PRINCIPAL INVESTIGATOR	PERIOD OF PERFORMANCE
Energy System Group (ESG), Rockwell International West Texas Utilities (WTU) Company University of Houston	Tom H. Springer	October 1979–July 15, 1980

SITE DESCRIPTION–WTU's Point Creek Power Station is located on a peninsula of the north shore of Lake Stanford in Haskell County, Texas, approximately 48 miles north of Abilene, Texas, on 138 acres of land. Adequate land is available north of the site for a collector field. The topography is gently rolling land used for grazing and wheat production. The average insolation at the site is about 5.37 kWh/m^2-day. There is a good match between peak power demand on the utility system and solar energy availability. The Point Creek Power Station Unit No. 4, currently under study, has a net power output of 105 MWe, is fired by natural gas under normal operation, and uses No. 2 fuel oil for emergency backup. At a repowering level of 60 MWe and with enough thermal energy to permit operation at full power for about 4 hours, it is estimated that approximately 64 billion cubic ft of natural gas (equivalent to 11 million barrels of oil) will be saved over the 30-year lifetime of the plant. Unit No. 4, built in 1971 and operated as a base load plant, employs a Rankine steam cycle with main steam at 1000°F, 1800 psia and with reheat steam at 1000°F, 507 psia. The turbine is a G-E tandem compound two-flow unit with a gross turbine heat rate of 8258 Btu/kW-h. The plant heat rate is 10,200 Btu/kW-h at full load.

PROJECT SUMMARY–A repowering level of 60 MWe has been chosen with the collector field sized for a solar multiple of 1.56, to provide about 4 hours storage at equinox. The storage level for winter solstice, 1.73 h at 60 MWe (this corresponds to 17 h at 6.0 MWe), is necessary for all-night operations at 10% solar plant capacity, the lowest practical value for control system stability. The objective is to achieve limited continuous operation at winter solstice.

CONCEPTUAL DESIGN–The plant uses liquid sodium for cooling the central receiver and as the storage media for the thermal energy storage system. The repowered Unit No. 4 will provide a solar power fraction of about 57% and a solar annual energy fraction of about 47%. The receiver will be of the external type and will be located on top of a 420-ft-high concrete tower. The solar collector system configuration consists of a predominately north-oriented collector field with 8152 heliostats on 380 acres of land north of the site.


7. WEST TEXAS UTILITIES Haskell, Texas.
Prime Contractor: Energy Systems Group-Rockwell Int'l.

PUBLIC SERVICE COMPANY OF NEW MEXICO–Reeves Station, Unit. No. 2

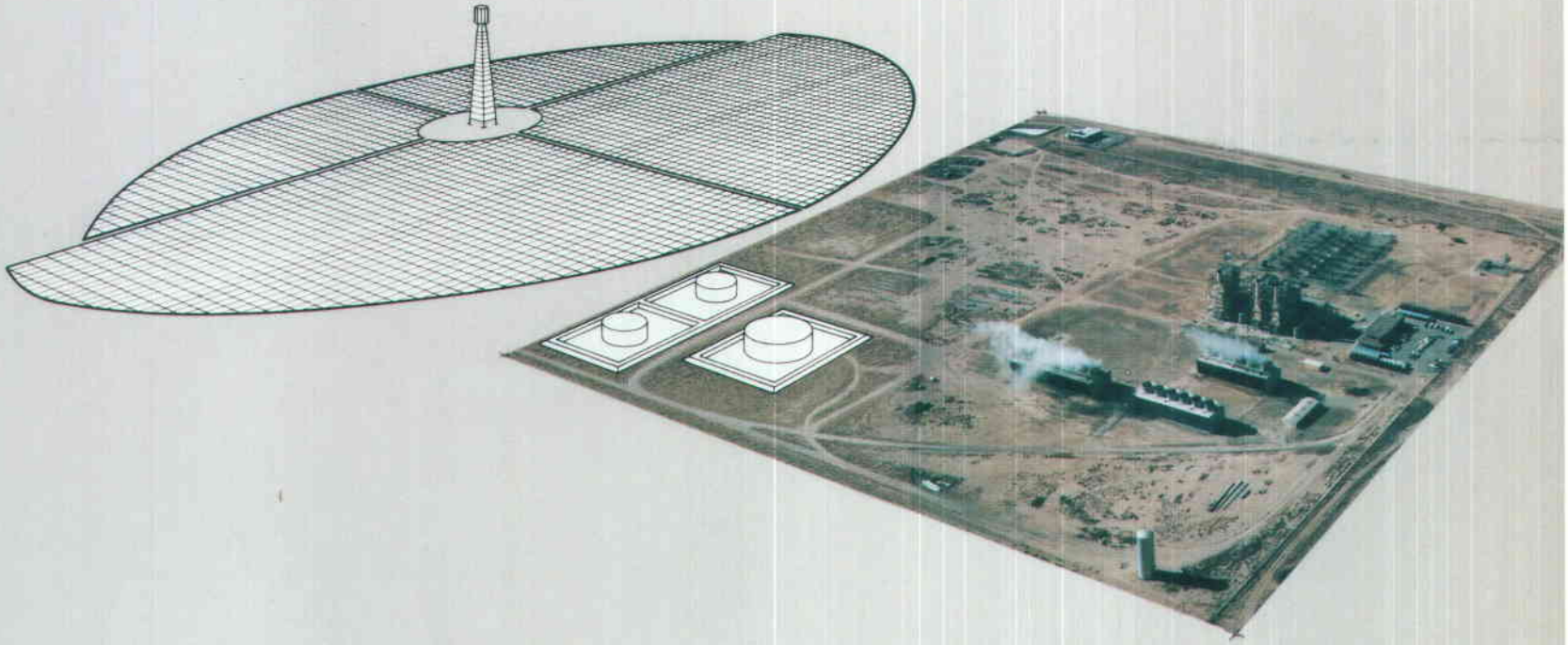
PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
Public Service Co. of New Mexico P. O. Box 2267 Albuquerque, NM 87103	J. D. Maddox	Stearns-Roger Services Westinghouse	September 30, 1977– September 29, 1978

