APFBC REPOWERING FOR FOUR CORNERS STATION UNITS 1, 2, AND 3

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Abstract

This paper describes a feasibility assessment that evaluated whether advanced circulating pressurized fluidized-bed combustion combined cycle (APFBC) repowering made sense at the Arizona Public Service Company's (APS) Four Corners power plant, which is located on the lands of the Navajo Nation near Fruitland, New Mexico.

A conceptual design effort provided data that enabled the evaluation of the merits of a phased construction approach to APFBC repowering. The paper focuses on repowering the three smaller units of the five steam electric generating units at the Four Corners station, a mine-mouth plant with an abundant supply of inexpensive coal nearby. Units 1, 2, and 3 are the focus of the repowering investigation.: Units 1 and 2, each 190,000 kW reheat units, and Unit 3, a 250,000 kW reheat unit. The existing 850,000 kW supercritical Units 4 and 5 are unaffected by the repowering upgrades.

A single Foster Wheeler APFBC island repowers each unit. Each of these three islands use Dresser-Rand turbomachinery for the combustion turbine. A phased construction introduces the equipment to the site with a minimum of interruption of station output. The APFBC repowering would extend the useful operations at the site. Heat rate is improved, so the low operating costs mean that these units would continue to remain among the most competitive in the Southwest. Environmental characteristics of APFBC are excellent, which allows offsets that permit significant expansion in capability at other sites. Water use is reduced, so other plants can be sited elsewhere on the system, in a region where water rights are costly. Coal use expands, as does power output, which means more jobs for the Navajo Nation, increased revenue for APS, and income royalties to the Navajo Nation.

This paper describes how the APFBC equipment would be added to the site, and the performance and environmental improvements it would offer. There are many factors that make this repowering look attractive. There are also risks associated with a first-of-a-kind installation. The paper identifies these, and shows how the approach developed for this possible project likely avoids the serious consequences often associated with first-of-a-kind plant installations.

The Four Corners Station

The host site for this repowering evaluation is Arizona Public Service's (APS) Four Corners steam generating station, shown in the photo above. The Four Corners station is a two million kilowatt mine-mouth coal-fired station located on the land of the Navajo Nation. It is in the northwest corner of New Mexico, near Fruitland, about 11 miles west of Farmington.

APFBC is very flexible in its ability to burn different fuels, and its in-bed limestone sulfur capture allows most types of solid fuels to be used wherever there is an economic advantage to do so. The Four Corners plant uses inexpensive strip-mined coal from the adjacent BHP Navajo Coal Company, which is perfectly suited to APFBC operations.

What Is APFBC?

An advanced circulating pressurized fluidized-bed combustion combined cycle (APFBC) power plant is a type of gas turbine combined cycle that is fueled entirely on coal. APFBC exhibits excellent environmental performance and is projected to have attractive low production costs (fuel cost plus fixed and variable operating and maintenance costs). Based on earlier DOE evaluations[1], plant repowering is an attractive way to demonstrate APFBC technology in early commercial applications. There are potentially many plants similar in size to the Four Corners station units that could benefit from APFBC repowering.

The APFBC system uses technologies developed by DOE and industry partners. Exhibit 1 illustrates the major components for the PFBC 1st-generation system used in the early project phases. Exhibit 2 illustrates the major components for an APFBC 2nd-generation system, which would evolve in the later project phases. APFBC uses a circulating pressurized fluidized-bed (PFB) combustor with fluid-bed heat exchanger to develop hot air for the gas turbine, and steam for the steam bottoming cycle. In addition, APFBC has a carbonizer (a pressurized, fluidized, jetting-bed device) to produce fuel gas from coal for the gas turbine topping combustor. These provide gas turbine firing conditions that allow high combined cycle energy efficiency levels using coal as the unit's fuel.

Exhibit 1. 1st-Generation PFBC Power System Sketch, for Operation in Earlier Project Phases

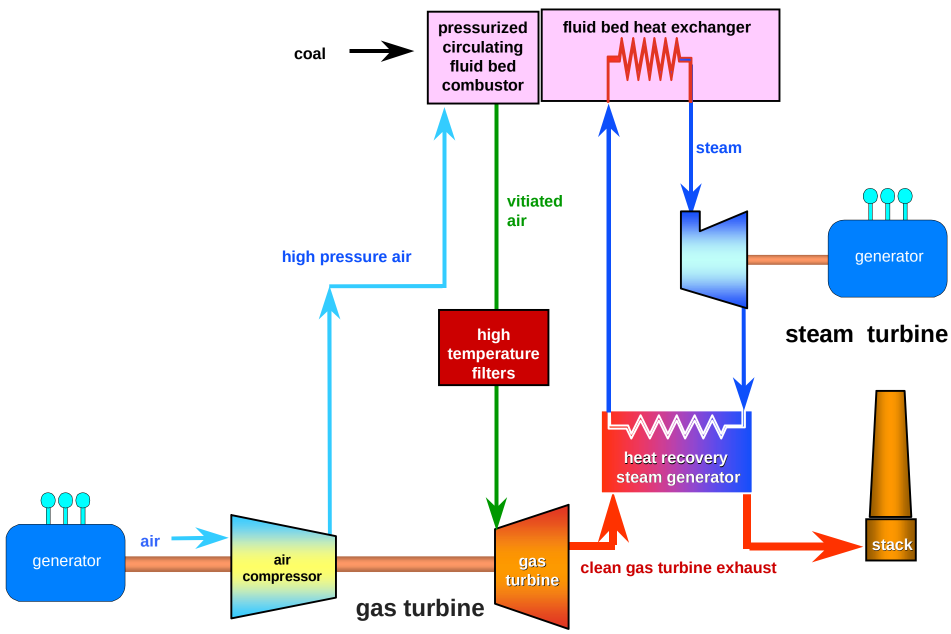
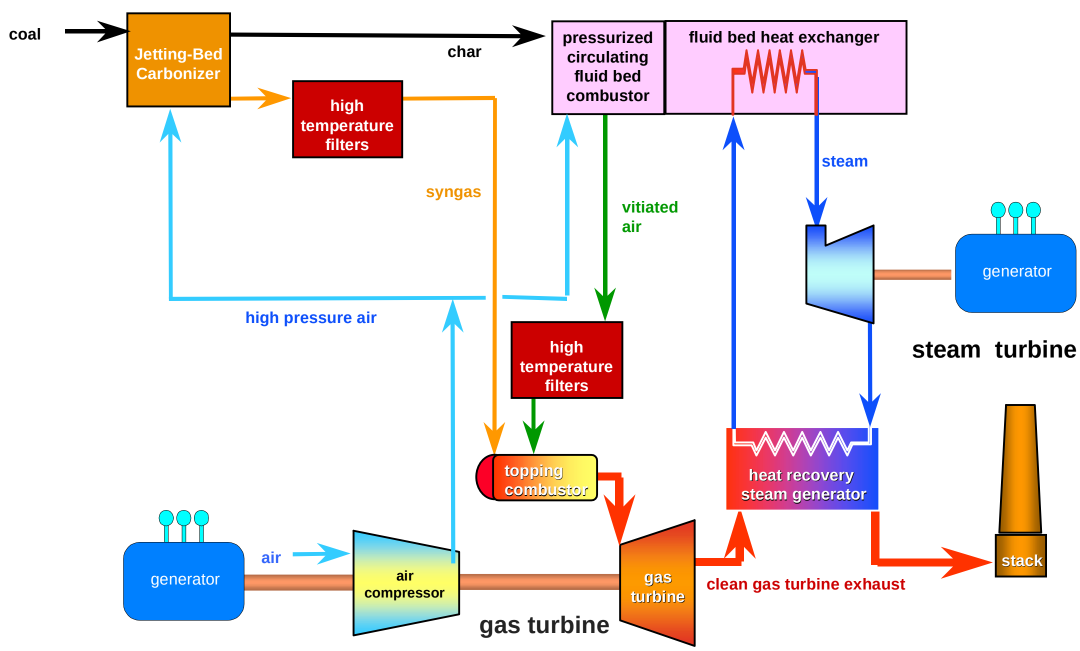


