Merchant Cost of Repowering With APFBC

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Abstract

Earlier evaluations provided concept evaluation estimates of the performance and cost for repowering two power stations with advanced circulating pressurized fluidized bed combustion combined cycles (APFBC). Each APFBC repowering evaluation used a Foster Wheeler APFBC island supplying a single APFBC-modified Westinghouse W501F gas turbine, retaining the use of the existing station's steam turbine/generator. The existing units evaluated from these stations were the following:

- The Carolina Power & Light Company's L.V. Sutton station. Two APFBC repowering configurations were assessed: repowering 106 MWe reheat Unit 2 with APFBC; and, repowering both Unit 2 as well as the 97 MWe non-reheat Unit 1 with APFBC.

- The Duke Energy Dan River station: repowering the 150 MWe reheat Unit 3 with APFBC.

These evaluations found that there are significant opportunities from repowering these units. Unit energy efficiency improves dramatically, output from the site is increased, and very significant environmental emission improvements occur. The low production costs of operating such plants are excellent, and both power companies found their projected use of this type of plant would make these aging units flagships in baseload dispatch, among the first coal-fired units in the dispatch order.

This paper discusses work in progress that evaluates "merchant plant" cost reduction opportunities compared to baseline regulated "utility" APFBC repowering designs. It shows how plant design might be changed to reduce capital cost with only slight losses in reliability and flexibility, but at no compromise in environmental quality. The paper gives estimates of the levels of cost reduction possible with these design changes. These "merchant plant" cost reductions can be substantial: 10 to 15 percent lower total plant cost than if the unit were designed instead for higher operational flexibility.

What is an APFBC?

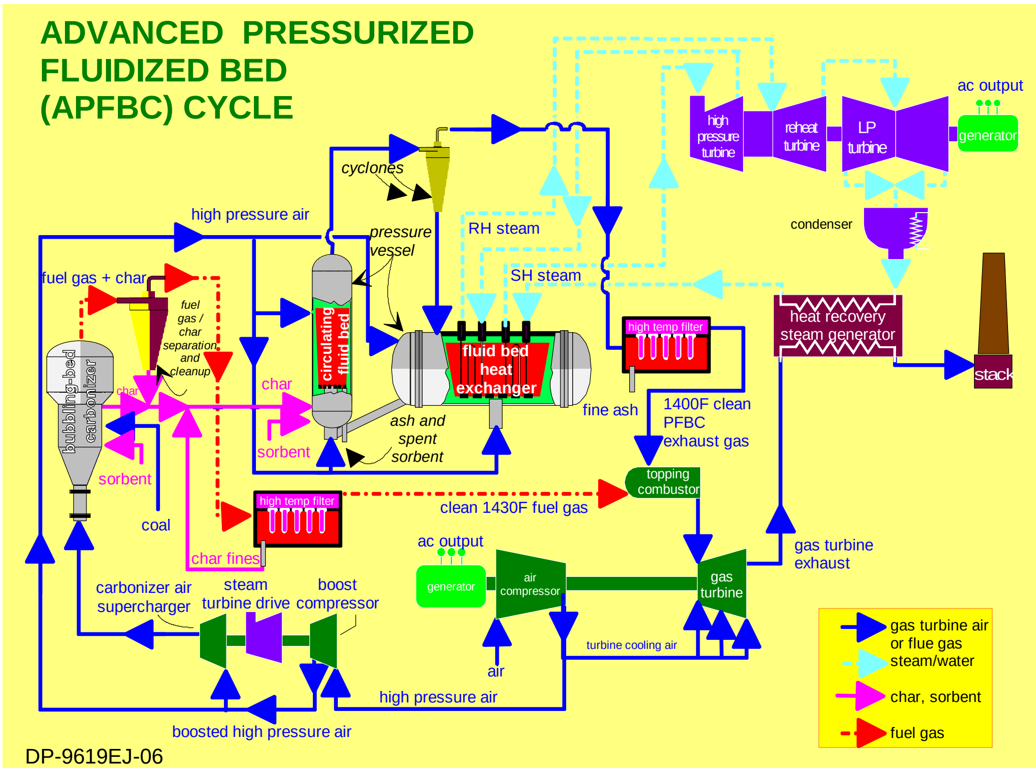
Advanced circulating pressurized fluidized bed combustion combined cycle (APFBC) technology uses gas turbine combined cycle technology in combination with coal-fired equipment. APFBC allows the gas turbine to operate free of corrosion and erosion damage. While a conventional combined cycle uses natural gas, APFBC operates at almost the same high levels of energy efficiency, but on less costly coal. APFBC has a wide tolerance for differing coal types and can use opportunity fuels, so the owner can take advantage of lowest energy price. This technology is also environmentally clean, which is important to generating companies subject to increasingly stringent regulations. Exhibit 1 gives a sketch of a typical APFBC process.

