Advanced Circulating Pressurized Fluidized Bed Combustion (APFBC) Repowering Considerations

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ABSTRACT

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.

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.

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.

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.

WHAT IS APFBC?

APFBC is an advanced type of coal electric generation technology under development by DOE and industry. It is being tested in large-scale applications.

- APFBC uses high efficiency combustion turbine combined cycle technology, so the energy efficiency of an APFBC-repowered unit is significantly higher than that of the existing pulverized coal plant (Exhibit 1).
- Today's combined cycles, however, use a premium fuel: natural gas. APFBC improves this by adding processes that allow the environmentally clean combustion of coal (Exhibit 2). Limestone in the fluid beds removes sulfur. Temperatures are low and uniform, so NOx production in the beds is small, and special gas turbine topping combustor burners are used that are specifically designed for low NOx production. There is special high temperature filtration equipment that protects the combustion turbine from dust and corrosion, which do an exceptional job of filtering most all particulates.
- APFBC is very tolerant of a range of low-rank fuels. Unlike many other technologies, it is easy to choose coal at the lowest price, and change when bargains arise. APFBC can operate on opportunity fuels, such as petroleum coke and Orimulsion®. Limestone addition is adjusted so the amount of sulfur control needed fits the characteristics of the fuel.
- APFBC produces low cost electricity.
- APFBC is well-suited for repowering existing steam plants. It adds power while dramatically dropping fuel use by 1/3 for every kilowatt generated. This moves marginal units to the top of the competitive dispatch list. APFBC repowering removes the unit from further damage from start-stop cycling, promoting the unit to "flagship" baseload dispatch, extending the useful life of the investment in the facility.

Exhibit 1. 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†
Unit 3 steam turbine gross	112,500 kWe	105,111 kWe	153,160 kWe	173,153 kWe†
Auxiliary losses	-6,500 kWe	-17,020 kWe	-9,420 kWe	-24,261 kWe†
Net plant output, kWe	106,000 kWe	226,491 kWe	143,740 kWe	287,292 kWe†
Net plant HHV efficiency	32.0%	42.4%	36.4%	41.9%†
Net plant LHV efficiency	33.3%	44.1%	37.9%	43.6%†
Net plant HHV heat rate	10,660 Btu/kWh	8,041 Btu/kWh	9,370 Btu/kWh	8,125 Btu/kWh†
reference	*[Weinstein, 1997c]*		*[Weinstein, 1997e]*	

† *In September 1997, when this paper was submitted for publication, only preliminary performance assessments were available for the Dan River Station, listed in the table above. In the Conference, revised estimates were presented. Contact Richard Weinstein for the latest estimate (phone: 610 / 855-2699 eMail: Richard_E_Weinstein@Parsons.COM)*

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]

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. 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]*.

APFBC is an option for a coal-fired repowering at a large number of sites where there is need for added capacity, where certain of the plant equipment (particularly the boiler) is in poor condition, where there is need for improved environmental performance, where a shorter licensing period than that required for new plant construction is important, and for other reasons. However, repowering an existing site with APFBC technology raises a number of plant integration issues that are important considerations for any company contemplating this type of upgrade. This paper focuses on these APFBC repowering issues, which include the following:

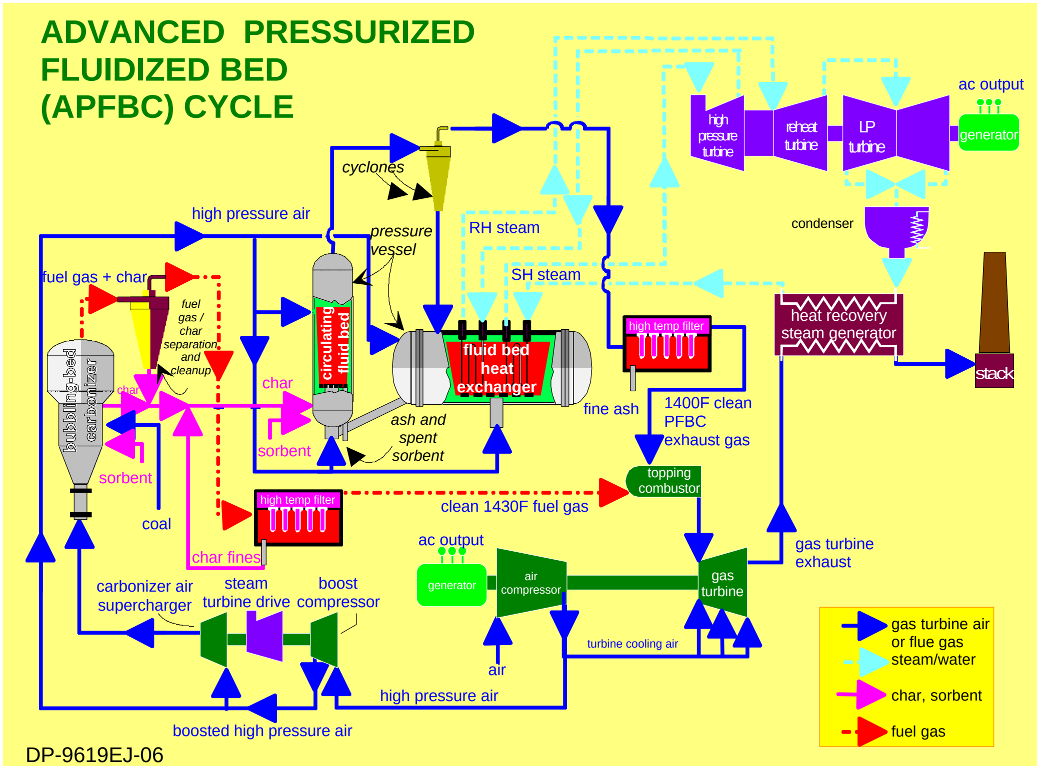
- APFBC greatly improves the energy efficiency (Exhibit 1), reducing production costs, with significant improvement in the unit's dispatch order.
- Combustion turbine type and size affect thermal and economic performance. Choose combustion turbine for the best match to supply steam needs.
- A close match to existing steam conditions is desirable, still, the cycle will likely be slightly compromised because exact match to steam turbine is unlikely.
- Wide fuel tolerance means lower cost high-sulfur low-rank coals or opportunity fuels can be used, and fuel can be bought for best economy from a range of suppliers. The fuel type can be switched easily throughout the plant's life.
- Switchyard and transmission need adequate capacity for added output.
- The steam turbine will be 1950s vintage, not 1997 technology, so refurbishment and upgrade with new improved steam turbine blading may be desirable.
- The existing unit is typically greater than 20 years old, and equipment may not be in good condition. Wear and tear issues are important, as the unit is not likely to be new and clean. It is important to know the current condition of the existing equipment that might be retained for extended use in APFBC service. A thorough condition assessment and overhaul is required
- High temperature piping runs should be short.
- Three to four acres of adjacent space is needed to locate the APFBC systems, the combustion turbine, and heat recovery system.