Exhibit 2. 2nd-Generation APFBC Power System Sketch, for Operation in Later Project Phases

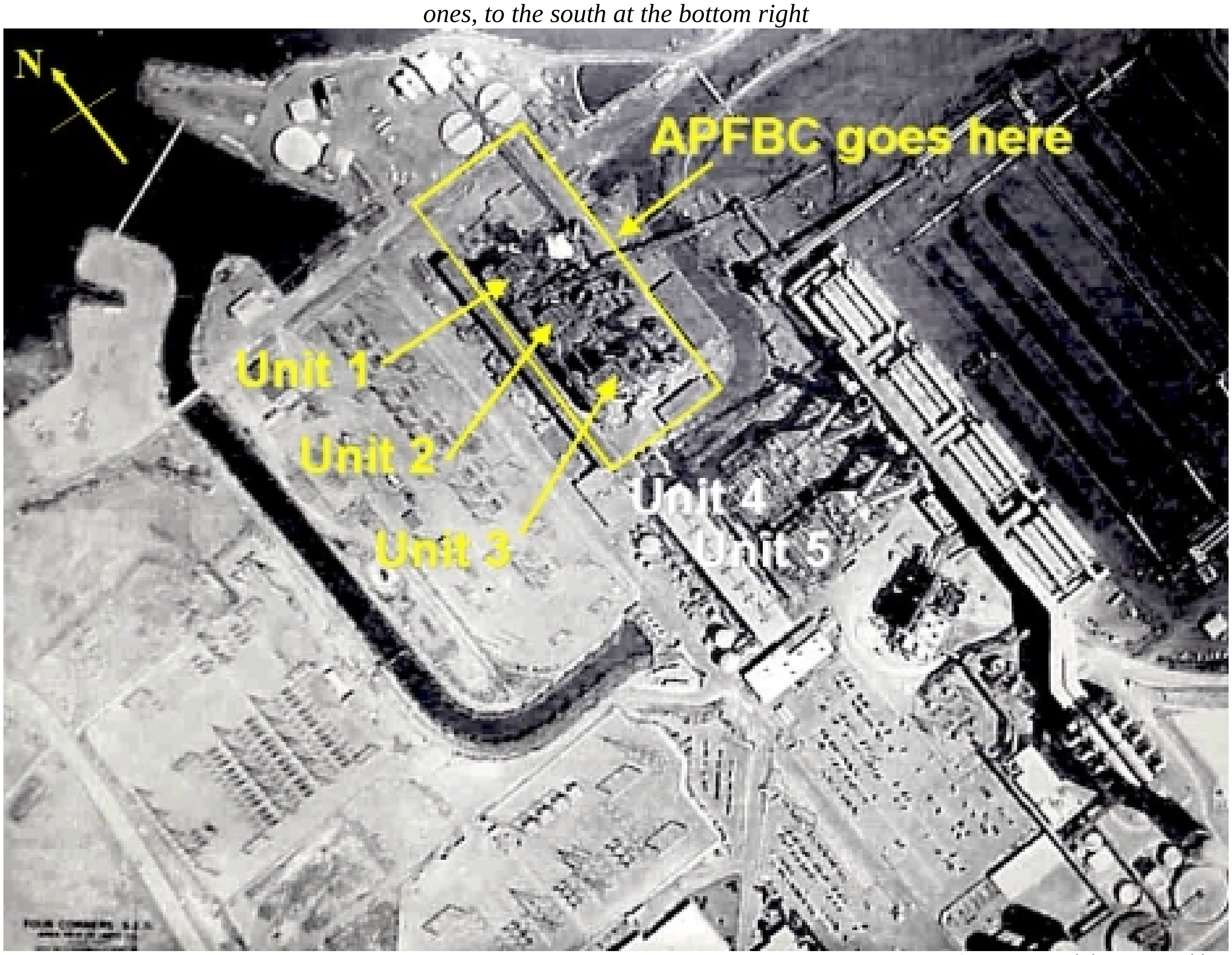


Locating the APFBC System at the Site

Exhibit 3 is an aerial photograph of the station. In this photo, north is along the diagonal axis of the plant from lower right to upper left. The common concrete stacks for Units 4 and 5 are furthest to the lower-right (south end). The two stacks right of center of the picture formerly served these units. The lime scrubbers for Units 1, 2, and 3 are toward the center of the picture at the top. Unit 1 is furthest to the upper left (north) in this image, with Units 2, 3, a space, then 4, and 5 further south along the north-south axis, diagonal in this view. There appears adequate room for an APFBC repowering, the three units amenable to APFBC repowering.