Several APFBC repowering evaluations of existing steam generating stations show favorable results. These would add an APFBC system to a site that retains the existing steam turbine/generator, and replaces the existing boiler. Studies show that this is an economical way to add power to a site.

An APFBC power plant is a new type of gas turbine combined cycle that is fueled entirely on coal. It provides environmental performance superior to NSPS requirements, and DOE estimates *[DOE, 1993]* that APFBC is capable of producing electricity at 42 to greater than 50 percent net plant efficiency (HHV). APFBC is projected to have attractive low production costs. Based on earlier DOE evaluations *[DOE, 1996]*, DOE found that plant repowering is an attractive way to demonstrate the technology in early commercial applications, add to the base of information on APFBC operability, firmly establish a base of capital and operating costs, and prove APFBC economy, reliability, and availability. There are potentially a large number of plants of similar size to the L.V. Sutton station and Dan River station.

Though it is approaching commercial readiness, APFBC is still under development. Some key component and integrated system testing by manufacturers and the U.S. Department of Energy (DOE) is underway at the DOE Power Systems Development Facility (PSDF) in Wilsonville, Alabama. DOE is also testing the special burners needed at the University of Tennessee Space Institute (UTSI). The first full-scale commercial demonstration of APFBC technology is being developed in a DOE-sponsored clean coal technology project at the McIntosh station owned by the City of Lakeland, Florida.

Exhibit 1. Advanced Circulating Pressurized Fluidized Bed (APFBC) Power System Sketch



APFBC can be used for either all new "greenfield" site applications, or as a technology to upgrade the capability of an existing steam plant. This paper focuses on APFBC repowering. The paper describes some important plant repowering design considerations one must understand when integrating an APFBC system to an existing steam plant. These and other considerations are detailed in a series of reports prepared for the DOE.

Repowering Considerations

It is often more economical to keep existing generation capacity in operation than to build new capacity. This is true for APFBC repowering. Studies show that all-coal-fired APFBC repowering is an economical alternative source for generating companies needing new baseload capacity. Investment is lower with APFBC repowering than for new pulverized coal plant construction, since a significant amount of existing equipment is retained, and production costs are outstanding.

Exhibit 2. Environmental Emission Reductions Expected From An APFBC Repowering Upgrade

	Existing Pulverized Coal Steam Plant	Plant Repowered With APFBC
SO_2	19.5 lb/MWh	0.7 lb/MWh
NOx	6.6 lb/MWh	2.2 lb/MWh
Particulate	0.43 lb/MWh	0.02 lb/MWh
CO_2	2,335 lb/MWh	1,630 lb/MWh

source: [Weinstein, 1997c]

Operations with APFBC have significantly lower operating costs, and APFBC use significantly improves environmental performance of existing units. Utility company production costing evaluations show that APFBC technology promotes a low-use unit from 10 to 20 percent capacity factors to first-dispatched baseload status with projected capacity factors in excess of 80 percent.