SITE DESCRIPTION–PNM's Reeves Station Unit No. 2 is located just north of Albuquerque's city limits in Bernalillo County, New Mexico. The Reeves Station site has approximately 30 acres available for the solar system. An additional 125 acres of vacant land to the south of the present site boundary can be made available through lease or purchase arrangements. The slope of this site is 3.6% and is comprised of sandy loam soil. The average direct normal insolation is approximately 6.6 kWh/m^2-day.

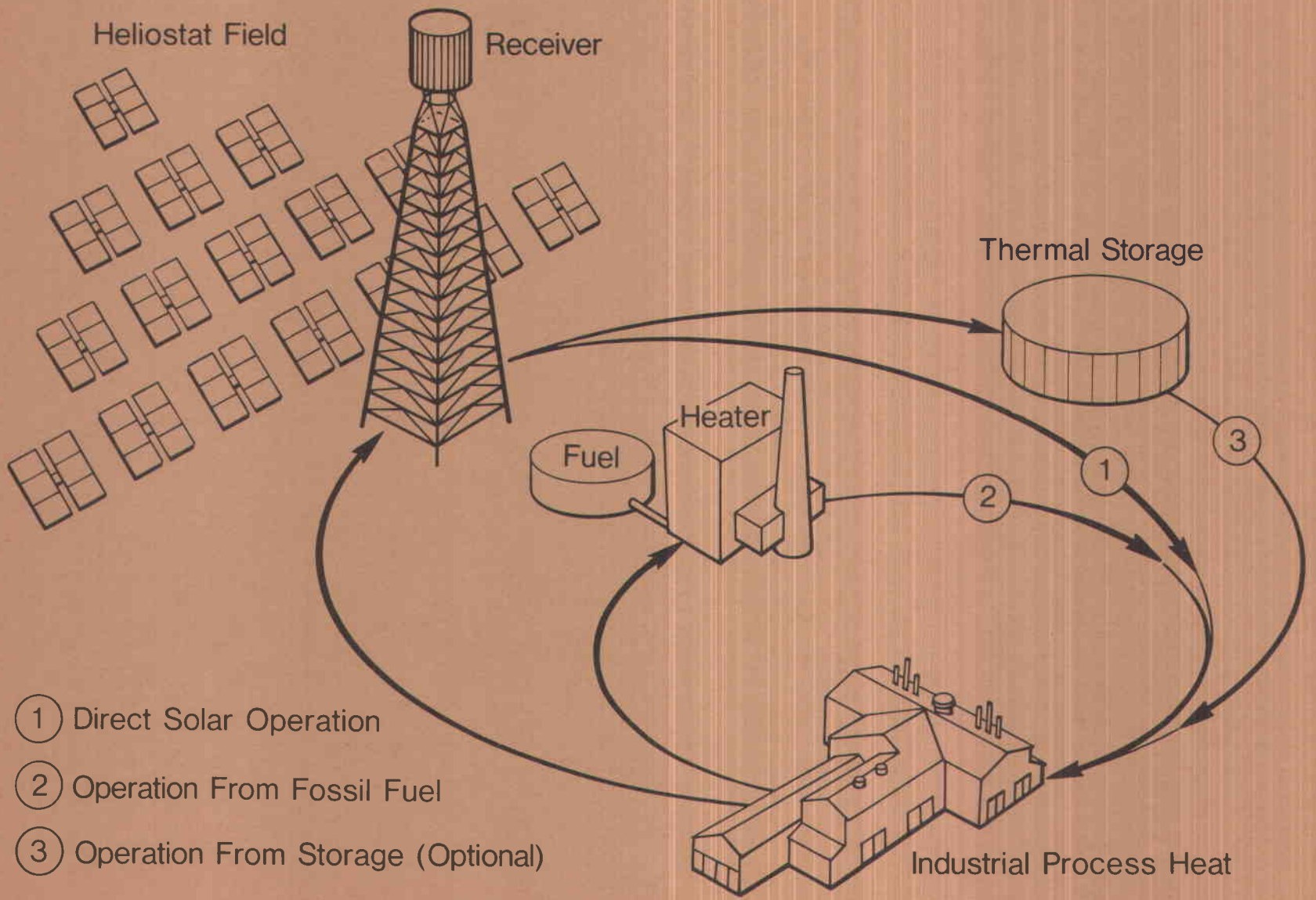
PROJECT SUMMARY–The Reeves Station has three oil/gas-fired steam electric units. Unit No. 2, a non-reheat steam turbine with a nameplate rating of 44 MWe, was selected for the repowering program for several reasons: The condition of the boiler and boiler auxiliaries is good; the boiler has minimal brick refractory and thus would be less affected by the expected temperature transients of hybrid operation; and the turbine generator is in good condition. The central receiver system will provide steam to generate 25 MWe at the design point insolation occurring at 2 p.m. winter solstice. The solar system nominally would provide 50% of full steam requirements, the remainder being supplied by the existing oil-fired boiler.