- One to two acres of nearby space is needed to locate limestone pile and receiving / handling equipment.
- Fitting the APFBC unit in the space available can cause other compromises.
- APFBC can be installed in phases. A gas turbine equipped with a topping combustor with APFBC capability can first be added as a simple cycle peaker fired on natural gas. As demand increases, the PFB combustor and fluid bed heat exchanger, and heat recovery steam generator (HRSG) can be added, making a 1-½ generation PFBC system, reducing the need for natural gas. Later, a carbonizer can be added, completing the phases, making an all coal fired 2nd generation APFBC

APFBC DESCRIPTION

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, Dan River station, and Greenidge station units that could benefit from APFBC repowering.

Exhibit 3. Advanced Circulating Pressurized Fluidized Bed (APFBC) Power System Sketch



The APFBC system uses the pressurized circulating fluidized bed combustion technologies developed by DOE and industry partners. Exhibit 3 shows the major components of an APFBC power plant. 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, and a carbonizer to produce fuel gas for the gas turbine topping combustor. This provides high combined cycle energy efficiency levels on coal.

- A boost compressor system is employed after the gas turbine compressor to overcome the pressure drop of the APFBC equipment, so that an aerodynamic match is made that preserves the use of gas turbine expansion sections designed for natural gas service. The boost system also assists start-up and improves operational flexibility. This system can be driven by either a steam turbine, or electric motor with variable speed capability.

- The pressurized carbonizer (a fluidized jetting-bed device) operates at 1700 °F, and converts part of the coal into synthetic fuel gas. This syngas is a low Btu gas, with an HHV heating value of about 136 Btu/scf. The remainder of the coal energy is in the form of char, which is sent to the PFB combustor. The syngas is cooled before it enters the candle filters.

- This hot 1430 °F syngas passes through ceramic candle filters to remove dust.

- The circulating PFB combustor operates at 1550 °F and burns the char to produce steam and to heat combustion air for the gas turbine. The PFB combustor completes the combustion, but has sufficient excess air (about 16 percent oxygen) that this vitiated (partly used) air can be used in the gas turbine topping combustor. The vitiated air is cooled before entering the candle filters.

- Hot cyclones separate out the solids from the vitiated air, and send the solids to the fluid bed heat exchanger to raise some of the steam for the steam turbine.

- Additional ceramic candle filters clean the hot 1400 °F vitiated air to remove dust.
- The gas turbine is modified to export high pressure air, accept high temperature air to combustor, and accept low Btu fuel gas. The gas turbine modifications needed for APFBC operations will likely result in a derate in output compared to the unmodified natural-gas-fueled production version.
- The clean synfuel gas and vitiated air burn in the gas turbine topping combustor, heating the gases to the combustion turbine's rated firing temperature. The gas turbine produces about half of the station output.
- The gas turbine heat recovery steam generator (HRSG) produces more steam. The steam conditions developed in the HRSG and the fluid bed heat exchanger match the existing steam turbine's needs, so the added steam-generated output results in high combined cycle efficiency levels.
- An APFBC system has combined cycle efficiency levels -- but on low-cost low rank coal or opportunity fuels.