Exhibit 3. Aerial View of the Four Corners Station

North is along the long axis of the plant, diagonally upward to the left in this photo, with the Units 1, 2, and 3 scrubbers furthest to the north at the top slightly left of center in the photo, and Units 4 and 5 scrubbers, the larger ones, to the south at the bottom right



APS4corners arial annotated.jpg

In this planned APFBC repowering, the first PFBC unit would be installed just north of Unit 1, where the scrubber controls building is presently located. Subsequent PFBC and APFBC equipment for Units 2 and 3 would be built in the spaces presently occupied by the boilers for Units 1, 2, and 3, which would each, in turn, be demolished, as the phased construction proceeds.[2]

Summary of the Phased-Construction Plan for the APFBC Repowering of Four Corners Station Units 1, 2, and 3

From the APS point of view, any tradeoff between power and efficiency should maximize power output. In tradeoffs between capital cost and efficiency, cost reduction should be the goal. These preferences are based on the very low fuel cost available to the Four Corners power plant, the relatively high capacity factor now experienced, and the growing need for more power. The proposed repowering of Units 1, 2, and 3 takes these preferences into account, in a phased-construction approach to upgrading the station with APFBC technology. The proposed repowering of Units 1, 2, and 3 would be accomplished in five phases, as follows:

- **Four Corners Phase I**: 1st- generation PFBC repowering of Unit 1.
- **Four Corners Phase II**: 1st-generation PFBC repowering of Unit 2.
- **Four Corners Phase III**: 2nd-generation APFBC repowering of Unit 3.
- **Four Corners Phase IV**: 2nd-generation APFBC repowering upgrade of Unit 2.
- **Four Corners Phase V**: 2nd-generation APFBC repowering upgrade of Unit 1.

Exhibit 4 lists the PFBC or APFBC operating conditions for each of these five project phases.

Site Plans for the Various Phases of Construction

Site plan view drawings for the phased construction at the project site are included as Exhibit 5 through Exhibit 13. The development of the Four Corners plant site to incorporate the new structures required for this repowering takes place within the geometric confines of the existing power plant incorporating Units 1, 2, and 3. By the end of Phase V, each unit will have its own APFBC island connected individually to its own existing steam turbine generator, resulting in individual repowered units. By the end of Phase V, all three pulverized-coal-fired boilers will be replaced, as well as the entire lime scrubbing facility. The plant coal preparation, silos, and supply system will remain, supplemented with new storage silos required. Each APFBC island will have its own coal sizing and injection facility. The lime sorbent blended with magnesium oxide would be supplied as a prepared 1/8x0 product trucked to the site. The lime sorbent removes sulfur from the coal combustion products.

Exhibit 4. The Operating Conditions for the Phased-Construction APFBC Installations

	Carbonizer Temp	Carbonizer Syngas Filter Temp	Syngas Alkali Getter	PFB Temp	PFB Vitiated Air Filter Temp	Vitiated Air Alkali Getter	Rotor Inlet Temp§ and Fuel	Topping Combustor	Turbo Machinery Manufacturer
Phase I: Unit 1 1550ºF Part-load 1st generation PFBC	None	None	None	1625ºF*	1560ºF*	Yes	1550ºF unfired	None	D-R
Phase II: Unit 2 1550ºF Part-load 1st generation PFBC	None	None	None	1625ºF*	1560ºF*	Yes	1550ºF unfired	None	D-R
Phase III: Unit 3 1550ºF Part-load 1st generation PFBC	None	None	None	1625ºF*	1560ºF*	Yes	1550ºF unfired	None	D-R
2nd generation Unit 3 APFBC Repowering	1700ºF*	1200ºF	No	1625ºF	1560ºF	Yes	1950ºF syngas	Yes	D-R
Phase IV: Unit 2 2nd generation Unit 2 APFBC Repowering	1700ºF* from U3	1200ºF	No	1625ºF	1560ºF	Yes	1720ºF syngas from Unit 3	Yes	D-R
Phase V: Unit 1 2nd generation Unit 1 APFBC Repowering	1700ºF* from U3	1200ºF	No	1625ºF	1560ºF	Yes	1720ºF syngas from Unit 3	Yes	D-R

PFB bed operates at temperature high enough to provide heat loss temperature drop, and hold rotor inlet temperature.