CONCEPTUAL DESIGN–The baseline central receiver design is a once-through-type water/steam boiler located on top of a 423-ft concrete tower. Energy is optically transmitted to the receiver by 4100 mirrors (heliostats), each with a reflective area of 38 m^2, located on an available land area just south of the main plant facility. The tower is located in the center of this heliostat field. The design of the collectors and the solar receiver was based on the preliminary design of the 10-MWe pilot plant at Barstow, California. The conceptual design for this system was completed in September 1978 and is available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

PUBLIC SERVICE OF NEW MEXICO Albuquerque, New Mexico
Prime Contractor: Public Service of New Mexico



SOLAR REPOWERING-Industrial Process Heat



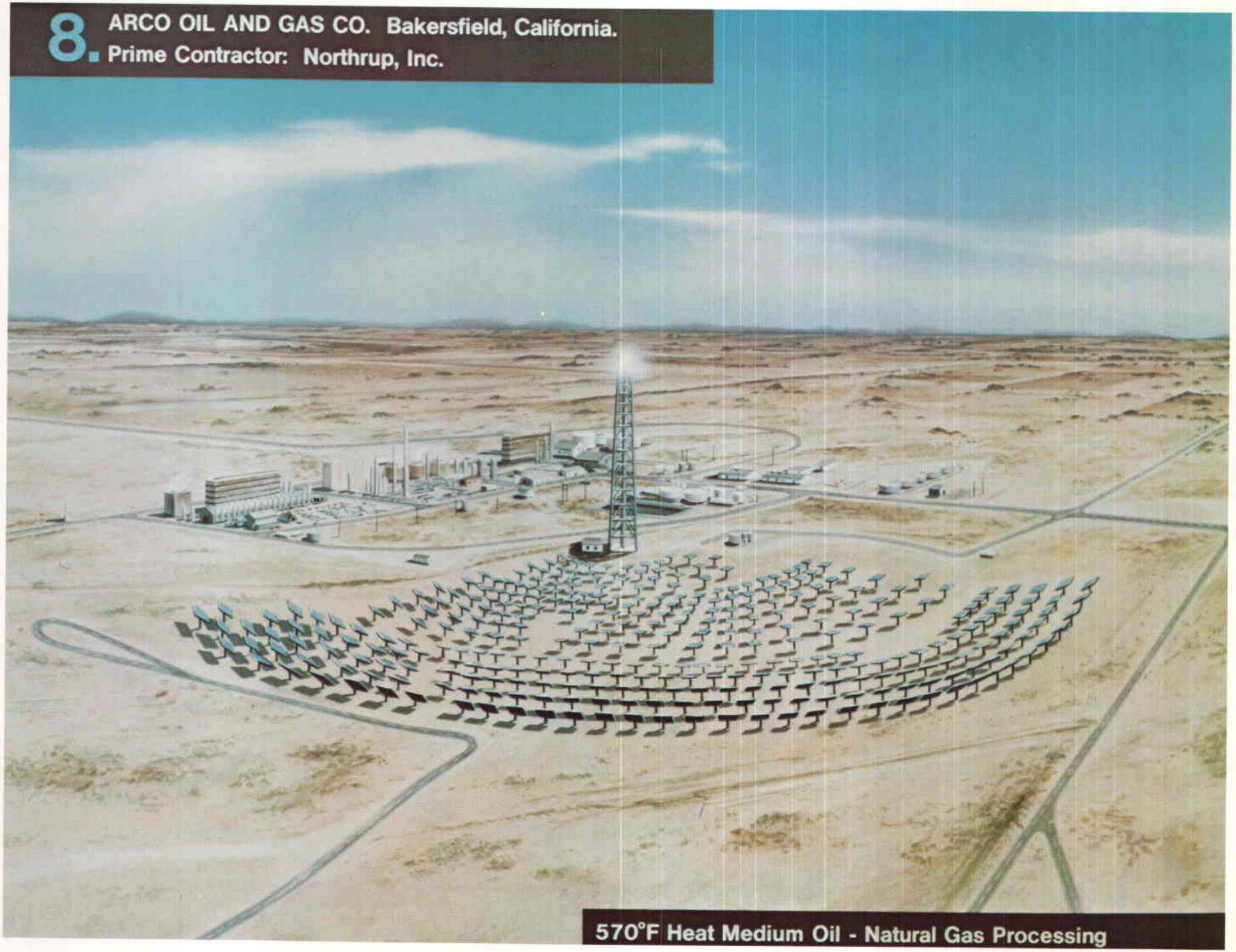
ARCO OIL AND GAS COMPANY–North Coles Levee, Plant No. 8

PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
Northrup, Inc. 302 Nichols Drive Hutchins, Texas 75141	Roy L. Henry	ARCO Oil and Gas Co.	September 26, 1979– July 15, 1980

SITE DESCRIPTION–The plant is located 22 miles west of Bakersfield, California. The plant is a refrigerated absorption oil plant that recovers propane, butane, and gasoline from raw natural gas. The terrain is flat and relatively level.

PROJECT SUMMARY–The project is a joint effort by Northrup, Inc., and ARCO Oil and Gas Company to design a solar-powered process heat system to be installed at the ARCO North Coles Levee Natural Gas Processing Plant No. 8. The process consists of bubbling raw gas through an oil that absorbs these hydrocarbons with molecular chains longer than methane's. The process oil is then heated to drive off the absorbed hydrocarbons which, in turn, are selectively heated to separate ethane, propane, butane, and gasoline. For safety reasons, the entire process avoids the direct use of flame and is powered instead by a remotely heated Heat Medium Oil (HMO). The system operates between 380 and 570°F, the process heat being supplied by a combination of two gas-fired heaters and two heat-recovery units that operate on waste heat from two continuously operated gas turbines. The solar retrofit system is being designed to displace natural gas directly by providing a heat source for that portion of the HMO that is circulated through the heaters. The system will deliver solar energy to the process with an annual average efficiency of 55% and has been sized to yield an average solar fraction of 38.8% relative to the plant's normal usage of 306×10^9 Btu's per year.