APFBC Implications

The high efficiency of APFBC is a direct consequence of combined cycle operation. Some of the output comes from a gas turbine, with the balance from the steam cycle. The unique arrangement of APFBC components allows all of this to occur using coal as the only fuel for all parts of the process. With APFBC, coal consumption is 30 percent less per kilowatt than the existing unit, and the coal consumption would be significantly lower per kilowatt output than for a new pulverized coal or atmospheric fluidized bed plant, the current commercial standards for coal-fueled generation. With its high efficiency, the APFBC will have 1/3 lower emissions of CO_2 per kilowatt than the existing unit, and lower emission of pollutants. The limestone in the fluidized bed has been tested and shown to be effective for sulfur capture, so 95 percent of the sulfur is removed at a calcium-to-sulfur molar ratio less than 2-to-1. This level of capture exceeds the 90 percent sulfur removal criterion in the NSPS, and only 70 percent reduction is needed at the site. Fluid bed temperatures are uniform and low, so NOx emissions are estimated below 0.3 lb/10^6 Btu, which are below those required by the Title IV NSPS at the site (carbonizer/PFB combustor tests have demonstrated NOx emissions at 0.1 lb/10^6 Btu (Robertson, 1996) below Title I requirements). In pilot plant tests, particulate emissions have consistently measured below 3 ppm (0.003 lb/10^6 Btu), which is an order of magnitude lower than NSPS requirements.

A successful repowering in the size evaluated in the DOE studies [see summaries: *Tonnemacher et al., 1997*, *Weinstein et al., 1997i* , and *Wolfmeyer et al., 1997*] would improve the prospects for earlier commercialization of APFBC, and pave the way for the introduction of similarly sized replicate repowering units and all-new stand-alone “greenfield” installations.

APFBC Repowering Concept

Several features of the proposed repowering include the following:

- Boiler replacement repowering with coal-fueled APFBC, leaves several choices for the existing boiler:
  - Demolish the existing boiler, or
  - Retire the existing boiler in place, or
  - Retain the existing boiler in standby for increased reliability states.

  If the boiler is demolished, space is made available that might be used for placing some or all of the APFBC equipment.

- The gas turbine used requires special modification to:
  - Export high pressure air to the APFBC system;
  - Accept the import of high temperature (about 1400 °F) vitiated combustion air;
  - Support combustion with low oxygen content (about 16 mole percent O_2) vitiated air;
  - Accept the import of high temperature (about 1400 °F) fuel gas;
  - Be capable of burning both low-Btu (about 135 lb/scf) fuel gas, and natural gas or oil for startup and emergencies; and,
  - Provide stable combustion of these gases, while minimizing the production of NOx.

- The carbonizer provides fuel gas for combustion turbine and char for the PFBC.

- Char plus additional coal (if needed) to the circulating pressurized fluidized bed provides steam and preheated combustion air for the gas turbine.

- Sulfur is captured by the limestone sorbent in the carbonizer and PFB combustor beds.

- High temperature candle filters remove dust that would damage the combustion turbine.
  - The 1700 ºF fuel gas from the carbonizer is cooled to 1430 ºF, before the fuel gas filters, and
  - The PFBC operates at 1550 ºF and its exhaust air is cooled to 1400 ºF before the filters, so the vitiated air filters after the PFBC operate at 1400 ºF.

Overcoming Pressure Drops

The gas-side pressure drop through the fluid beds, filters, vessels, and piping is greater than the corresponding pressure drop through the combustor of a simple gas turbine fueled by natural gas.

- There are a number of choices for accommodating APFBC system pressure drops.
- Some require major changes to a combustion turbine, but are the most efficient.
- Others use boost compressors to minimize combustion turbine re-design.
- The DOE APFBC repowering studies each use an "n" stage external boost compressor type of design; these place a separately powered compressor after the combustion turbine compressor discharge, using either motor drives or steam drives with some method of providing efficient variable speed control. These repowering studies assume early commercial implementation, and this method allows the minimum modification to existing combustion turbine designs. It also improves start-up, and provides operational flexibility.

DOE's Assessment of APFBC Status for Year 2002 Repowering Application

Exhibit 4 and Exhibit 5 summarize DOE's assessment of the technical readiness of APFBC. Tests programs are in place for all major components, and the Wilsonville PSDF and the Lakeland McIntosh Station Clean Coal project will prove large scale integrated commercial operation.

With the exception of the hot gas filters for the carbonizer fuel gas and for the circulating PFBC exhaust gas, all of the major components of the coal-gas PFBC power plant have either been successfully tested or are commercially available.

