AN EVALUATION OF GAS TURBINES FOR APFBC POWER PLANTS

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Abstract

This paper describes a concept screening evaluation of gas turbines from several manufacturers that assessed the merits of their respective gas turbines for advanced circulating pressurized fluidized bed combustion combined cycle (APFBC) applications. The following gas turbines were evaluated for the modifications expected for APFBC service: 2 x Rolls-Royce Industrial Trent aeroderivative gas turbine configurations; a 3 x Pratt & Whitney Turbo Power FT8 Twin-Pac (6 FT8s) aeroderivative gas turbine configuration; 1 x General Electric PG7121EA gas turbine configuration; several Siemens Westinghouse gas turbine configurations that included 1 x and 2 x V64.3, 1 x V84.3, and 1 x W501F gas turbines; and several configurations of Dresser-Rand turbomachinery units.

These gas turbines were core elements used in the concept APFBC repowering of five U.S. electric generating units: Carolina Power & Light Company L.V. Sutton Unit 2; Duke Power Company Dan River Unit 3; AES Greenidge Unit 4; Nebraska Public Power District Sheldon Unit 1 and Unit 2; and Arizona Public Service Unit 1, Unit 2, and Unit 3. Each concept evaluation used APFBC equipment from Foster Wheeler, with ceramic filters from Siemens Westinghouse, and was thoroughly evaluated.

APFBC technology is a coal-fired technology now under test in large-scale demonstrations. As these tests progress, coal-fired APFBC should become ready for commercial repowering installations around year 2005, making this an appropriate time to begin investigating potential suppliers of gas turbine equipment for the first several commercial applications of APFBC service expected before the end of this decade.

Modifications are needed to the existing designs of each of these gas turbines, which are presently offered as natural gas units. If the gas turbine is to operate in an APFBC system, casings must be modified to export compressor air, and import hot syngas and vitiated air from the APFBC process. New topping combustor designs are needed. These and several other requirements needed for APFBC service are described.

The paper shows that each of these gas turbines could be modified for APFBC operations, were the gas turbine manufacturer motivated by a potential market APFBC. However, there are differences in the ease with which these could be modified, and differences in how well the present capability of the APFBC manufacturer would be able to accept these units. This paper provides a good overview of these issues and considerations, and is useful as a broad overview of the capability of APFBC technology as a repowering option for existing coal-fired plants.

What Is APFBC?

The APFBC system uses the pressurized circulating fluidized bed combustion technologies developed by the U.S. Department of Energy (DOE) and industry partners. Exhibit 1 shows the major components of an APFBC power plant. 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.