CONCEPTUAL DESIGN–The solar process heat system is of the central receiver type. It will be located north of, and adjacent to, the existing plant. The general arrangement shows a 35-acre array of 413 heliostats. It lies due north of a solar receiver located atop a 200-ft-high steel tower. During periods of sufficient insolation, the entire HMO that normally flows to the heaters is diverted through the receiver and back to the heaters. The heaters then "top off" the heat required to maintain an outlet temperature of 575°F. Fuel flow to the heaters is automatically controlled to supply only enough heat to meet the ΔT requirement, or carry the entire plant load during periods of insufficient insolation. This method of interfacing the solar and non-solar HMO system offers several advantages: (a) all solar energy collected is used; (b) all heat supplied by heat recovery units is used; (c) direct heaters are maintained at operating temperature and can respond rapidly to transient conditions; (d) system control is extremely simple; and (e) there is minimum interruption of existing plant operation.


8. ARCO OIL AND GAS CO. Bakersfield, California.
Prime Contractor: Northrup, Inc.
570°F Heat Medium Oil - Natural Gas Processing

EXXON CORPORATION–Edison Field

PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
Martin Marietta Corp. P. O. Box 170 Denver, CO 80201	David N. Gorman	Exxon Corp. Foster Wheeler Black & Veatch	September 28, 1979– July 15, 1980

SITE DESCRIPTION–The site selected for the Solar Thermal Enhanced Oil Recovery (TEOR) project is Exxon's Edison Field near Bakersfield, California. The use of steam stimulation has been well established at the field since 1965. The Edison field is typical of TEOR operations. As such, it would provide a good demonstration of the potential benefits of solar TEOR in the oil production industry. The terrain is flat, alluvial plain at an average elevation of 600 ft. The climate is warm and semi-arid. Summers are normally cloudless, hot, and dry. Annual average direct normal solar insolation is between 6 and 7 kWh/m^2-day. Total field size is over 1000 acres and, at the end of 1979, will have nearly 200 producing wells.

PROJECT SUMMARY–The particular concept being studied utilizes a central receiver solar thermal power system to replace the combustion of oil for generation of steam used for TEOR operation in Exxon's Edison Field. Standard pumping techniques can produce only a small portion of the crude oil from underground reservoirs. The decrease in ground pressure, coupled with a high flow resistance in the oil-bearing formations, causes production rates to fall below economic levels while abundant amounts of oil remain. Furthermore, a larger portion of the world's known reserves consist of particularly heavy, viscous crude which cannot be pumped at all. As available crude oil reserves have been depleted and prices escalate, various methods of enhancing production capability have been developed. The most cost-effective process is the injection of steam into the reservoir, which heats and pressurizes the formation, allowing the oil to flow to recovery wells where it is pumped by normal means. Steam generators with output ratings of 22 MBtu/h and 25 MBtu/h are presently used in the Edison field. The baseline design solar system would produce 23 MBtu/h average over a typical year. Peak noon winter solstice output would be 29.3 MW (100 MBtu/h).

CONCEPTUAL DESIGN–Individually driven heliostats track the sun, aiming the concentrated reflected energy into the apertures of a tower-mounted dual-cavity receiver. Interior surfaces of the cavity receiver consist of natural-circulation boiler panels that produce saturated steam at about 550°F. Steam exits the receiver into distribution piping to the point(s) of injection. Oil-bearing geological formations provide a high heat capacity, low-thermal-loss buffer thermal storage capability, so that intermittent shutdown at night and during cloudy periods can be tolerated.