These and other considerations are detailed in a report prepared for the DOE *[see Weinstein et al., 1997a]* that were developed as part of the work in a series of DOE-sponsored APFBC repowering concept evaluations. A number of related DOE repowering concept studies provided the basis for the observations made here: repowering evaluations at the Carolina Power & Light (CP&L) Company's L.V. Sutton power station Units 1 and 2 *[Tonnemacher et al., 1997, Weinstein, 1997b, 1997c, Weinstein et al., 1997i]*, at Duke Energy's Dan River power station Unit 3 *[Wolfmeyer et al., 1997, Weinstein, 1997d, 1997e,]*, at the New York State Electric & Gas (NYSEG) company's Greenidge power station Units 3 and 4 *[Weinstein, 1997f, 1997g]*, and from other APFBC repowering studies prepared for the DOE *[DeLallo et al., 1997]*.

What Is a "Merchant Plant?"

Today's generating company owners are exposed to an increasingly competitive electric sales environment. In the past regulated environment, they developed their generation unit purchase strategies based on the long-term return from a near guaranteed customer bas and rate base. This generally led to more capital intensive "utility" plant design decisions that yielded the lowest life-cycle cost.

Today, however, with units in some jurisdictions subjected to increased competition, the required investment payback period is shorter, and there is less certainty of either customers or financial return. Rather than relying on long- payback times and assurances of return from a "utility" design, these "bare-bones" merchant-plant designs employ design features which significantly reduce the initial capital expense (and hence investment risk exposure). This low initial capital investment "merchant plant" variant of the baseline "utility" type of design is suited for a merchant plant business approach in an uncertain and/or competitive market. That merchant plant approach is not without significant owner decisions, however, since the design choices that lead to lower cost also reduce- some of the redundant trains in the baseline plant to single trains, reducing the initial capital investment but with a slight sacrifice in operational flexibility and operating cost, and possibly in the amount of maintenance costs needed to retain unit availability; lower initial capital cost might come at some sacrifice in later operations costs.

Availability and Its Relationship to Design and Maintenance

Maintenance considerations remain a significant portion of the decision process for any generating company that plans to bring an APFBC-repowered unit into service. The availability of the unit, its ease of operations, it costs for maintenance, and its ability to easily start/stop/cycle depends largely on decisions that are made when the plant is designed.

It is here where the "utility" design and the "merchant plant" design philosophies differ, which have a significant impact on the unit's equipment and arrangement. The "utility" configuration requires initial capital cost for components, subsystem redundancy and equipment arrangements that give it a higher potential availability, and have the potential to make it less costly to operate and maintain. The "merchant plant" configuration instead minimizes the initial capital investment, which results in design compromise features likely to make it more expensive to operate and maintain. The "utility" or "merchant plant" decision process is thus one of either "pay me now or pay me later."

One critical concern in any plant design is the operational availability of the unit to run when it is most profitable to run. While the theoretical maximum possible availability of a unit is a design characteristic, in actual practice it is optimal overall operational economics often occurs at a maintenance cost level that results in simply "acceptable" availability. Finding the best economic compromise requires decisions on on-site spares inventory, preventative versus corrective maintenance needs and preferences, investment in the skills of the operating and maintenance staff, freedom (or lack thereof) for scheduling unit maintenance outages, etc. that have significant impact on the economics of operating a unit.

The costs for maintaining a unit can be evaluated against the potential for providing desired unit availability goals. One method of evaluating the cost trades involved is to plot the relevant trades in a decision field, such at that illustrated as Exhibit 3 [Knoll, 1981]. Exhibit 3 is a sketch of a decision field that might be expected for a "utility" configuration unit. Such a decision field is obtained by using the logic model of a fault tree analysis. In creating such a field, each component is ranked twice:

- According to their importance to the unit availability.
- According to their importance to the unit economics.

Availability improvement is strongly a function of changes in component maintenance policies. The lower boundary to the curve of the decision field, is called the "best performance curve," and shows the lowest cost strategy that has the analytically-projected potential for achieving the goal level of availability. Annual maintenance costs can be higher, but never lower, than the best performance curve.