§ Total temperature after first stator vanes but before first rotor airfoils

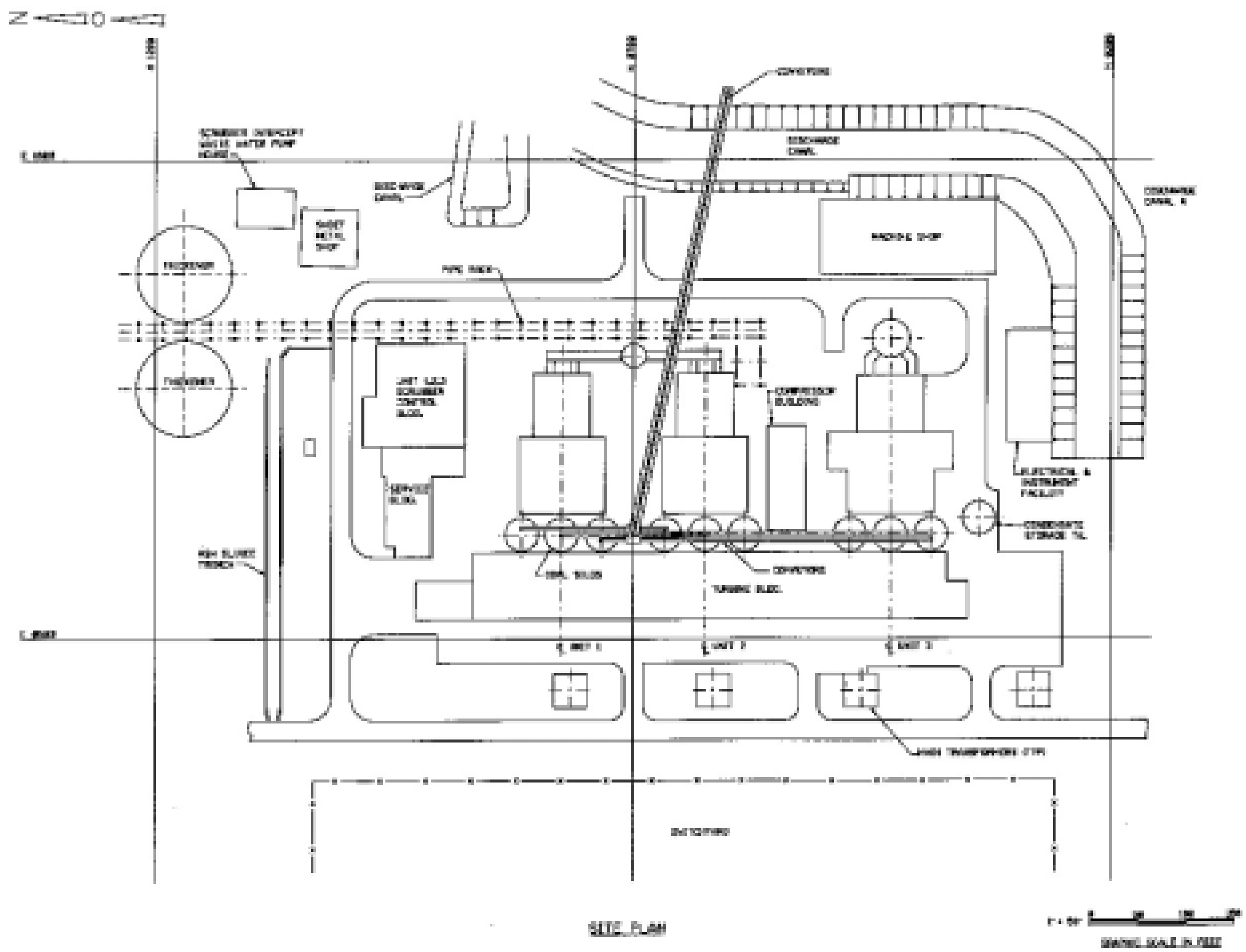


Exhibit 5. Units 1, 2, and 3 Existing Site Plan Prior to Construction

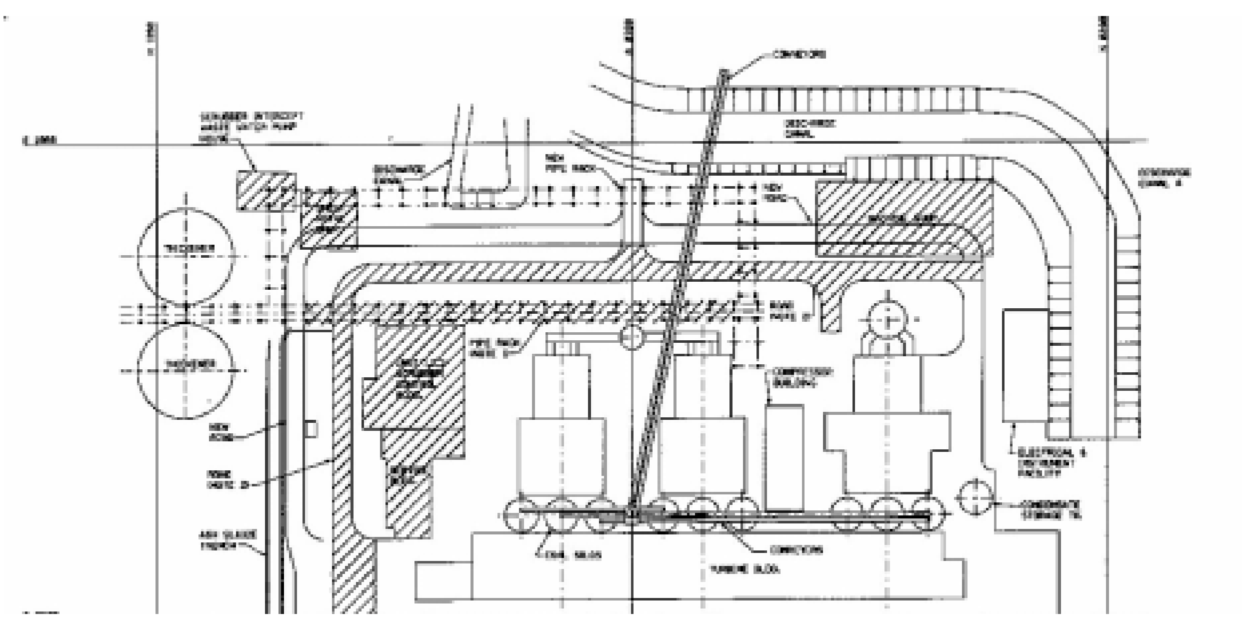


Exhibit 6. Units 1, 2, and 3 Initial Demolition and Site Construction

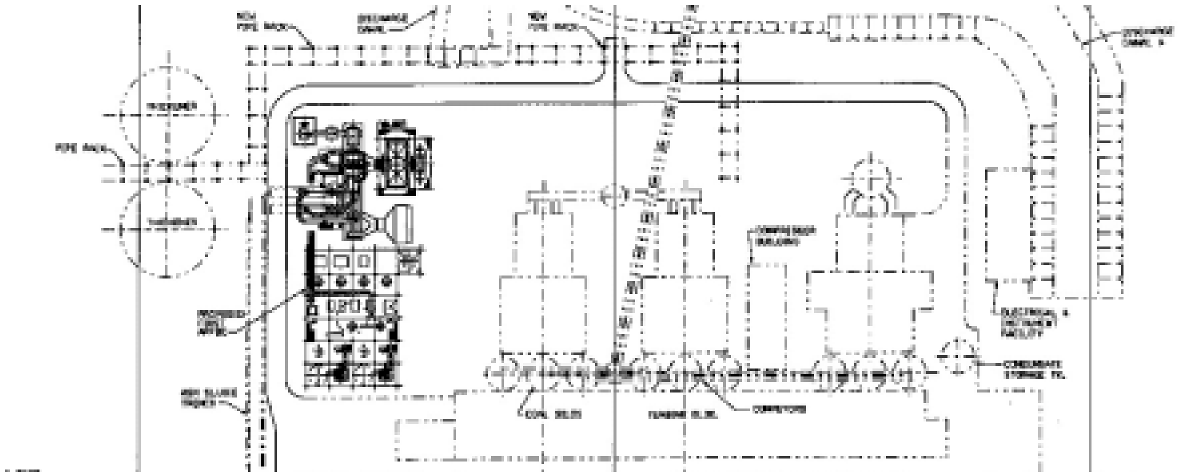


Exhibit 7. Unit 1 APFBC

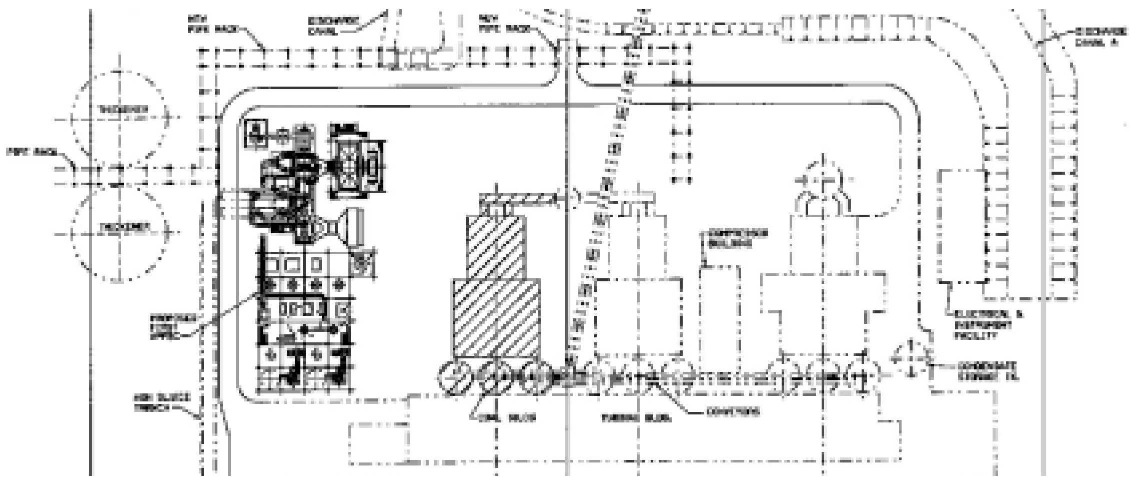


Exhibit 8. Unit 1 Demolition

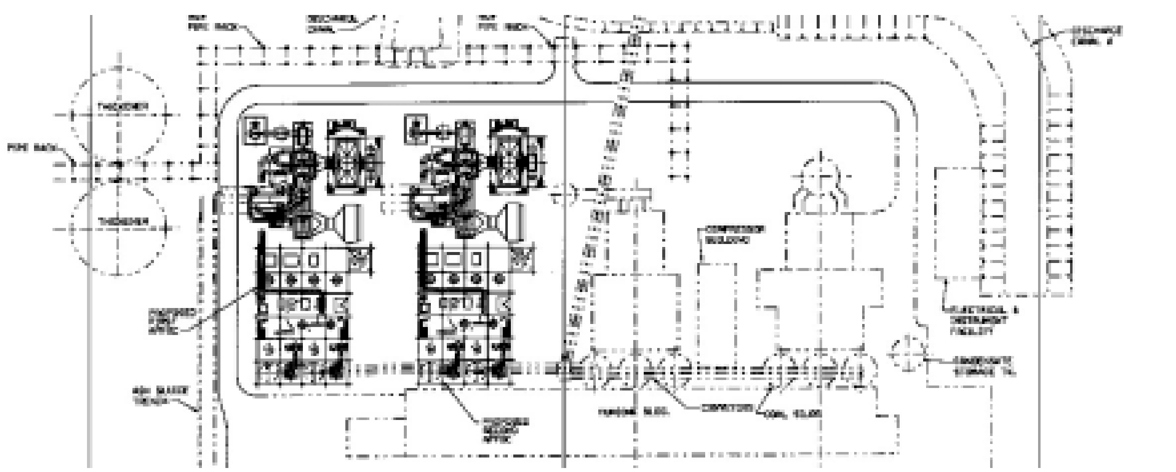


Exhibit 9. Unit 2 APFBC

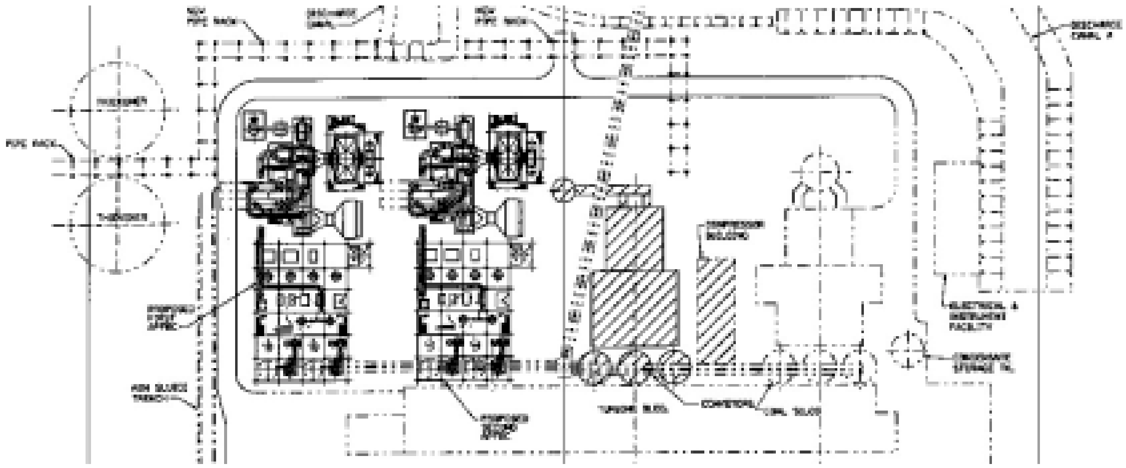


Exhibit 10. Unit 2 Demolition

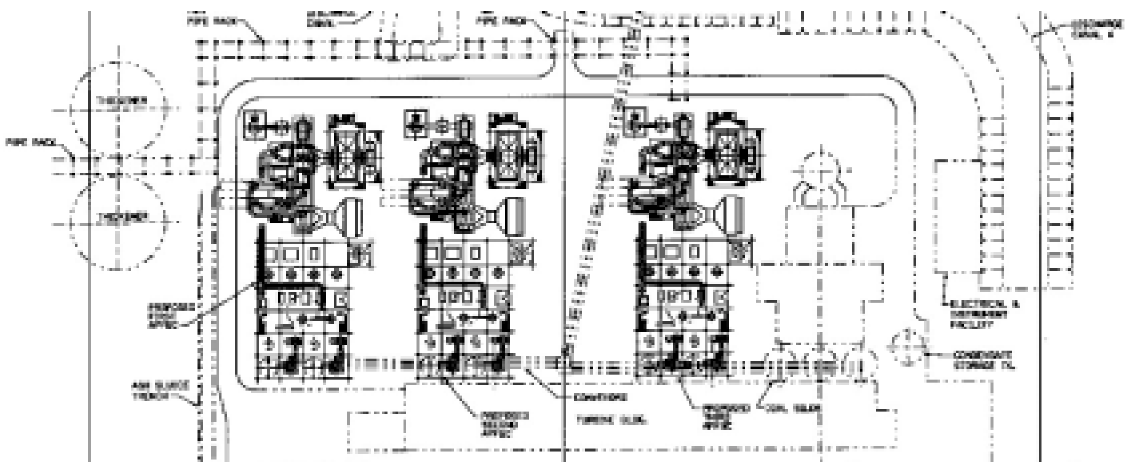


Exhibit 11. Unit 3 APFBC

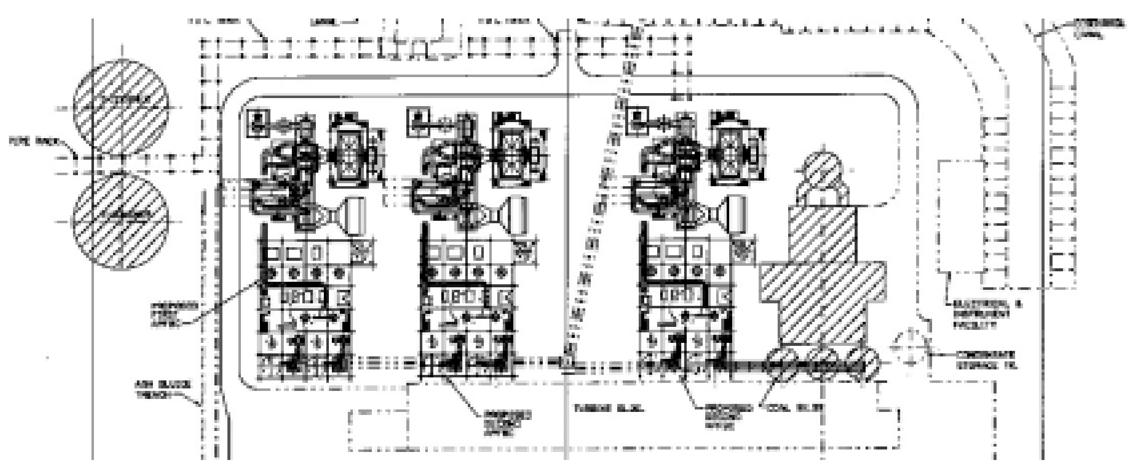


Exhibit 12. Unit 3 Demolition

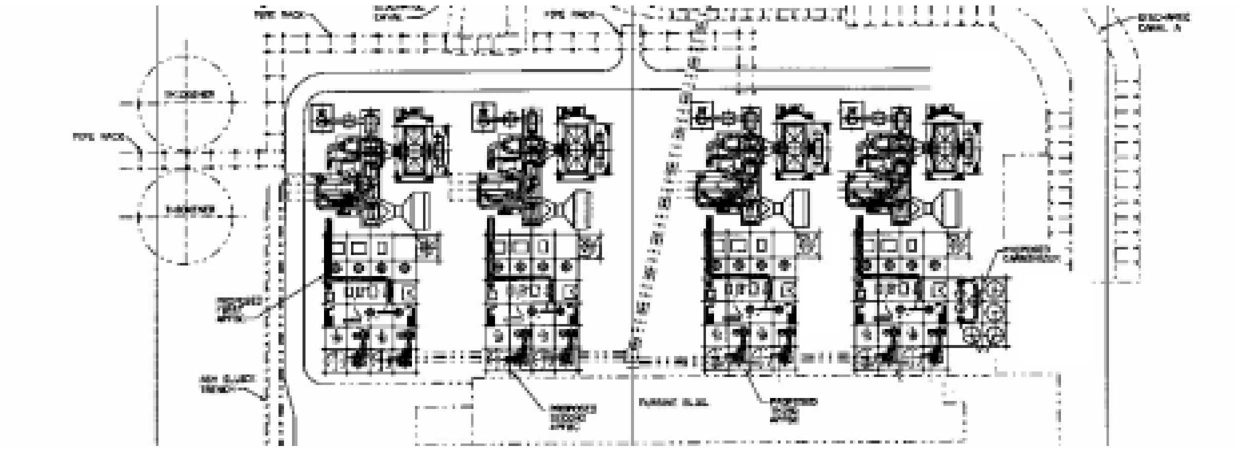


Exhibit 13. Unit 3 Carbonizer Feeding All Three Units

The plant arrangement at the completion of the project, Exhibit 13, is a compact and workable facility combining coal supply, sorbent supply, new power generation by combustion turbine generators, and existing steam turbine operation.

Four Corners Phase I: 1st-Generation PFBC Repowering of Unit 1

