THE COSO GEOTHERMAL POWER PROJECTS

James L. Schoonmaker

Mission Power Engineering Co.
Irvine, California

ABSTRACT

The California Energy Company Inc. (CECI) and Mission Power Engineering Co. (MPE) formed a team in 1987 to develop Units 2 through 9 of the COSO Project. Each of these units are 30 MW nominal, dual flash design. They are located on four sites in the COSO KGRA in Central California. This paper describes the Project and progress to date on the 8 units.

The wells at specific sites have developed with enthalpies ranging from 420 to 1000 Btu/Lb. The same basic hardware, including the turbine-generator sets, have been used for this full range of conditions in order to allow the very rapid development of this resource area. The generating plants of this paper were started in March 1988. As of May 1989, four units are in commercial operation and the remaining four are in construction.

INTRODUCTION

The Projects are in the COSO Known Geothermal Resource Area (KGRA), which is approximately 30 miles from Ridgecrest, and located on the U. S. Navy China Lake Naval Weapons Center (NWC). The Project is a development of the U.S.Navy through the NWC Geothermal Program Office, headed by Dr. Carl F. Austin. Purposès of the Program include;

a. Demonstration of beneficial uses of the Weapons Center which are compatible with the primary mission of weapons testing.
b. Development of an energy source which is not dependent on imported fuel.

The compatibility is accomplished by occasionally removing all personnel from the power area for a few hours, leaving the units in-service and automatically controlled, unattended.

The development was made possible by a complex set of enabling legislation. The lease areas and resultant plant sites are named for the governmental entities who manage them for the United States; "Navy 1", "Navy 2", and "BLM". Figure 1 shows the location of the KGRA, and Figure 2 the location and identification of the Project sites. The California Energy Company (CECI) is the manager-operator of the leases, and the manager of the extensive drilling program. The Owners are affiliates of CECI and Caithness Corporation. Mission Power Engineering is the turnkey EPC (Engineer/Procure/Construct) contractor for the 8 units (units being wellhead to generator) and a 230 KV transmisssion line to connect to the power purchaser, the Southern California Edison Co. (SCE). The construction sequence is:

230 KV Transmission Line
(energize October 1988)
Units 2 and 3 at the Navy 1 site
(synchronize November/December 1988)
Units 7 and 8 at the BLM east site
(synchronize December 1988)
Unit 9 at the BLM west site.
(synchronize July 1989)
Units 4,5 and 6 at the Navy 2 site.
(synchronize Dec. 1989/Feb. 1990)

This Paper presents the concepts used, design implementations of those concepts, and the experience to date in constructing the plants.

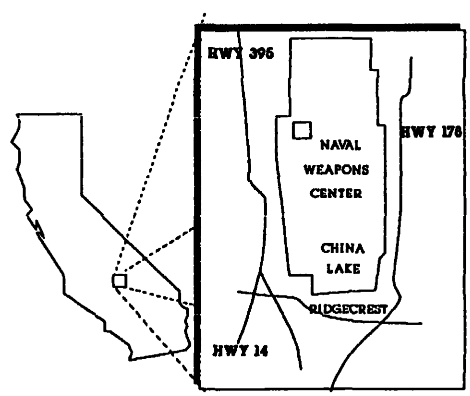


Figure 1. COSO PROJECTS LOCATION

CONCEPTS

The features of unusual interest in this facility are its size (220 MW in 8 units), location on a Weapons Test Center, and the fast track schedule with its related reactions to unexpected resource and licensing occurrences.

Fast Track Schedule.

For economic and licensing reasons, the Owner determined that it was desirable to develop the resource on a fast track basis. Fast track in the design stage meant overcoming the typical 18 month lead time for the turbine-generator sets; the typical pacing item. This was aided by early order of the turbine-generator, and making the supplier selection based largely on schedule factors after available quality suppliers were found who could deliver the technically required product. The single most substantial ingredient in "fast tracking" was to implement the same design 8 times: the well known cookie cutter. As typical, the cookies did not quite come out identical. However, long lead time items were repeated at each location, thus allowing expedited timing of all major equipment. This includes the turbine generator sets, the Separators (HP and LP), the DCS (Digital Control System) controls, and the cooling towers and condensers, with some modifications.