The region above that curve indicates the region of maintenance strategies that are less cost-effective. It is not possible to achieve operations below that curve boundary for any sustained period of time. All reasonable maintenance strategies would provide predicted levels of availability near this lower boundary. However, poor practices could be costly and ineffective, and result in ineffective maintenance with costs above this boundary.

There is usually an optimal point in maintenance practice that balances the costs of unplanned outages versus the costs of preventative and corrective maintenance. For illustration, it is assumed that when the "utility" unit was operated, it would be maintained at its optimal point on the best performance curve, indicated by the "most economical availability goal" arrows on Exhibit 3.

A "merchant plant" has different equipment, and thus a different decision field, as illustrated in Exhibit 4. Here, the owner accepts higher operations costs. However, even though the plants have different designs, it is possible for both the "utility" design and the "merchant plant" design to operate at the same unit availability levels (even though it will cost the merchant plant owner more money to achieve the same level), so long as the economic optimum level of availability is below the maximum attainable capability of the respective design.

Exhibit 3
Hypothetical Cost-Availability Decision Field of a "Utility" Configuration APFBC Repowered Unit

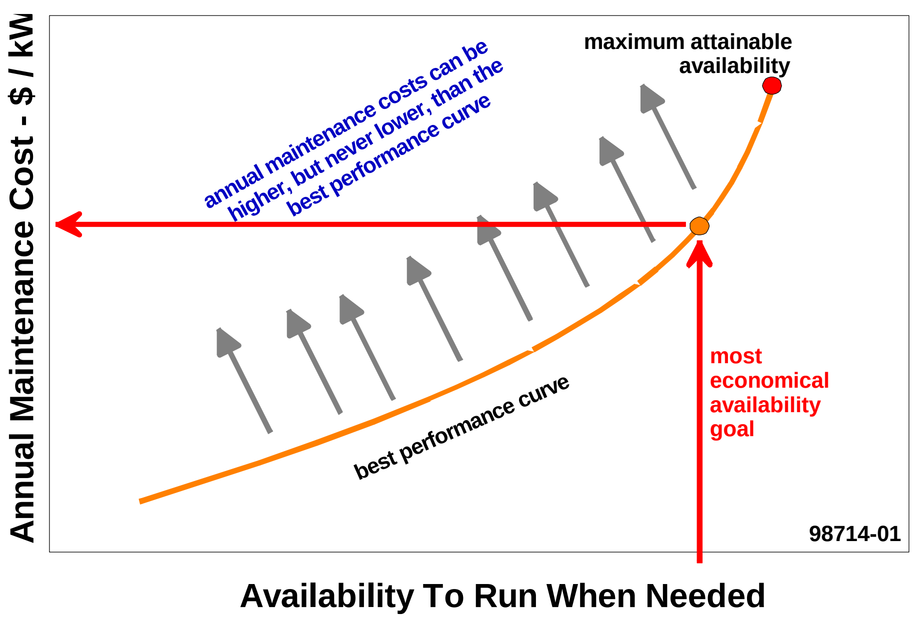
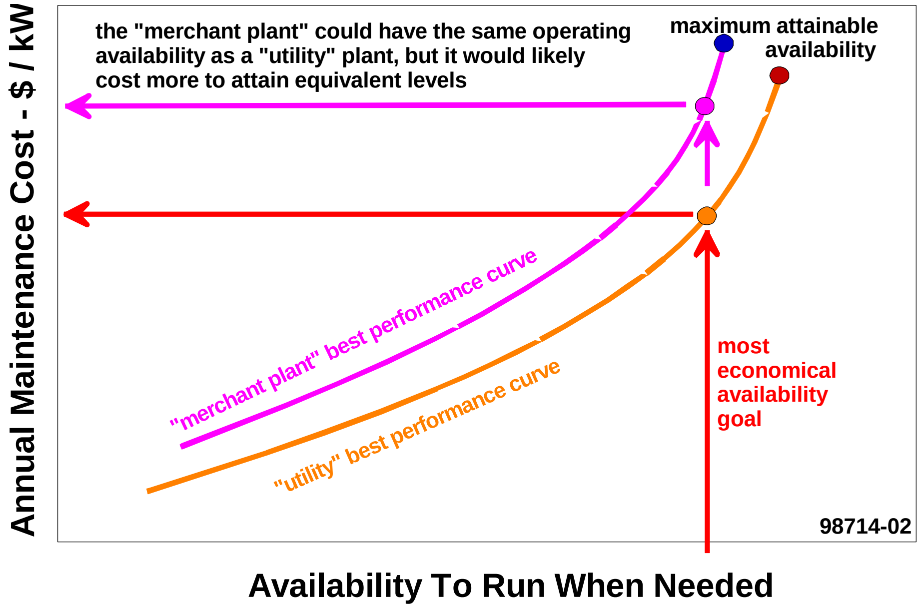