Exhibit 4. Sketch Showing DOE Assessment of APFBC Status

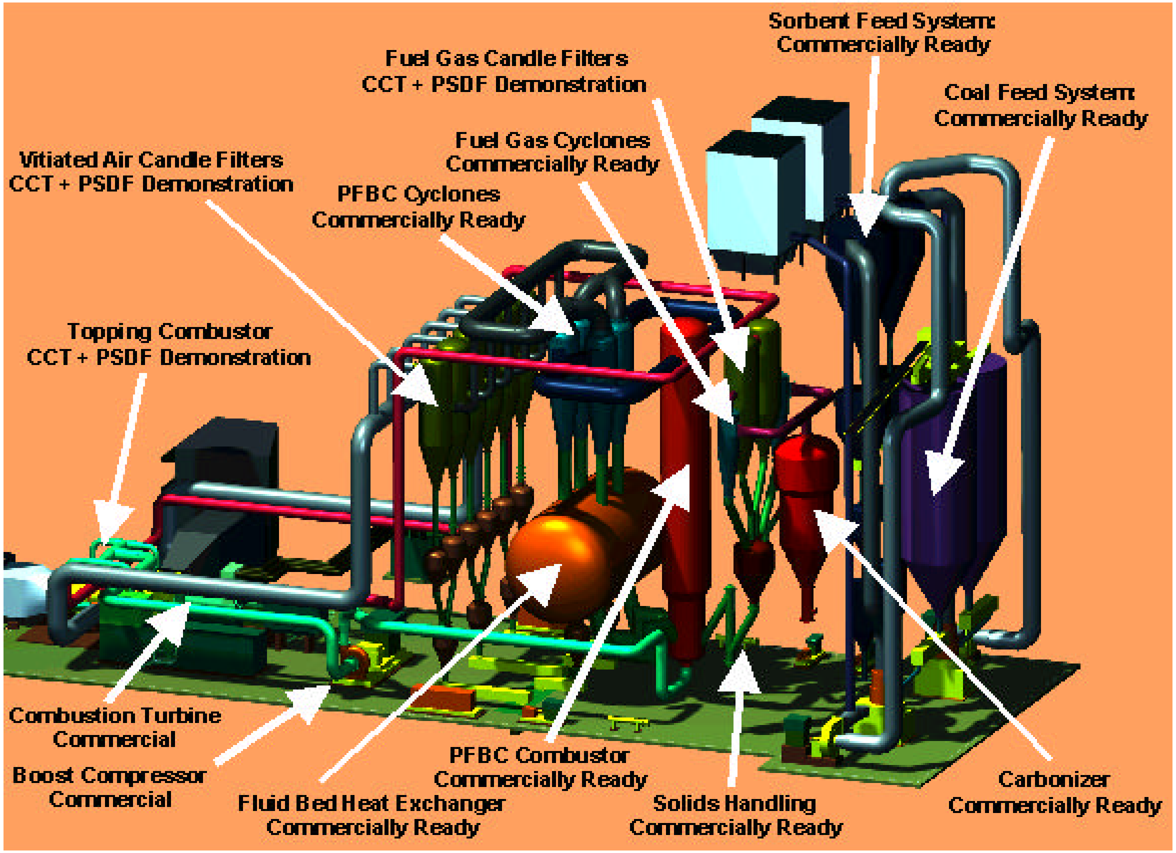


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Exhibit 5. DOE's Assessment of APFBC Developmental Status

Zone	Status	Issues	Resolutions
Fuel Forwarding System	**Commercial**	Dry feed is proven technology. Paste feed simpler, but rotary parts wear out. Paste consistency hard to maintain.	Use existing dry feed methods. New feed concepts are under development; monitor, and change if promising.
Carbonizer	**Commercially Ready**	Dry feed no problem. Paste feed bench tested.	Use existing dry feed methods. New feed concepts are under development; monitor, and change if promising.
Char Transfer System	**Commercially Ready**	No problem anticipated. Need large scale demo.	Demo - PDU & CCT
PFBC Combustor	**Commercially Ready**	Problems with cyclone loop seal have been fixed.	Demo - PDU & CCT
Fluid Bed Heat Exchanger	**Commercially Ready**	No problem.	N/A
Ash Transport System	**Commercially Ready**	No problem.	N/A
Hot Gas Cleanup	**CCT Demonstration**	Durability, bridging, drainage	Test programs at Wakamatsu, Karhula, Wilsonville, Piñon Pine
Topping Combustor	**Full Size Combustor Tested**	Low Btu gas from carbonizer successfully tested at UTSI; more tests to come. Must handle high temperature syngas and vitiated air.	On track; no problems anticipated.
Gas Turbine	**Commercial**	Aerodynamic core uses natural gas product designs, but needs provision to export air and accept hot gas input.	Designs with easy transition to air ducts preferred
Steam Turbine System	**Commercial**	No problem.	N/A

N/A = not applicable

APFBC REPOWERING CYCLE SELECTION CONSIDERATIONS

There are many design trade-offs needed to establish an APFBC power cycle configuration. This section addresses one of the key issues: how do you select and match a combustion turbine to an appropriately sized steam turbine?

This is a problem for an all new APFBC unit at a new site. For a repowering unit, there are even more considerations. These are described below.

APFBC Repowering Considerations

There are a number of significant differences in considering APFBC for repowering applications than exist in new site applications. The main considerations involved in repowering include the following:

- Combustion turbine type and size affect thermal and economic performance.
- A close match to existing steam conditions is desirable, unless the choice is to abandon steam turbine.
- High-temperature piping runs should be short to minimize material costs.
- There is a need for about three to four acres of adjacent space to locate the PFBC, the combustion turbine, and heat recovery system. One to two acres of nearby space is needed to locate limestone pile and receiving / handling equipment.
- Wide fuel tolerance means opportunity fuels can be used; coal or other opportunity fuels can be bought for best economy from a range of suppliers.
- Environmental emissions are superior to NSPS requirements, and significantly lower than those of the existing unit (Exhibit 2).
- Switchyard and transmission need adequate capacity for added output.

APFBC in Greenfield Application

To understand the implications of using APFBC technology for repowering applications, it is important to know the design choices available to the designer of an all-new APFBC plant. Exhibit 6 shows the characteristic "trajectory" of steam cycle design choices that exist when a fixed combustion turbine is selected.