During Phase I, a 1720 ºF-capable Dresser-Rand APFBC system for Unit 1 is installed, but operated as a 1st-generation PFBC unit. This unit will use Foster-Wheeler APFBC equipment, Siemens Westinghouse ceramic filters, and Dresser-Rand industrial turbomachinery[3]. The connection to the Unit 3 carbonizer would eventually be added later, in Phase V. Only the 1st-generation equipment needs to be installed. The filters and pipes would operate at 1550 ºF for 1st-generation PFBC mode. Later, in Phase V, these would operate at 1400 ºF. The Dresser-Rand turbomachinery would be 1720 ºF capable, but initially operated unfired, without the topping combustor, operating during Phase I at 1550 ºF rotor inlet temperature.

Later, in Phase V, when Unit 1 is converted to syngas operation using Unit 3 syngas, the Unit 3 APFBC compressors will supply all of the air for the Unit 1 and Unit 2 syngas production. The Unit 1 turboexpander sets must have the flow capability to accept this added massflow that would occur during Phase V 2nd-generation operations.

Unit 1 Phase I Site, Structures, and Systems Integration Modifications Required for Repowering. Exhibit 5 shows the plant site before construction. First, initial relocations have to be made of the pipe rack for piping to the scrubber facility, followed by reconnections. Then auxiliary buildings for scrubber control and the old pipe rack are demolished to make room for the new equipment, Exhibit 6. After the site is cleared, the Unit 1 APFBC is built, Exhibit 7.

The arrangement described above permits construction to proceed on the entire APFBC addition with minimal interference to operation of the existing plant. Access and construction laydown space are minimal at the site. However, with careful planning and scheduling of the entire project, the construction time can be minimized, and interference with ongoing plant operations can be avoided.

The outages required to make the necessary tie-ins to the existing units can be very short; the total plant outages may be governed by the time required to refurbish the original steam turbine generator sets, and then start up and test the integrated plant.

Four Corners Phase II: 1st-Generation PFBC Repowering of Unit 2

Exhibit 8 shows demolition of the Unit 1 boiler. The coal bunkers remain in place as they are used for the coal storage of the new APFBC system. With the Unit 1 boiler demolished and removed, the site for the Unit 2 APFBC is cleared for construction.