9. EXXON Bakersfield, California.
Prime Contractor: Martin Marietta
550°F Steam - Enhanced Oil Recovery

GULF RESEARCH AND DEVELOPMENT COMPANY–Mt. Taylor Uranium Mill

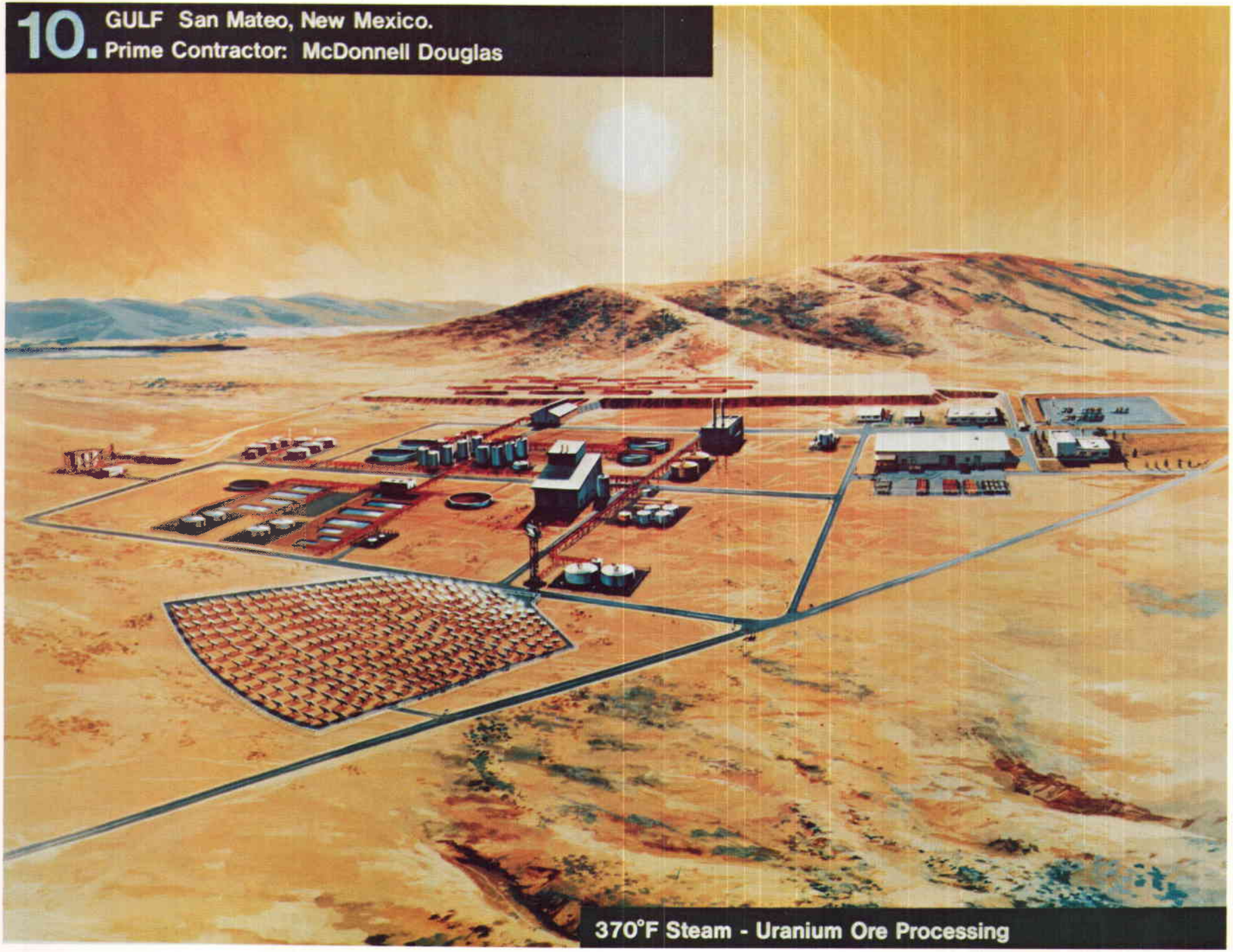
PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
McDonnell Douglas 5301 Bolsa Avenue Huntington Beach, CA 92647	L. W. Glover	Gulf Research Foster Wheeler University of Houston	September 24, 1979– June 23, 1980

SITE DESCRIPTION–Gulf Mineral Resources Company, a division of Gulf Oil Corporation, proposes the construction of a uranium mill located 3.5 miles northeast of San Mateo, New Mexico (60 miles west of Albuquerque), at an altitude of 7200 feet above mean sea level. It is scheduled for completion and operation by the end of 1981. The mill site is in a relatively level valley where ample land is available north of the mill for a heliostat field. The mine supplying ore to the mill is three miles south of the mill. The proposed Mt. Taylor Uranium Mill is designed to process 4200 tons of blended ore per day to yield 25,000 lb/day of U_3O_8 as finished yellow cake product, when operating 24 hours/day, 340 days/year. The average direct normal insolation in the area of San Mateo is 6.8 kWh/m^2-day.

PROJECT SUMMARY–In conjunction with the fossil-fuel-fired boiler, a solar central receiver will provide at least 23% of the average annual energy requirements of the Mt. Taylor Mill, displacing fossil fuel oil. Steam is used at several points in the process to heat ore slurry for more efficient chemical reactivity and to preheat boiler feed water.

CONCEPTUAL DESIGN–A field of 331 heliostats reflects and concentrates solar energy onto a tower-mounted receiver. In the baseline system, the receiver is a natural recirculation boiler which will supply saturated steam to the milling process. The solar steam generator will operate in parallel with the fossil fuel steamers, providing a common steam supply (150 psig) with a maximum output of 100,000 lb/hr. The fossil fuel steamers will be capable of a 20:1 turndown ratio and will be operated continuously with a steam demand-control cycle. The mill requires approximately 25,000 gallons/day (peak) of No. 2 petroleum fuel oil delivered to the site. The baseline solar system will eliminate 753,000 gallons of fuel oil annually.