A common and succesful technique of fast tracking is to take advantage of multiple suppliers for essentially every component during the design/procure process. Supplier competition can be encouraged in terms of schedule as well as quality and cost. The majority of remaining construction material was procured based largely on schedule. Substantial leverage was afforded by ordering material for 8 units at one time. Particular advantage is gained by domestic suppliers for much equipment because of eliminating long transportation times. At the start of the Projects, domestic shops producing for the power market were generally operating at under their capacity, which aided the aggressive schedule. All sources of supply except the turbine-generator are provided by domestic suppliers.

Because of the size and location of the resource wells, pipe became the largest material procurement item in terms of both cost and weight. It has also been the most difficult to expedite. The steam system includes pipe sizes up to 48 inch diameter, and tens of thousands of feet of large bore pipe are involved.

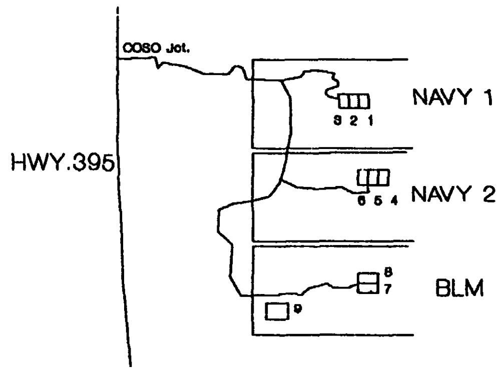


Figure 2. PROJECT IDENTIFICATION

DESIGN

Facility Layout.

One result of the aggressive schedule was that some of the resource wells were still developing while design was finished on the power plant. Obviously this did not allow testing of all of the final resource fluid before design of the power conversion equipment. This obstacle was managed by predicting resource development based on some well completion and testing. As should be expected, the prediction was sometimes imperfect. One means to handle this difficulty is to locate the steam/water separators in the resource areas, away from the power equipment, in order to allow as long a delay as possible of that equipment,i.e.; much large steam piping and all the power area equipment could be installed without having to wait for final well information. There are now two distinct areas of each Plant:

A. The Gathering / Injection area, which includes resource wells, HP and LP separators, injection pumps, injection wells, suporting electrical buildings, and other supporting equipment such as silencers, steam traps, etc.
B. The Power Block area, which includes the turbine-generators, switchyard, condenser, cooling tower, gas compressors, the control building, and other supporting buildings for air compressors, office, warehouse, and electrical equipment.

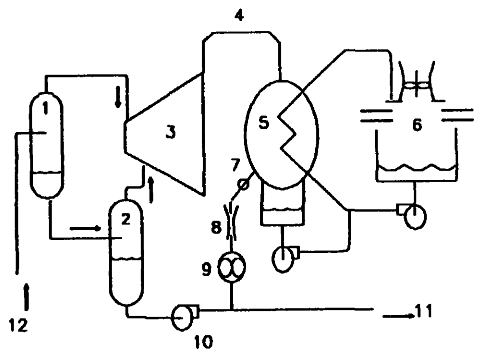
Other means employed to help manage the uncertain resource are:

1. a high pressure to low pressure bypass at the turbine. If the resource enthalpy developed at higher than expected values, the bypass allows the low pressure section of the turbine to be supplied by high pressure steam. This of course would have some negative effect on overall heat rate, but the effect would be small in the case of high enthalpy. Plant capacity, of course, would remain intact.

2. oversized piping to minimize pressure drops, which would protect the plant capacity in the event of decreasing resource pressure.

3. Connection to the steam system of more separator and resource well capacity than required in the early years of operation. This also has the advantage of providing flexibility for well or well area equipment maintenance outages.

The plant layout includes outdoor construction of the turbine-generators, vertical turbine exhaust, condenser crossover duct, condenser at grade, open air switchyard, and buildings for electrical gear, control room, and air compressors.