Exhibit 4
Cost-Availability Decision Field of a Hypothetical "Utility" Configuration Compared To That of a "Merchant Plant" Configuration



The L.V. Sutton Merchant Plant Configuration

In this section we focus on the design changes from a "utility" designed APFBC repowering, and contrast the "merchant plant" changes. For both plant configurations, L.V. Sutton Unit 2 is APFBC-repowered with a single APFBC-modified Westinghouse W501F. These adjustments modify the "utility" repowering conceptual design presented in

Exhibit 5. The "merchant plant" cost reduction adjustments to the "utility" design might require some compromise in energy efficiency, operating flexibility, reliability, or operating cost. Since "merchant plant" has some plant equipment that differs from the baseline design, these modifications change some of the details in the plant layout from those shown for "utility" in the body report.

The discussions below for this "merchant plant" cycle describe the changes to the plant concept that were made from "utility" configuration, and gives estimates of the cost and economic implications of the modifications. These concept estimates take the cost assessment as far toward increased economy as is possible without first developing the details needed from a complete design.

Reducing Initial Capital Cost

The capital cost reductions in a "merchant plant" approach came after a review of each major system in the established code of accounts of a "utility" design. Wherever possible, we reduced the number of components to the minimum number required for system functional capability. In most cases this means a potential reduction in plant reliability, or operating flexibility.

The ""merchant plant"" cycle is a functional system. Certain items were kept redundant: mills, for example, which are expected to be high maintenance items. Still, with these changes, the ""merchant plant"" cycle may potentially be more vulnerable to outage than the "utility" cycle. The level of change chosen here for the "merchant plant" cycle is one that remains good levels of reliability. In many cases, some of the features removed for capital economy could be added later as plant upgrades, if proven necessary by actual operating experience.

In general, spares are not provided for the ""merchant plant"" cycle, although multiple items at fractional system capacity are used where single components are too large or otherwise impractical. At this level of estimate, pricing for each type of component is not adjusted except if size or capacity changes. No reductions are taken for other methods of reducing price: foreign sourcing, materials and/or finish downgrades, or other quality reductions.

This assessment is felt to be a reasonable compromise for cost reduction. Still, there is still some room for further cost reduction. The changes here only have small impacts on the plant. Changes beyond these will have increasingly significant impacts on the unit. Further reduction can be made if the increased sacrifices in operational flexibility, maintainability, and reliability are acceptable to the owner.

The Merchant Plant Cost Reductions Chosen and Changes to Equipment Lists, Performance, and Cost

The "merchant plant" cycle cost reductions compared to the baseline "utility" configuration come from the a number of changes to the "utility" plant configuration.

The subsections below provide an illustration of the types of merchant plant changes needed for a "merchant plant" configuration for one of the studies. The underlay for the equipment lists below repeats the L.V. Sutton changes in "utility" Unit 2 APFBC repowering configuration equipment list items, and shows how they are modified for "Merchant Plant" service.