10. GULF San Mateo, New Mexico.
Prime Contractor: McDonnell Douglas



370°F Steam - Uranium Ore Processing

PROVIDENT ENERGY COMPANY–Mobile Refinery

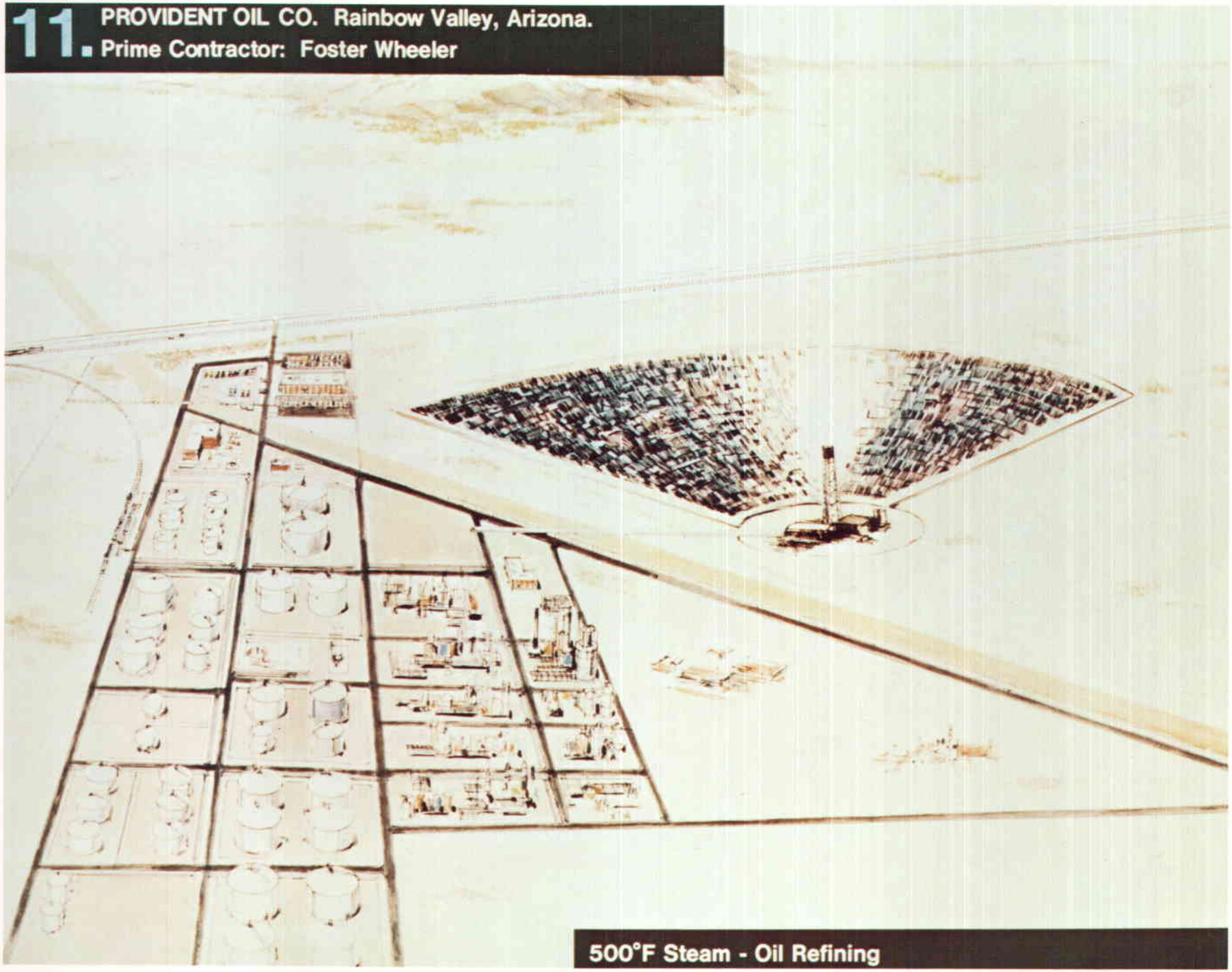
PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
Foster Wheeler Dev. Corp. 12 Peach Tree Hill Road Livingston, NJ 07039	D. R. Raghavan	Provident Energy Corp. McDonnell Douglas Foster Wheeler	September 28, 1979– July 15, 1980

SITE DESCRIPTION–The Provident Energy Company (PEC) refinery, to be designed and built by Foster Wheeler, will be located in Mobile, Arizona, 25 miles southwest of Phoenix, and is expected to be on-line by 1983. The site consists of 248 acres of relatively flat desert at an elevation of 1328 ft. The average direct normal insolation at the PEC site is about 6.9 kWh/m^2-day. The site is strategically located alongside an existing pipeline that will transport crude oil to the PEC refinery.

PROJECT SUMMARY–The objective of this program is to prepare a conceptual design for a central receiver system that will provide practical and effective use of solar energy in an oil refinery. The net annual input from the solar plant, 339 x 10^9 Btu's, 20% of the annual refinery steam demand. The proposed solar plant would displace about 420 x 10^9 Btu's or about 67,400 barrels per year of the fuel oil produced by the refinery that would otherwise be burned in the fossil boiler.

CONCEPTUAL DESIGN–The baseline solar energy system proposed consists of a tower-mounted natural-circulation water/steam receiver with a flat-panel absorber which generates saturated steam that is superheated to the desired temperature in a separately oil-fired superheater before it enters the main refinery superheated steam header. Solar energy is concentrated on the receiver by a 59-acre field of 1274 heliostats north of the tower. As currently planned, the refinery's fossil boilers will be operating during solar operation–but at a very low output. The control system's function is to modulate the fossil boiler output in response to the steam header pressure to vary steam flow to satisfy refinery demands. Ramp rates of the fossil boilers appear adequate to compensate for possible transients in solar-generated steam production, so no thermal energy storage is proposed.