KEY

1. H P Separators
2. L P Separators
3. Turbine
4. Crossover Piping
5. Condenser
6. Cooling Tower
7. Intercondenser
8. Jet Ejector
9. Gas Compressor
10. Injection Pump
11. Injection Wells
12. Resource Wells

Figure 3. BASIC CYCLE

Cycle.

Selection of the two-flash cycle was made early. The resource known at the time of turbine selection produced fluid with an energy level (Enthalpy) in the range of 420 to 450 Btu/Lb. The cycle optimization was straightforward, and resulted in a turbine inlet pressure in the 100 psig range, and the second flash at slightly over atmospheric pressure for the 4,000 ft. altitude. Cooling tower makeup water is supplied from condensate, with excess over evaporative requirements returned to the geothermal reservoir along with the spent brine. Reference Figure 3. The turbine selected is a 7 row (4 HP, 3 LP) 2 admission single flow turbine with upward exhaust, coupled to a 33 MVA generator of closed cycle air cooled configuration.

Noncondensable Gas Control.

The resource produces small amounts of noncondensable gas along with the brine; 3000 to 7000 ppm in brine being typical. The gasses consist of CO_2 with small amounts of ammonia, hydrogen, and gaseous hydrocarbons. The gas also includes hydrogen sulfide in quantities just high enough to prevent untreated discharge. Licensing concerns and the nature of the resource made it clear to CECI very early that the noncondensable gas generated with the steam would best be managed by injecting all the gases produced with the geothermal water and steam back into the reservoir, along with the cooled resource brine. This meant that gas and water cleanup devices, as is typical of vapor-dominated reservoirs such as the Geysers, would not be required, but that large gas compressors for the injection process would be required. Partitioning of soluble gasses in the condenser, particularly the small volume of hydrogen sulfide, of course remained an imortant factor. The partitioning effectiveness of the condenser is effected very strongly by the ratio of hydrogen sulfide to ammonia, and the resultant pH of the vapor. This resource has "cooperated" by providing good chemical characterisitcs. Partitioning is achieved very well by use of a shell and tube condenser with appropriate design to promote separation effectiveness.

Header System.

The resource of the first two units, Navy 1 units 2 and 3, developed with unequal production from two geographic areas. It was therefore determined during design development that it was advantageous to have a common rather than unitized resource/steam system for each Plant (i.e.; Navy1, Navy2, BLM). This concept was carried forard to the remaining sites. As many as three units, and as few as one, are connected to each header system. Reference Figure 4. Each HP separator is supported by 1 to 4 resource wells. The HP separators are each capable of a nominal 15 MW, or half load of one unit. Each LP separator is capable of supporting the low pressure steam demand of one unit at full load. It can be seen that combinations of wells, HP separators, LP separators, and associated headers will provide a very high degree of flexibility. The Navy 2 header system, in order to supply 3 turbines, will be include 7 HP separators and 3 LP separators.

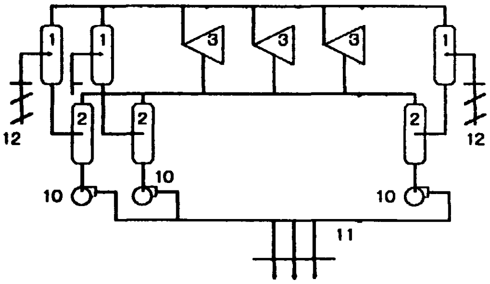


Figure 4. PLANT AND HEADER (see KEY on Figure 3)

The sometimes difficult task of controlling a header configuration is managed using turbine controls appropriately:

With 2 or 3 Units in service, at least one unit controls main steam pressure by varying load as required, and the other Unit(s) maintain fixed load. The overall plant load, except for transients, is controlled by manually (remotely) operating well-head control valves from the turbine area control room. Future automation of these valves can readily be done with existing equipment if desired.

Startup and other transients on the header system are managed by use of several specific devices:
HP separator pressure let-down.
HP separator high level control
LP separator pressure let-down
LP separator high level control
HP and LP header pressure letdowns
All the above being vented to silencers, and all in addition to code protection of the pressure vessels or piping.