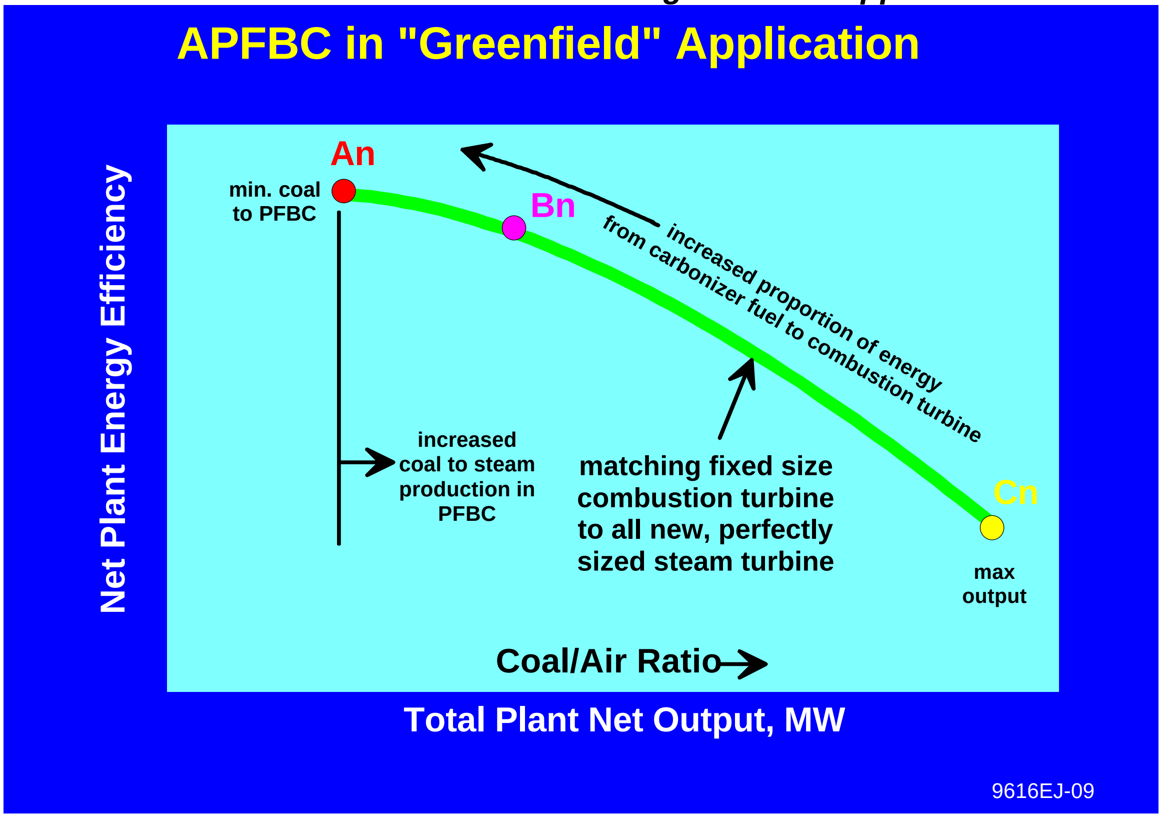
There are a number of different choices in steam plant size once the combustion turbine is picked. Since an APFBC plant is a combined cycle, the greater the proportion of energy that passes through the combustion turbine "topping cycle," the higher the energy efficiency of the overall plant. Point "An" (n = all-new plant, all-new steam turbine) on Exhibit 6 illustrates the point where the maximum possible proportion of coal energy is sent to the carbonizer to maximize fuel gas production for the combustion turbine. The PFBC-FBHE subsystem burns the char produced in the carbonizer to add to steam power production, with little or no supplementary coal needed. Point "An" is the maximum efficiency point.

If more output is the goal with a fixed combustion turbine size, then more coal can be added to the PFBC-FBHE subsystem to supplement the amount of steam raised by the char. The more coal that is added, the more steam power output, point "Bn." However, adding more and more coal to the PFBC-FBHE subsystem only provides energy to the steam bottoming cycle, and some of the combined cycle energy efficiency advantage is lost. The more coal that is added, the higher the output, but the lower the efficiency, point "Cn."

Why produce output at lower efficiency? Because the main capital investment is in providing APFBC capability in the first place. Once that equipment is purchased, say at $700/kW, the additional output gained by increasing coal to the PFBC-FBHE subsystem requires only modest cost increments to increase the size of the vessels and add tube surface. This added output can occur at perhaps $300/kW or less. The point for best operation along this curve is an economic choice, and involves the change in unit dispatch order discussed below.

Exhibit 6. For a Fixed Size Combustion Turbine, APFBC Energy Efficiency Can be Traded for Inexpensive Added Output, by Firing Added Coal in the PFBC

Shown here is the situation for a "greenfield" application.



Dispatch Implications

A major motivation to repower is to take advantage of the high energy efficiency of APFBC technology. High energy efficiency means that the production costs for operation ($/kWh) are low. The major contribution to the production costs includes the fuel cost (the largest contribution), and variable operating costs, including limestone consumption, startup fuel costs, ash disposal, and other variable costs.