Similar changes were used when "merchant plant" configuring the APFBC repowering of L.V. Sutton Unit 1 and Unit 2, and for APFBC repowering the Duke Energy Dan River station Unit 3.

Changes in Account 1A: Coal Receiving & Handling

- Delete one of two new coal silos; increase size of remaining silo to equivalent capacity. The replacement silo is changed to a double outlet configuration.

Changes in Account 1B: Limestone Handling & Preparation

- Delete this entire system. The reduced cost plant will be based on delivery of pre-ground limestone, delivered by truck, transferred pneumatically into a storage silo, ready for immediate use. The covered outdoor limestone storage pile, rail spur, and equipment as listed in the equipment list are deleted.

- Replace entire system with truck delivery of dry sized product, at increased operating cost.

Changes in Account 2A: Fuel Preparation & Injection

- This system is modified to result in one equipment train with two roller mills (including their feeders and spinner separators). The original system was comprised of two complete subsystems. The resulting cost savings are about$ 1,000,000 at the equipment level of the capital cost spreadsheet. The roller mills are the most expensive pieces of equipment, but relying on a single unit of this relatively high maintenance item could compromise plant availability to an unacceptable degree; thus, two are chosen.

  Use one instead of two:
  - cone-bottom cyclone collector,
  - rotary valve,
  - dust collector rotary valve,
  - exhaust fan,
  - main mill fan, and
  - crushed coal silo.

- The "utility" coal handling system was estimated to cost $ 4,200,000. The net savings from above "merchant plant" equipment changes amounts to about $ 1,000,000, so final equipment cost of these systems is estimated at about $ 3,200,000.

Changes in Account 2B: Sorbent Preparation and Feed

- Delete the gravometric. feeders, rod mills, and Fuller Kovako screw pumps. These are not required with the delivery of pre-ground limestone. The blowers are retained as they are required for transfer of the limestone from the delivery trucks to the silo.

- One larger storage silo is provided, compared to two in the original case. This silo has increased capacity, to allow continuous operation during temporary difficulties in truck delivery.

- The added operating cost of "just-in-time" closed dry-transfer truck delivery of sized limestone needs to be added.

- Parking space for delivery trailers, and provision for increased traffic at the plant are needed.

- The limestone storage bin needs to be increased from 24 hour/260 ton storage to 72 hour/600 tons, with double outlet bottom.