Control System.

The fast track nature of the Projects made a distributed Digital Control System an obvious choice for overall plant control, due to its flexibility, particularly at the late stages of the work. The resource well areas were connected by a few coaxial cables to the power block area, thus saving significant time in design and construction. Manufactured buildings were designed and constructed to provide a large (50 x 40 ft.) Control Room to house the computers, touch-screen videos, Turbine Generator pre-manufactured control panels, and support.

Electrical.

Cable Tray was universally used in lieu of duct bank or buried conduit for bulk electrical runs on the first four units. This allowed the grading work to proceed early because conflict would not exist with underground duct banks. A "back bone" system of pipe and cable tray routing was developed in the power block area very early in the design, and equipment layout followed from that fundamental. A typical system of 13,800/4160/440/utility and DC Voltage systems were designed.

Transmission Line.

Transmission of power for the first Unit had been accomplished with a 115KV power line from Navy 1 to the SCE Inyokern Substation, 30 miles away over environmentally and archaelogically sensitive terrain. The first two units, Navy 1 units 2 & 3, tied in to this line. Subsequent power transmission was handled with a new line parallel to the first. The new line has been constructed for 230 KV operation. However it was initially energized at 115KV. It will be upgraded to 230KV on completion of the SCEdison Inyokern to Kramer transmission line in the near future. Dual voltage main stepup transformers were installed for the 3rd thru 5th units installed (BLM Units, 7,8 and 9) to handle the interim until upgrade of the SCE portion of the line. In the long term, the Navy 1 units will operate at 115 KV, the remaining plants at 230 KV. The line uses double bundled 1590 KCMil conductor, and H-Frame wood structures. This approach generally allowed the use of the 115 KV structure spacing (ruling span), and the disturbed construction areas previously used, thus minimizing the added environmental impact for the second Line.

EXPERIENCE

The fast track goals were met in the important aspects. The year-end tax credit opportunities for the initial four units were achieved. Doing so required a major effort, including a work force that exceeded 2,400 craft employess at its peak. It also required very major effort on the part of many suppliers all across the U.S. and in Japan. The acceptance of design criteria occurred in May 1987. Mobilizing of the construction crew and ground breaking on the first 2 units was in February of 1988, and first synchronization was achieved in November - a 19 month Project schedule with an 11 month construction schedule. Turbine sets for the second two units (BLM 1 and 2) were ordered in January 1988, and were synchronized in December, 1988, after a construction time of under 8 months. These results were achieved despite several competing factors, including cold weather, location on a military base, and a location remote from the major centers of construction employees.

As typical of fast Projects, licensing was tracking just ahead of design and construction generally. However, a major perturbation occurred when, in February of 1988, it became necessary to split what had been a 3 Unit BLM site into 2 distinct sites approx. 1 mile apart; the easterly site having 2 units and the westerly site one unit. At the same time it became necessary to relocate the Navy 2 power block site. These moves had the effect of maintaining all the plants at least one mile from any neighboring plant site. It was also necessary to reduce the size of the BLM easterly units to 24 MW Gross each under average conditions. The was accomplished by:

1. Installing one less stage of high pressure blading, rotating and stationary, at the manufacturer's shop.
2. Installing one less rotor bar in the generator rotating field.
3. Installing reduced fill in the cooling tower.
4. Various other smaller changes.

The changes have produced the predicted effect.

Weather.

Startup in December, in the high desert, naturally means cold weather. Unfortunately, insulation and heat tracing needs to be installed near the end of construction. Before completion of heat tracing, very low temperatures, combined with snow, rain, and heavy winds, did cause multiple instrument sensing problems. This was particularly a factor on the 3rd and 4th Unit as Startup occurred with more construction items remaining.

Figure 5. NAVY 1 GATHERING AREA.