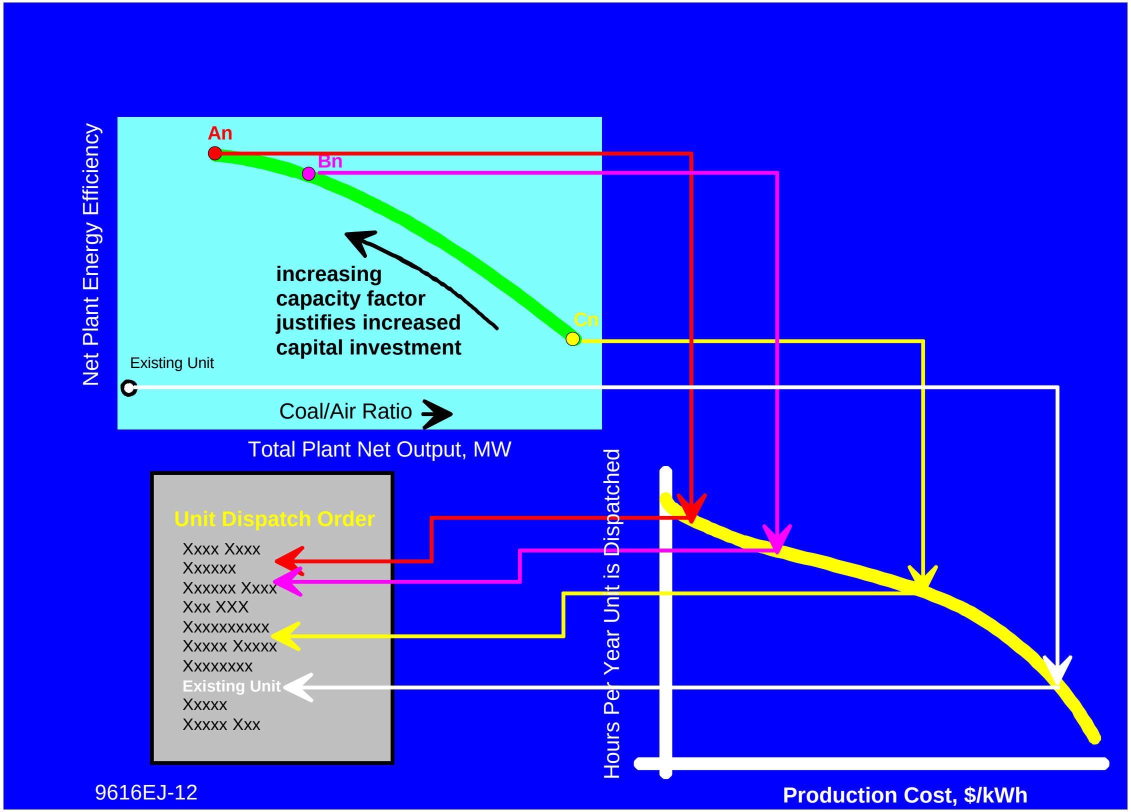
An APFBC plant would have to dispatch against all of the other units owned by the generating company. In order to enter the unit dispatch order as power demand increases to the next “block,” a generating company dispatches the next unit into operation under the theory of “least production cost increment.” The first unit dispatched is the unit that costs the least to operate, the one with the lowest $/kWh production cost. That unit operates until demand exceeds its capability, and a new block is needed; here, the next lower cost is called into service, etc.

Units with low production cost thus operate for many more hours, enjoying a high baseload capacity factor. Units with high production costs are relegated to swing-load and start-stop operation, and are used only when demand is high. The units with the highest production costs are only used for peaking duty, and have very low capacity factors, operating only a few hours a year.

This has significant impact on the decision as to where is the best point to operate an APFBC repowering, and in the types of unit upgrades that make sense on the existing unit.

Exhibit 7 shows a hypothetical case that is typical for most repowering upgrades involving existing units. This unit is an aging pulverized coal unit, displaced in the dispatch order by more cost-effective generation. The existing unit has moderate to high production costs compared to the other units dispatched in the power pool, so the unit is dispatched infrequently, and has a low capacity factor.

Exhibit 7. The Trade of Energy Efficiency for Added Output Has Important Unit Dispatch Implications



Adding APFBC dramatically improves its dispatch order because of the low production costs. If the "An" peak efficiency integration is chosen in Exhibit 7, the unit is promoted to near the top of the list: it becomes baseloaded, with high capacity factor. If an intermediate integration is chosen with some coal to the PFBC, the "Bn" energy efficiency drops, slightly increasing production costs, and decreasing the dispatch order and capacity factor. If "Cn," the "maximum output" integration is chosen instead, still further deterioration in dispatch order and capacity factor occurs.

The shape of the dispatch load duration curve is different for every generating company, and changes from week to week, year to year, as other units, competing utility companies, bulk power sales, weather, unit maintenance drop-outs, and many other factors occur. These dispatch decisions are made by high-speed computer dispatch programs that update the dispatch order and unit load setting every few tenths of a second, because the cost of dispatch errors has a huge effect on operating cost. These dispatch decisions are emulated in production costing programs that predict future dispatch.

The shape of the curve is significant. If the APFBC repowering is much more efficient than the other units it dispatches against, obviously the "Cn" case makes sense; the greater output allows the profitable sale of more kWh. If, however, the decision causes a significant deterioration in capacity factor, there will be fewer hours of operation to pay for the capital expense of adding "C" capacity, less equipment can be purchased, and design decisions will favor lower cost implementations; thus, a "B" or "A" integration might make more sense.