11. PROVIDENT OIL CO. Rainbow Valley, Arizona.
Prime Contractor: Foster Wheeler



500°F Steam - Oil Refining

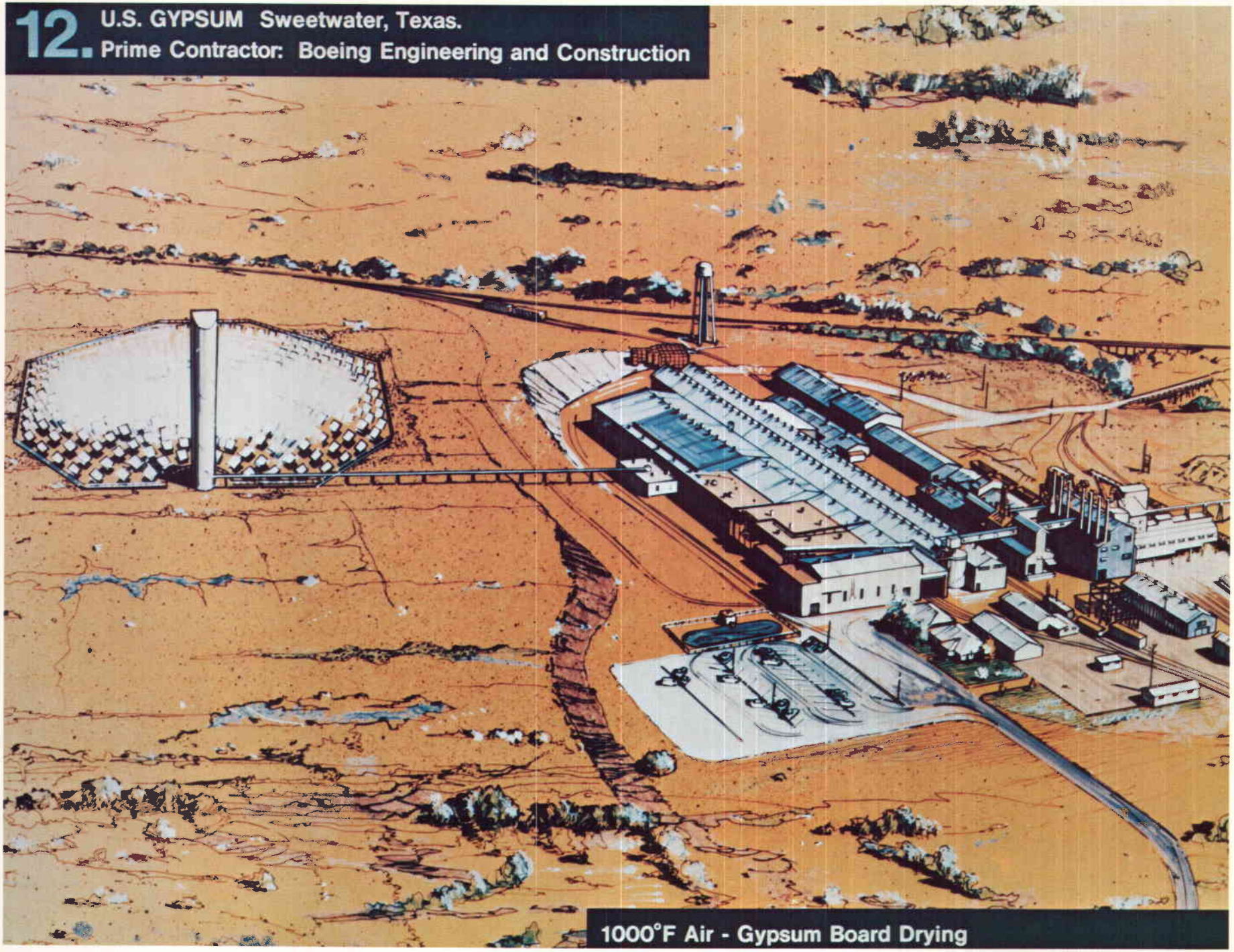
UNITED STATES GYPSUM COMPANY–Sweetwater, Texas Plant

PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTOR	PERIOD OF PERFORMANCE
Boeing Engineering P. O. Box 3707 Seattle, WA 98124	Donald K. Zimmerman	U. S. Gypsum Co. Institute for Gas Technology	September 30, 1979– July 15, 1980

SITE DESCRIPTION–The U.S. Gypsum Sweetwater Plant, located on a 3800-acre tract east of Sweetwater, Texas, currently produces 300,000 tons/year of calcined gypsum products, of which 90% is gypsum board. The site is 45 miles west of Abilene, Texas. Major operations at the site include open-pit mining, crushing, and calcining of the gypsum; board manufacturing; and product warehousing and shipping. All current manufacturing operations are performed in a 16-acre site. The immediate terrain around the manufacturing plant is clear and relatively level. The site is approximately 2150 feet above sea level. Total plant energy consumption in the form of natural gas was 987×10^9 Btu in 1978, with about one-third for calcining and two-thirds for board drying.

PROJECT SUMMARY–The solar retrofit system will supply solar-heated air during insolation hours to a wallboard-drying kiln at the USG Sweetwater plant to replace air heated by natural gas combustion. For the No. 2 kiln at Sweetwater, this would represent replacing 100% of the natural gas consumption during solar operation and represents a savings of about 25% of the yearly gas usage. The solar-heated air would be mixed with kiln recirculating air and passed over wallboard moving through the kiln in a 14-high deck arrangement. The hot air dries the board as it moves through a 200-ft-long kiln.

CONCEPTURAL DESIGN–The solar plant would occupy approximately 16 acres of relatively level land north of the board plant. It would consist of approximately 450 heliostats, a cavity receiver, and a 200-ft steel tower on which the receiver would be mounted. Compressed air would be heated to ~ 1200°F in the receiver, expanded through a turbine which drives the compressor, and delivered to the furnace of the board kiln at 860°F. Whenever adequate insolation was not available, the fossil-fired system would provide the energy requirements of the plant.


12. U.S. GYPSUM Sweetwater, Texas.
Prime Contractor: Boeing Engineering and Construction
1000°F Air - Gypsum Board Drying