RESOURCE DEVELOPMENT

The development of the lease resources, in terms of both timing and produced fluid energy levels, caused some changes in design interpretation. The first two units, Navy 1 units 2 and 3, used 7 rather than 4 high pressure separators, 3 rather than 2 LP separators, and other associated changes. The second pair of units, on the BLM east lease, had been designed for enthalpy levels of 550 Btu/Lb based on initial and limited testing. After the licensing impacts and subsequent field development, the actual resource developed at 480 Btu/lb. This resulted in brine production exceeding the expected by more than 50%, and therefore the noncondensable gas also exceeding expected values, by the same amount. This problem has been vigorously addressed by the Owners and Contractor. Temporary piping, gas removal vacuum pumps, and booster pumps to improve performance of the steam jet ejector condensers, were obtained and installed.

Capacity Factor.

Following their November synchronizing, the first two units achieved a capacity factor of over 90% by January, 1989. The second two Units, at BLM east site, were slower in power ascension because of impacts of the developed enthalpy. However, by June of this year both of these units have also achieved commercial operation, and have capacity factors exceeding 90%.

Equipment Performance.

For the most part, equipment has performed as designed. Turbines by Fuji Electric have performed very well. The separators, designed by Ben Holt Co. and fabricated by competetive bid to steel fabricators, have been very successful. The "New Zealand Drop Pots", condenser partitioning, and pumps have generally been successful. As one might expect, the gas compressors, which are called upon to handle a difficult gas, have required more effort at "fine tuning". Injection pump mechanical seals are also requiring attention. Turbine-generator automatic starting and steam header pressure / plant load controls are working well.

FUTURE

Progress on the Project continues. Unit 9 at the BLM western site is expected to synchronize in the next 2 months, with completion of all power block and resource areas by year end. The Navy 2 site units, numbers 4,5,and 6, are proceeding: the major equipment is delivered, the foundations are well along, and turbine-generator for unit 4 is being set. These three units will be completed shortly after year end, and the Projects will end this phase of development.

Figure 6. Navy 1 Power Plant Area

CONCLUSION

Fast tracking of a Project can mean many things, and require many skills to accomplish. Chief among these skills are the ability to handle the unexpected. Flexibility in design and management methods is imperative if difficult schedule goals are to be met. And a little luck.

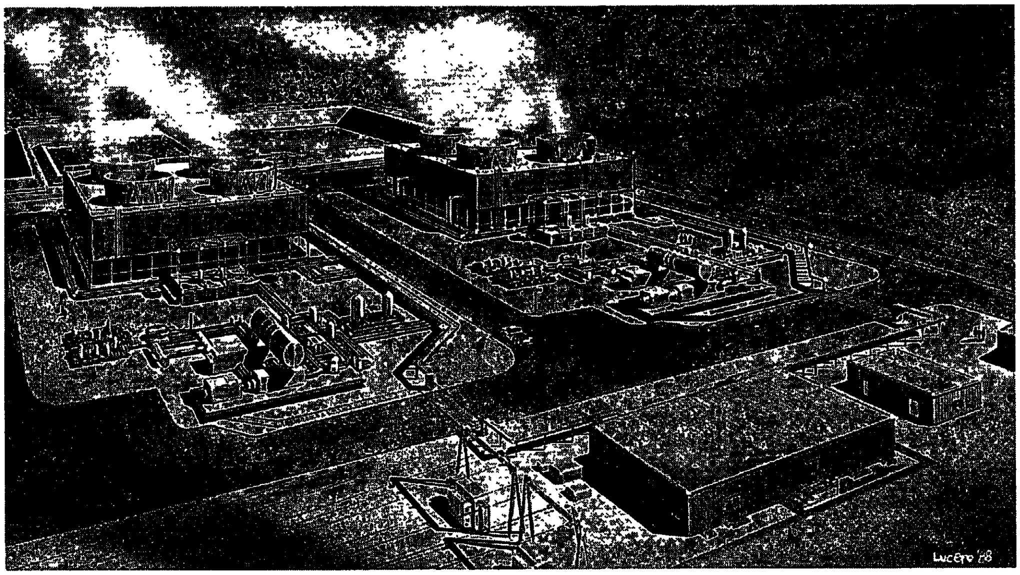


Figure 7. BLM East