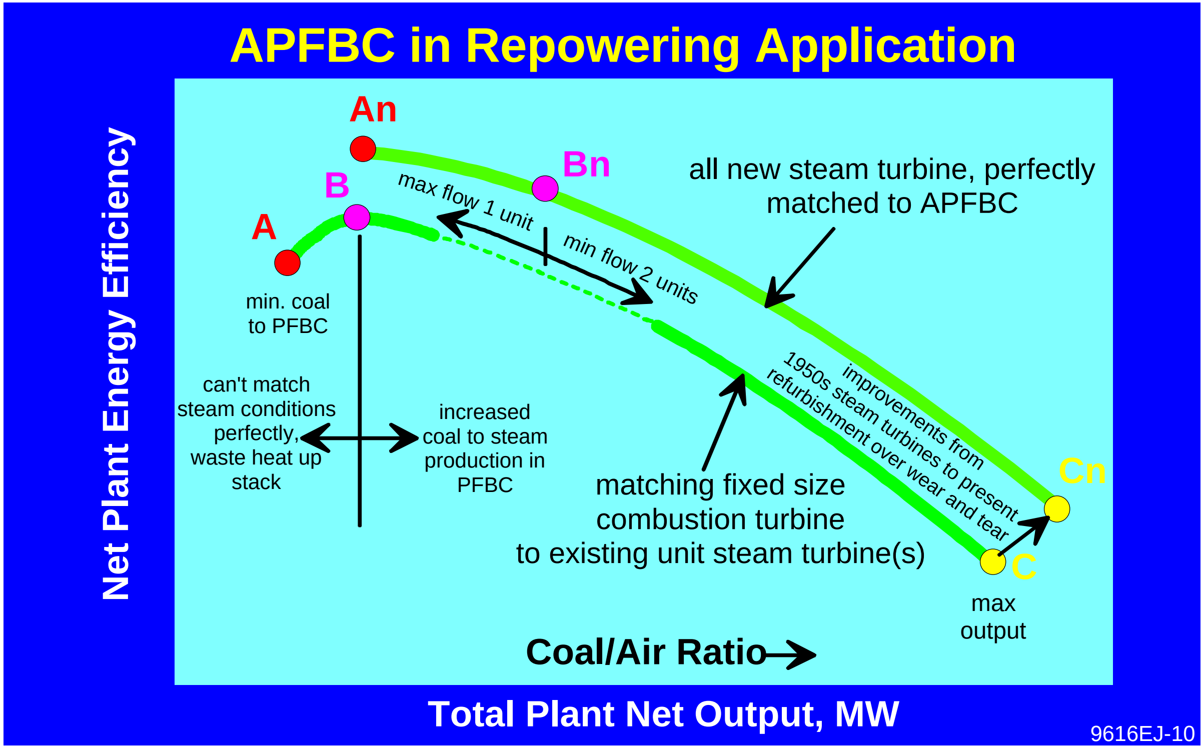
For repowering this also has a significant impact on balance-of-plant upgrade decisions. For example, suppose the existing steam turbine would benefit by adding new low-pressure section airfoils to the existing steam turbine. If the existing unit has, for example, 10 percent capacity factor, it is hard to justify an investment for the steam turbine blade upgrades because the low use level won't pay back. However, in that same example, if the unit was repowered with APFBC, the capacity factor increases significantly, for example to 80 percent. Here, clearly, the investment in improved steam turbine airfoils must be considered; there are many more use hours to pay off the investment. Basically, APFBC repowering makes a unit approach “flagship” status: many upgrades become justified in addition to simply adding APFBC. The higher the energy efficiency of the integration, the more capital investment can be justified.

These decisions require generation production costing assessment.

Considerations for APFBC in Repowering Application

An APFBC plant, however, is not an all-new steam cycle. Rather, the steam cycle exists and has fixed design and part-load characteristics. Here, it is important to select a combustion turbine, also of fixed size, so the operation causes the least compromise in combined cycle performance.

Exhibit 8. For Repowering Applications, the Decision Factors Are More Sophisticated; There Are Numerous Design Compromises and Considerations



It is unlikely that the steam turbine will match exactly the thermal integration needs operation at the "A" operating point, where the combustion turbine power output is large relative to the steam turbine power. Exhibit 8 shows the likely circumstances for a repowering, compared to the same combustion turbine that has been perfectly matched to an all new steam turbine system "An."

In the example illustrated by Exhibit 8, Point A, providing the most energy to the combustion turbine does not generate enough steam to power the existing steam turbine at full output. The steam turbine is at part-load conditions, and loses energy efficiency by being at off-valve-point operation, and at other than design flow conditions. In a repowering, where the steam turbine size is fixed, the real "peak efficiency" point may occur with some added coal to the PFBC to generate steam that picks up the steam cycle efficiency. This is point "B" on the Exhibit.

Notice that none of the points on the repowered plant "trajectory" is as high as an all-new "greenfield" steam cycle designed to perfectly match the capability of an APFBC system. This is due to several reasons:

- The existing system has suffered wear and tear, and is unlikely to be performing in its "as-new" condition.
- Even if the existing turbine were refurbished to its "as-new" condition, it would be less efficient. For example, the existing turbine was built with 1950s technology; new equipment would use modern steam turbine/generator designs that are inherently more efficient.
- The existing steam turbine cycle is usually optimized for feedwater heaters in service; efficient APFBC integration uses economizer duty to replace feedwater duty. An all-new system would be optimized for the specific conditions of the APFBC application, whereas an existing system will not be, and most always involves some compromise in repowering.