The common steel stack for the Unit 1 and 2 boilers must remain in service as the Unit 2 boiler would still remain in operation in the early parts of this phase. The breeching connection of Unit 1 to this stack is removed and a cover plate is required to cover the opening.

When removing the existing Unit 1 boiler and preparing the excavation area, care must be observed in removing the foundations. The existing piping and electrical cables and control lines must be properly disconnected from service. Disconnection is to be made from the scrubbing system as to piping and flue gas breeching ductwork connections at the stack. These respective services for the Unit 2 and 3 boilers are to remain in operation.

In the cleared space will be built an APFBC unit similar to that installed for Unit 1, a 1720 ºF capable, but 1550 ºF-enabled APFBC system. Unit 2 will be installed in the space formerly occupied by the Unit 1 boiler. The site arrangement for Phase II after this installation is shown in Exhibit 9. The Unit 2 APFBC tie-in must be made in the shortest possible time. The APFBC-repowered Unit 2 will be operated in 1550 ºF rotor inlet temperature 1st-generation PFBC mode. Later, in Phase IV, this unit would be converted to syngas firing, using syngas supplied from the Unit 3 carbonizer.

Four Corners Phase III: 2nd-Generation APFBC Repowering of Unit 3

This is the most sophisticated of the phases, and involves several steps. In this phase, the area now occupied by the Unit 2 boiler is cleared to make room for the 1st-generation Unit 3 equipment, Exhibit 10.

A fired 1950 ºF rotor inlet temperature capable Dresser-Rand APFBC system for Unit 3 will be installed as an APFBC repowering system from the start, with carbonizer and topping combustor capable of delivering 1950 ºF rotor inlet temperature. The first of two sets of 1st-generation equipment is installed in the former Unit 2 boiler space, Exhibit 11.

Two APFBC islands are needed to repower Unit 3. Since there is not enough room to immediately install either the second APFBC island or the 2nd-generation carbonizer until after the Unit 3 boiler is demolished, it is prudent to initially operate the first APFBC island for Unit 3 in 1550 ºF unfired 1st-generation mode. This will provide partial steam output to the Unit 3 steam turbine.

At this time, the Unit 3 boiler, and all of the Unit 1, 2, and 3 scrubber equipment and pipe racks are no longer needed. The Unit 3 boiler is demolished. Exhibit 12 shows the site before either the second APFBC island or the carbonizer is added.

The demolition of the Unit 3 boiler must occur before construction of this second APFBC island can commence. The demolition of the pipe racks and scrubber can occur in parallel to the construction of the second APFBC island and Unit 3 carbonizer. When pipe rack and scrubber are demolished and removed, the elevated coal conveyor must be avoided and the proper relationship of crane and equipment installation must be followed.

When the Unit 3 boiler is demolished, the second APFBC island is installed, connected, and operated in 1st-generation mode. This returns the Unit 3 steam turbine to full output. Then, the 2nd-generation equipment for Unit 3 is installed.

The Unit 3 carbonizer will eventually feed all three units. Unlike most other APFBC installations, where the carbonizer supplies only one unit, in this installation, a single carbonizer instead feeds three units. The Unit 3 carbonizer is thus oversized, so that by the end of Phase V, it supplies the syngas for all three APFBC-repowered units. In those periods where Units 1 and 2 are not in operation, supplemental coal will be supplied to the Unit 3 PFBC to make up the missing char from the carbonizer. When Units 1 and 2 are not in operation, so their syngas supply is not needed, as will be the case after this Phase III, the carbonizer will operate at a part-load condition, with only a portion of its design coal supply.

Since the Unit 3 carbonizer supplies all three units with syngas, the Unit 3 compressor sets must have the flow capacity to supply all of the carbonizer air needs for the syngas production supply for Units 1, 2, and 3, when the Unit 2 and Unit 1 topping combustors come online later in Phases IV and V. The Unit 2 and Unit 1 turboexpander sets must have the flow capability to accept the added massflow of the Unit 3 syngas.

When the carbonizer is brought into service feeding Unit 3, this completes the major construction part of the construction for the plant. Only the final conversions of Unit 2 and Unit 1 to APFBC syngas firing remain in the last phases of the project. Exhibit 13 shows a plan view of the site after the second APFBC island and carbonizer are installed.

Four Corners Phase IV: 2nd-Generation APFBC Repowering Upgrade of Unit 2

Phase IV of the repowering project upgrades the 1st-generation PFBC repowering of Unit 2, completed earlier in Phase II, to 2nd-generation coal-fired operations.

A 1720ºF-capable topping combustor is added. The piping from the Unit 3 APFBC carbonizer to the Unit 2 topping combustor will be installed in the space reserved. The added equipment will convert the 1st-generation PFBC repowering into a 1720 ºF capable 2nd-generation APFBC repowering. The APFBC-repowered Unit 2 will be operated in 2nd-generation 1720 ºF PFBC mode, with syngas from the Unit 3 carbonizer. In this Phase IV mode, the Unit 3 carbonizer is operating closer to full-load capability, and the char needed for steam production will supply more of the PFBC steam generation energy; the Unit 3 PFBC will not need quite as much coal supplement as it would for Phase III.

If the Unit 3 carbonizer is down, Unit 2 will be operated in 1st-generation mode. If Unit 2 is down, Unit 3 will be operated in the Phase III mode.

The site arrangement and plot plan shown earlier for Unit 2 in the Phase II effort is little changed in Phase IV. The only additions are piping for the hot syngas from the Unit 3 carbonizer, and the gas turbine topping combustor.

Four Corners Phase V: 2nd-Generation APFBC Repowering Upgrade of Unit 1

Phase V of the repowering project upgrades the 1st-generation PFBC repowering of Unit 1, completed earlier in Phase I, to 2nd-generation coal-fired operations, similar to that done for Unit 2 in Phase IV. In Phase V, the Unit 3 carbonizer is finally operating at full-load capability, and the char needed for steam production will supply PFBC steam generation energy, so it no longer needs the Phase III coal supplement.

If the Unit 3 carbonizer is down, Units 1 and 2 will be operated in 1st-generation mode. If either or both Units 1 and 2 are down, Unit 3 will be operated in the Phase III or Phase IV mode.

Phase V completes the APFBC repowering project, Exhibit 13. At the completion of Phase V, Units 1, 2, and 3 would all have been converted to APFBC repowering. The smaller Units 1 and 2 would be operating with 1720 ºF APFBC equipment, the larger Unit 3 with 1950 ºF APFBC. The existing Units 1, 2, and 3 boilers and scrubbers would have been demolished and removed.