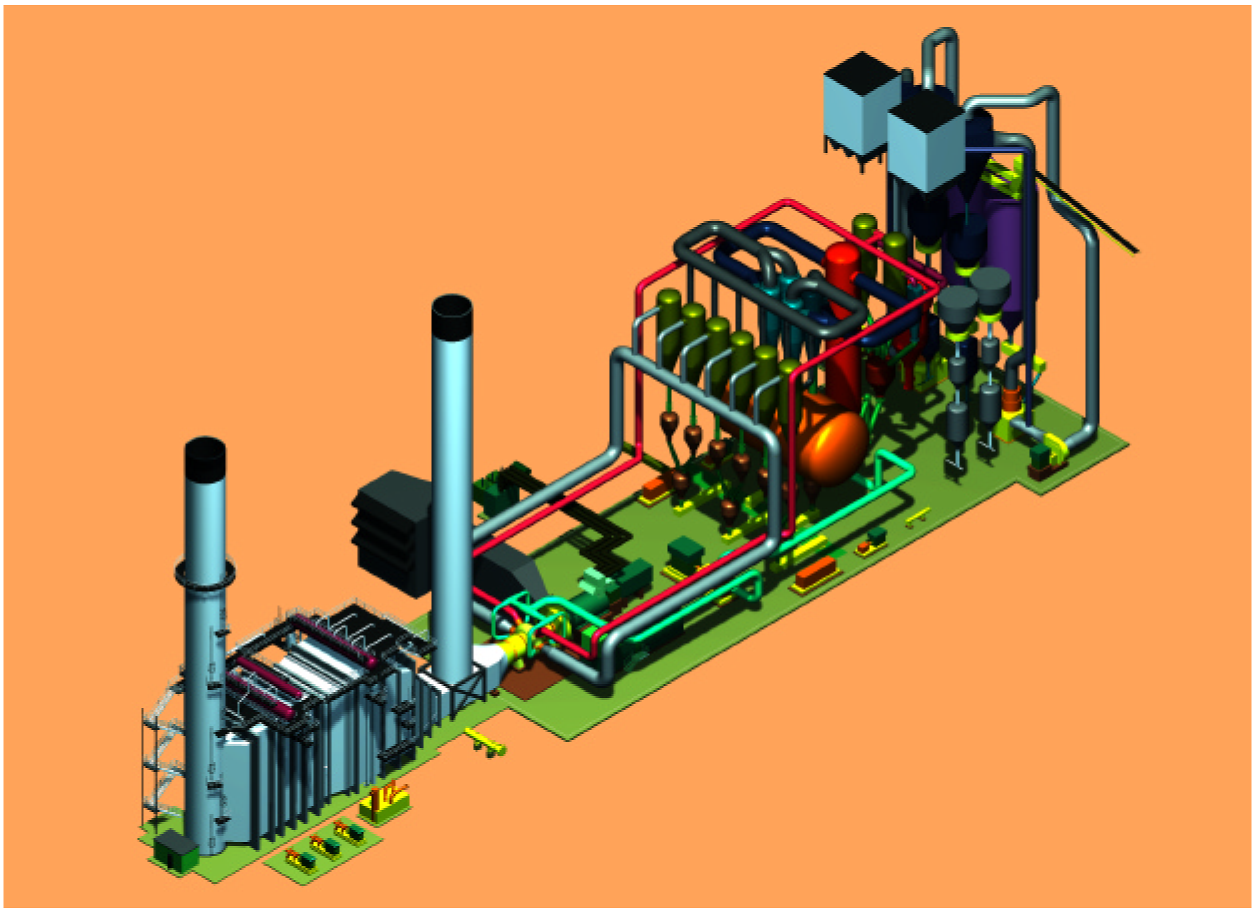
- There should be sufficient parking for temporary trailer storage during periods of anticipated bad weather (hurricane, etc.), when truck delivery might be temporarily hampered longer than the 72 hour capacity of the storage silo.

- Two limestone transfer blowers need to be included.

No Changes in Account 3A: Condensate & Feedwater, and 3B Miscellaneous Equipment

There are no significant changes in this account. No change; most of the items in these accounts are existing equipment. APFBC repowering adds considerable output to the plant, but at most sites would not significantly alter the condenser cooling duty, nor require re-permitting for thermal discharge.

Exhibit 5
Sketch of "Utility" Baseline System Showing Dual-Pipe Routing from Fuel Gas Filters and Vitiated Air Filters to Gas Turbine MASB



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Changes in Accounts 4 and 5: Carbonizer, PFBC, and Auxiliaries

- The carbonizer cyclone/filter trains are reduced from 2 each to 1 each. One tier of filters is added, so the height of the filter vessel increases. Face velocity increases by less than 10 percent.
- The CPFBC cyclone/filter trains are reduced from 4 cyclones/6 filters to 2 cyclones / 4 filters.

As an option, the hot gas piping may use stainless steel without refractory vs. the present arrangement of carbon steel pipe/refractory lined/Hastelloy inner liner. The following applies only to piping downstream of the candle filter vessels. Piping upstream of the filters remains as is: refractory lined, but without inner Hastelloy liner, the filters will remove any spalled refractory. Comparative piping dimensions are as follows:

Fuel Gas Piping Options A and B (single pipe route from filter outlet to MASB inlet):

- Both Options A and B: delete one fuel gas pipe leg, change to larger single pipe with route having sufficient flexibility to avoid expansion joints
- Refractory Option A: 48 inch OD carbon steel, 0.500 inch wall, 9 inch refractory
- Stainless Option B: 30 inch OD 316H stainless, 1.875 inch wall, no refractory