VALLEY NITROGEN PRODUCERS–El Centro Ammonia Plant

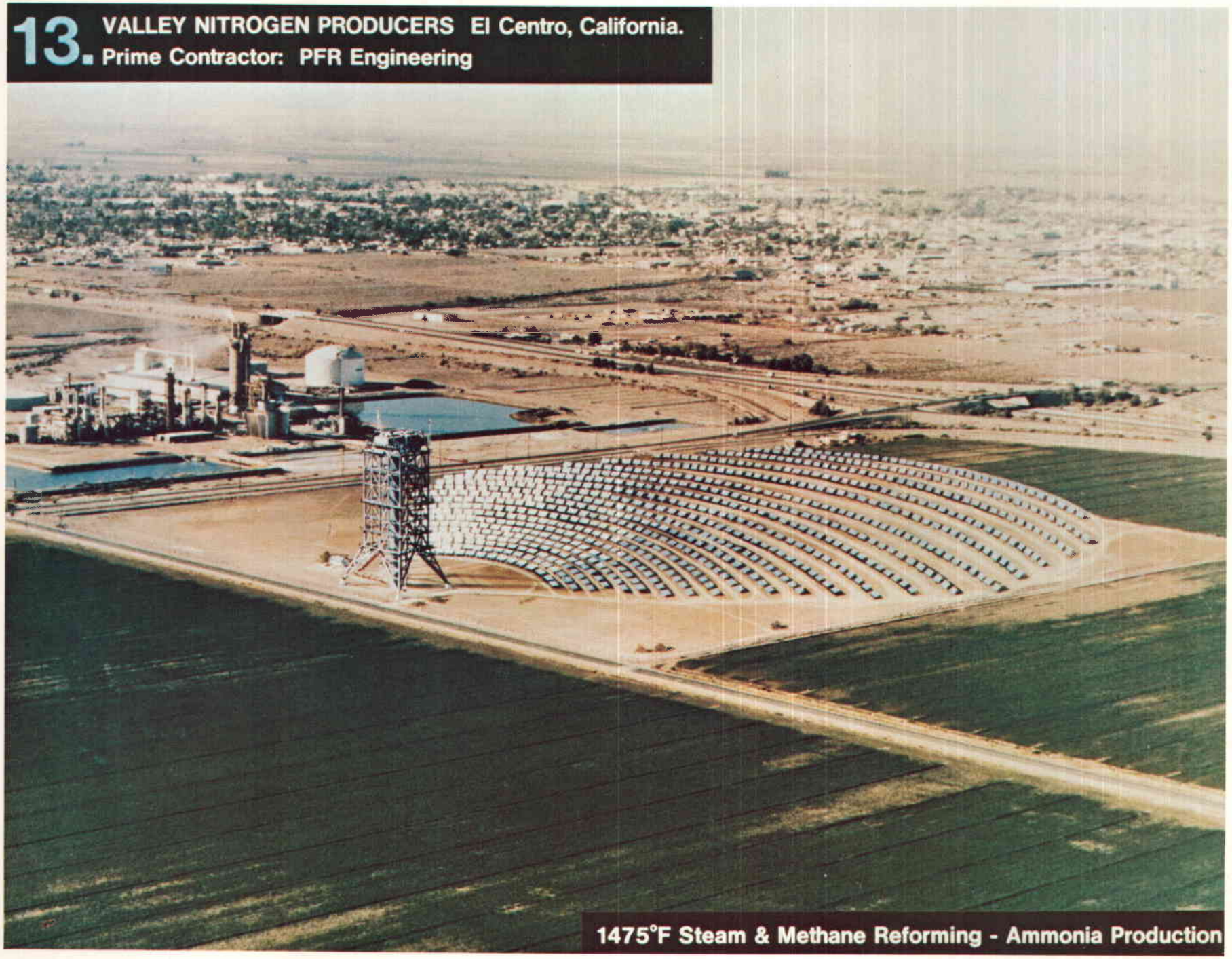
PRIME CONTRACTOR	PRINCIPAL INVESTIGATOR	SUBCONTRACTORS	PERIOD OF PERFORMANCE
PRF Engineering Systems, Inc. 4676 Admiralty Way, Suite 832 Marina Del Rey, CA 90291	Tzvi Rosenman	Valley Nitrogen Producers McDonnell Douglas	September 30, 1979– July 15, 1980

SITE DESCRIPTION–The El Centro Ammonia Plant is part of a fertilizer-producing complex located in El Centro, California. It is spread over 220 acres approximately 1 mile south of Interstate 8 and consists of an integrated fertilizer facility which produces ammonia, urea, nitric, and ammonium nitrates. Most of the ammonia produced in the plant is used in fertilizer. The complex is owned by Valley Nitrogen Producers, Inc., a farmer-owned cooperative of about 5000 members serving the California Central Valley farms. The plant location is very suitable for solar energy application. The climate is hot and dry with a high percentage of clear, cloudless skies; annual rainfall is only 2.83 inches and, on the average, only 30 cloudy days occur yearly.

PROJECT SUMMARY–The objective of this project is to displace natural gas presently used in the combustion chamber of the primary methane-steam reformer. A solar central receiver is the baseline system. It will operate in parallel with the existing fossil-fired reformer. This configuration will provide a peak solar utilization of 37 MWt or a total annual contribution of 28%. Other than the production of steam in a separate boiler, the reformer is the only major energy consumer in the fertilizer manufacturing plant.

CONCEPTUAL DESIGN–The proposed baseline system employs a solar central cavity-type receiver operating in parallel with the existing fossil-fired reformer. A north field heliostat array focuses the solar energy through the receiver aperture. Inside the receiver, internal reflection and re-radiation heat the vertical primary reformer tubes to 1420°F maximum. Methane and steam flowing inside the tubes react catalytically to form a hydrogen-rich product gas ultimately used to prepare ammonia. The solar retrofit's characteristics and its interface with the existing plant are simple, incorporating state-of-the-art components with proven technology. The retrofit does not alter the normal plant operation. No storage system or complex control is required. The solar reformer will be directly connected to the fossil reformer by an insulated piping system. During the day, the flow will be routed to the solar reformer and the energy will be provided by the heliostat field. At night, the flow is routed to the existing fossil reformer, with the solar reformer shut down. Full natural gas firing takes place in the fossil reformer and full plant operation will continue. The solar reformer is sealed during the night to maintain reformer tube, insulation, and cavity temperature; this minimizes thermal cycling of these components, and simplifies restart in the morning.

13. VALLEY NITROGEN PRODUCERS El Centro, California.
Prime Contractor: PFR Engineering



1475°F Steam & Methane Reforming - Ammonia Production