The existing 850,000 kW supercritical Units 4 and 5 would remain in service, and are unaffected by the repowering upgrades.

Laydown and Construction Access

Access to the new construction required for this project is by truck delivery. Railroad delivery can be made to Gallup, New Mexico and then transloaded to truck. The powerhouse site will have truck access roadway as shown on Exhibit 7. For construction purposes, laydown space will be provided close by as may be determined by construction management and plant personnel. Development of this site requires careful planning and scheduling for on-site arrival and storage of materials and equipment. Reference is made to Exhibit 13, which shows the final three-unit complex of the APFBC systems that would exist at the end of the project. This layout shows that the access to the construction sites for demolition and new equipment access is from the east side of the power plant. Since the various vessels, tanks, and machinery units are heavy and large, a good constructability plan is necessary. Crane mobility and clearances are of prime importance for removing the boilers, preparing each individual construction site, and moving and erecting such large vessels and equipment from temporary laydown storage to specific locations. Since access is required for all three APFBC units, the changes to the moved pipe rack must be designed to provide adequate vertical clearances for the entire construction plan.

In order to maximize access during construction, it appears prudent to schedule the delivery of the combustion turbine after most of the heavy construction on the PFB island is completed, and the delivery of the HRSG after the combustion turbine generator is set. This sequence will maintain access from the roadway by heavy equipment as each major functional area is completed.

Construction Schedule and Tie-In Time

All three units are dispatched at high capacity factor, so it is important they remain in operation throughout construction. Rapid tie-in time for the new APFBC equipment is important.

The majority of the construction of the APFBC equipment can be accomplished without disrupting the operations of the existing units. Tie-ins can be accomplished during a period similar to the normal maintenance outage period for the unit. The principal disruptions will be the tie-in of the steam lines and feedwater lines. Since the tie-in can be accomplished in nearly the same time span as the normal maintenance outage, disruption of output and reserve capacity should cause negligible financial consequence.

Operator and Maintenance Training Considerations

The plant operations and maintenance staff will need training in the operation and maintenance of the new APFBC equipment. Training for Phase I service is particularly important, since there would be no similar equipment installed at the site. The Phase I operations will form the experience base for the subsequent phases of the project, and the better Phase I is executed, the fewer problems will occur during the later project phases.

Phase II. The staff will probably not need significant training since the Phase II equipment for Unit 2 is a replicate of that in Unit 1.

Phase III. The plant operations and maintenance staff will need training in the operation of the new APFBC equipment for Unit 3, and its maintenance.

- **1st-Generation Operations and Maintenance Training**. The 1st-generation PFBC equipment for Unit 3 will be familiar to the staff, but there is sufficient difference in the equipment for Unit 3 from that of Unit 1 and 2 that some added training is necessary.

- **2nd-Generation Fired Topping Combustor Operations and Maintenance Training**. Training for fired combustion turbine operations is particularly important, since this mode of operation is new, and there would be similar equipment placed in operation at Unit 2 and Unit 1 in later project phases. This phase introduces the operation of the carbonizer, syngas production, integrated APFBC operations, and fired topping combustor operations, all of which require new operating skills. The Phase III 2nd-generation APFBC operations will form the experience base for the subsequent phases of the project, and the better Phase III is executed, the fewer problems will occur during the later project phases.

Phase IV and V. The 2nd-generation APFBC equipment for Unit 2 and Unit 1 will be familiar to the staff, since it is similar to that for Unit 3, already operating, though the Unit 1 and Unit 2 topping combustors operate at lower temperature.

The syngas for Unit 2 and Unit 1 comes from the Unit 3 carbonizer. The major new operator considerations will be those associated with the revised Unit 3 carbonizer operations, which now will be accommodating greater air, coal, sorbent, and solids flow conditions. This will require some experience for operating the equipment in the new operating regimes, and in safely accomplishing transitions in the unlikely event of problems requiring maintenance or emergency shutdown of either the carbonizer, or Unit 1, Unit 2, or Unit 3, while keeping the remaining equipment in operation.

Control Room Tie-In Considerations

The station employs a digital control system (DCS), so the new equipment controls and actuators will be designed for tie-in into the data bus and computers. Check-out of the new controls and actuators would likely be exercised through the use of a plant simulator, during development and check-out. Once the safe operation of the controls and interlocks is verified, the bus can be permanently linked to the data bus during the APFBC tie-in plant outage. There should be no interruptions in operations when the system is brought into service. The new operator screens for the APFBC equipment would then be enabled.

Electric System, Switchyard, and Transmission System Tie-In Considerations

Switchyard and transmission tie-in for Phases I, II, and III are each a necessary disruption is the plant bus and in the high voltage tie-in to the switchyard, which must be carefully scheduled, planned, and coordinated with operating units. This could be accomplished during the normal annual outage. There are no switchyard or transmission issues associated with the latter phases of the project.

Conclusions

When this paper was written, in July 2000, the operational economics were still being evaluated; the results of the economic assessment will be available when this paper is delivered in November 2000. Still, sufficient work occurred to draw the following observations:

- A phased-construction repowering of Four Corners Unit 1, Unit 2, and Unit 3 is possible.

- The equipment fits on the site, and the construction can be accommodated with minimum interference with power production.

Related evaluations allow other conclusions to be drawn about the prospect of APFBC technology:

- This upgrade, were it to be accomplished, would significantly increase unit output, while affording admirable environmental improvement at the site.

- ABFBC equipment development is sufficiently advanced that planning for its possible incorporation as a repowering option at coal-fired plant sites is appropriate.

- APFBC needs full-scale long-duration demonstration. Test programs are in place to establish much of the operational information needed. It is time for a full-scale first-of-its-kind installation.

- One should expect a first-of-a-kind installation learning curve with the kind of units described here. However, it appears there is a sufficient experience base so that problem areas have appropriate and sufficient design alternatives that they can be mitigated.

Does APFBC repowering make sense for these three APS units? Perhaps.

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[2] Weinstein, R.E., et al. APFBC Repowering Series Volume XI: Repowering the Four Corners Station with Advanced Pressurized Fluidized Bed Combustion (APFBC). Parsons Report No. EJ-10099. Draft. July 14, 2000.

[3] The design of this turbomachinery is discussed in the following technical paper: Goldstein, H.N., Bonk, D.L., Loughlin, R.M., and Raskin, N.R. "PFBC Design with Industrial Components." Power-Gen International 2000. Orlando, Florida. November 14-16, 2000.