Vitiated Air Piping Options A and B (two pipes from Filter outlet to MASB inlet with sufficient flexibility to avoid expansion joints)

- Refractory Option A: 66 inch OD carbon steel, 0.500 inch wall, 9 inch refractory
- Stainless Option B: 48 inch OD 316H stainless, 2.375 inch wall, no refractory

Vitiated Air Piping Option C (single pipe route from Filter outlet to MASB inlet)

- Stainless Option C: 66 inch OD 316H stainless, 3.250 inch wall, no refractory
- Delete one vitiated air pipe leg, change to larger single pipe with route having sufficient flexibility to avoid expansion joints
- Choose lower cost of the following two options: Fuel Gas Refractory-Lined Pipe from filters to MASB; or, Fuel Gas Stainless Steel Pipe from filters to MASB
- choose lower cost of the following three options: Vitiated Air Refractory-Lined Pipe from filters to MASB; or, Vitiated Air Stainless Steel Pipe from filters to MASB; or, Vitiated Air Stainless Steel Pipe from filters to MASB.

No Changes in Account 5: Flue Gas Cleanup

The "utility" configuration and the "merchant plant" configuration are identical; all sulfur removal is inherent in the operation of the PFB beds, no special equipment is needed..

No Changes in Account 6A: Combustion Turbine & Accessories

A single APFBC- modified Westinghouse W501F is used in the "utility" plant and "merchant plant." There is no difference between the configurations in the equipment in this account.

Changes in Account Account 6B: Boost Subsystem

Boost compressor and driver needs are unchanged between the "utility" and "merchant plant" configurations.

Changes in Account 7: Waste Heat Boiler, Ducting, & Stack

- Delete bypass stack and diverter valve, eliminating the capability to operate the gas turbine as a simple cycle on natural gas without first establishing water/steam flow in the HRSG tubes.

Changes in Account 8: Steam Turbine Generator & Auxiliary Equipment

- Delete cost of upgrades to improve heat rate based on "latest technology aerodynamics, etc." Only incorporate repairs necessary for the unit to operate reliably and safely.

Exhibit 6. Performance Improvements from Two APFBC Repowering Evaluations

	CP&L		Duke Energy	
	Existing L.V. Sutton Unit 2	L.V. Sutton Station Unit 2 Repowered with APFBC	Existing Dan River Unit 3	Dan River Station Unit 3 Repowered with APFBC
Gross output, kWe				
Gas turbine gross	--	138,400 kWe	--	138,400 kWe
Steam turbine gross	112,500 kWe	105,111 kWe	153,160 kWe	163,069 kWe
Auxiliary losses	-6,500 kWe	-17,020 kWe	-9,420 kWe	-11,060 kWe
Net plant output, kWe	106,000 kWe	226,491 kWe	143,740 kWe	290,409 kWe
Net plant HHV efficiency	32.0%	42.4%	36.4%	43.2%
Net plant LHV efficiency	33.3%	44.1%	37.9%	45.1%
Net plant HHV heat rate	10,660 Btu/kWh	8,041 Btu/kWh	9,370 Btu/kWh	7,891 Btu/kWh
Total Plant Cost Configured "Utility"		$243,451,000 $ 1,075/kW		$253,346,000 $ 872/kW
Configured "Merchant Plant"		$206,751,000 $ 913/kW -15.1%		$229,408,000 $ 790/kW -9.4 %

No Changes in Account 9: Cooling Water System

The equipment in these accounts are the same regardless of whether it is a "utility" or "merchant plant" configuration.

Changes in Account 10: Ash Removal

- delete one of two ash silos; increase size of remaining silo to 1000 tons.

Performance And Cost Changes for APFBC Merchant Plants

Exhibit 6 shows the performance and costs associated with a "utility" configuration and "merchant plant" configuration for two APFBC repowering evaluations.

The "utility" and "merchant plant" 100 percent load point performance is identical, however the capital and operating costs differ significantly.

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