Another consideration is necessary depending on the size of the existing steam turbine compared to the selected combustion turbine added for APFBC repowering. Adding coal to the PFBC increases steam production, but an existing steam turbine has a fixed maximum flow capability (particularly with feedwater heaters out of service). Once this is reached, no further output capability exists at the site. An all new design would simply add a larger steam turbine, allowing a decision to move to output point "Cn." At some sites, such as the L.V. Sutton station repowering and the Greenidge station repowering, there is more than one steam turbine that can be repowered at the site. If more output is needed at such sites, it is feasible to add more coal to the PFBC, and develop sufficient steam to repower two steam turbines, allowing operation at point "C."

ACKNOWLEDGMENT

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REFERENCES

The references used for this paper include the following:

Clean Coal Today, Winter 1996.

DeLallo, M.R., Goldstein, H.N., Buchanan, T.L., and White, J.S., May 1997, Advanced Technology Repowering, Final Draft of Parsons Power Report No. EJ-3081, prepared for the U.S. Department of Energy Federal Energy Technology Center-Morgantown, as Task 1 under Contract No. DE-AC21-94MC31166.

DOE 1993, Clean Coal Technologies, Research, Development, and Demonstration Program Plan, DOE/FE-0284.

DOE, April 1995, Tidd PFBC Demonstration Project, First Three Years of Operation, Topical Report, DOE/MC/23132-5037.

DOE, issued October 31, 1996, “DOE Gives Lakeland, FL, Go-Ahead for World’s Most Advanced Coal Combustion Power Plant,” DOE Techline, from Internet site: http:/www.fe.doe.gov/techline/tl_lklnd.html. Downloaded January 3, 1997.

Robertson, A., September 16, 1996, Foster Wheeler Development Corporation, Second-Generation / Topping Cycle Pressurized Fluidized Bed Combustion: Program Overview Presented to Carolina Power & Light, Project File FT-1002.

Tonnemacher, G.C., Killen, D.C., Weinstein, R.E., Goldstein, H.N., White, J.S., and Travers, R.W., December 9-11, 1997, "Site Considerations for Repowering With Advanced Circulating Site Considerations for Repowering With Advanced Circulating Pressurized Fluidized Bed Combustion (APFBC) from the L.V. Sutton Station Concept Assessment," Power-Gen International '97, Dallas Convention Center. Dallas, Texas. Abstract 970562.

[Weinstein, 1997a] Weinstein, R.E., principal investigator, August 1997, *APFBC Repowering Series, Volume I:* Background and Considerations for Repowering Existing Steam Stations with Advanced Pressurized Fluidized Bed Combustion [APFBC], Draft of Parsons Power Report No. EJ-9710, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein, 1997b] Weinstein, R.E., principal investigator, August 1997, *APFBC Repowering Series, Volume II:* EXECUTIVE SUMMARY Repowering the L.V. Sutton Steam Station with APFBC, Draft of Parsons Power Report No. EJ-9616-ES, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein, 1997c] Weinstein, R.E., principal investigator, August 1997, *APFBC Repowering Series, Volume III:* Repowering the L.V. Sutton Steam Station with Advanced Pressurized Fluidized Bed Combustion [APFBC], Draft of Parsons Power Report No. EJ-9616, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein, 1997d] Weinstein, R.E., principal investigator, August 1997, *APFBC Repowering Series, Volume IV:* EXECUTIVE SUMMARY Repowering the Dan River Steam Station with APFBC, Draft of Parsons Power Report No. EJ-9619-ES, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein, 1997e] Weinstein, R.E., principal investigator, August 1997, *APFBC Repowering Series, Volume V:* Repowering the Dan River Steam Station with Advanced Pressurized Fluidized Bed Combustion [APFBC], Draft of Parsons Power Report No. EJ-9619, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein, 1997f] Weinstein, R.E., principal investigator, September 1997, *APFBC Repowering Series, Volume VI:* EXECUTIVE SUMMARY Repowering the Greenidge Steam Station with APFBC, Draft of Parsons Power Report No. EJ-9703-ES, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein, 1997g] Weinstein, R.E., principal investigator, September 1997, *APFBC Repowering Series, Volume VII:* Repowering the Greenidge Steam Station with Advanced Pressurized Fluidized Bed Combustion [APFBC], Draft of Parsons Power Report No. EJ-9703, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein, 1997h] Weinstein, R.E., principal investigator, September 1997, *APFBC Repowering Series, Volume VIII:* Briefing Sourcebook for Presentations on Advanced Pressurized Fluidized Bed Combustion [APFBC] Repowering, Draft of Parsons Power Report No. EJ-9621, prepared for the U.S. Department of Energy as Task 20 under Contract No. DE-AC01-94FE62747.

[Weinstein et al., 1997i] Weinstein, R.E., Goldstein, H.N., White, J.S., Travers, R.W., Killen, D.C., and Tonnemacher, G.C., May 11-14, 1997, "Repowering An Existing Steam Plant With Advanced Circulating Pressurized Fluidized Bed Combustion [APFBC]," 14th International ASME Conference on Fluidized Bed Combustion, Hyatt Regency, Vancouver, Canada.

Wolfmeyer, J.C., Jowers, C., Weinstein, R.E., Goldstein, H.N., White, J.S., and Travers, R.W., December 9-11, 1997, "Advanced Circulating Pressurized Fluidized Bed Combustion (APFBC) Repowering Concept Assessment at Duke Energy's Dan River Station," Power-Gen International '97, Dallas Convention Center, Dallas, Texas, Abstract 970561.