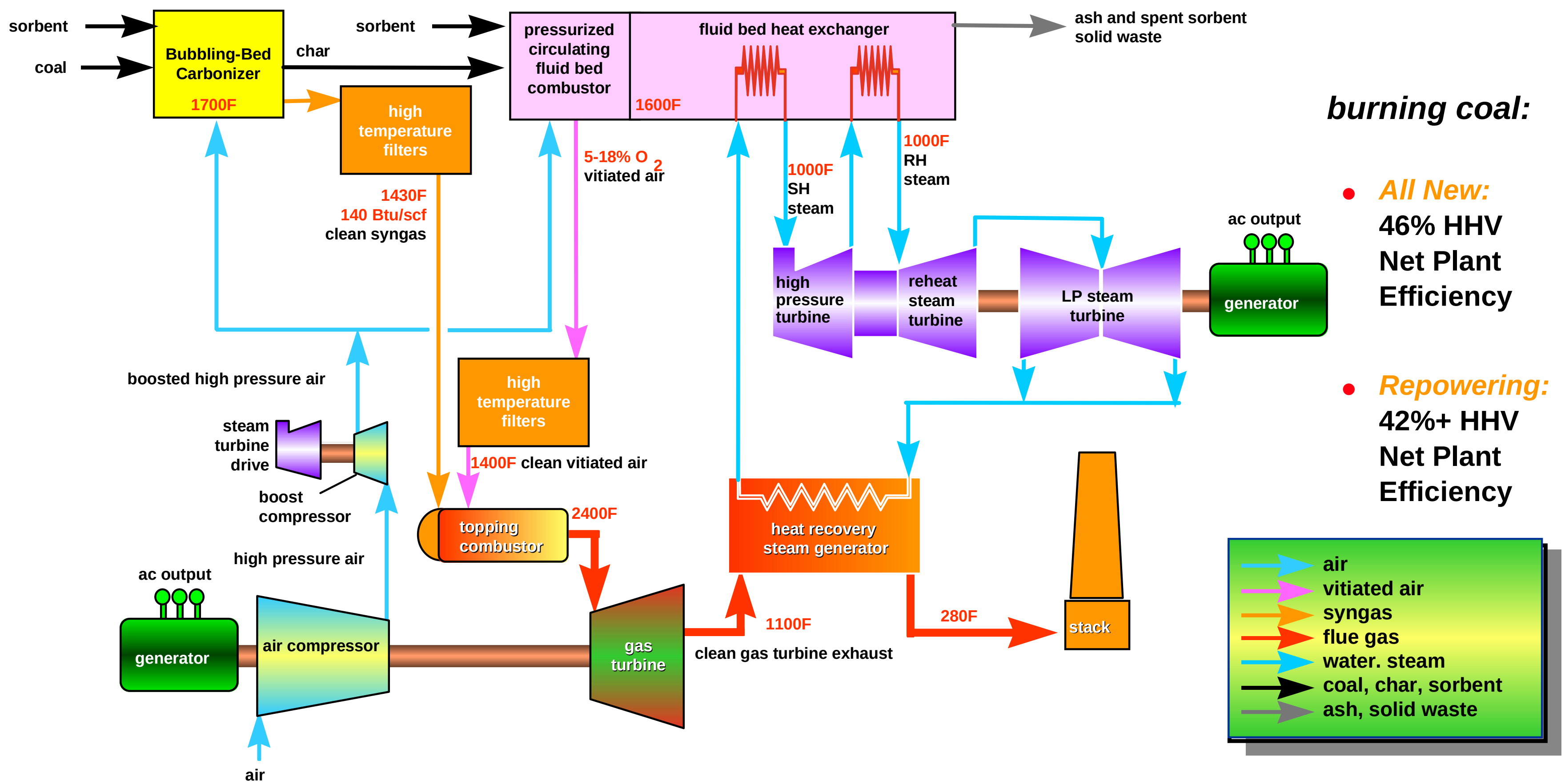
The APFBC systems evaluated in this paper used a Foster Wheeler circulating pressurized fluidized bed combustor (PFBC) to develop hot vitiated air for the gas turbine's topping combustor and steam for the steam bottoming cycle. A jetting-bed carbonizer produced hot fuel gas for the gas turbine's topping combustor. APFBC includes sulfur, alkali, and particulate removal upstream of the gas turbine, which allows the gas turbine to operate free of corrosion and erosion damage. This provides high efficiency combined cycle power in a completely coal-fired unit. APFBC technology is also environmentally clean, which is important to generating companies subject to increasingly stringent air quality regulations.

APFBC is now in the commercial demonstration phase of development. Some key component and integrated system testing by manufacturers and DOE is underway at the DOE Power Systems Development Facility (PSDF) in Wilsonville, Alabama. Testing of the special gas turbine burners needed was done at the University of Tennessee Space Institute (UTSI), and at the PSDF. The first full-scale commercial demonstration is being developed in a DOE-sponsored Clean Coal Technology project now in the process of being sited.

Based on earlier DOE evaluations, plant repowering is an attractive way to:

a. Demonstrate the technology in early commercial applications;
b. Add to the base of information on APFBC operability;
c. Firmly establish a base of capital and operating costs; and
d. Prove APFBC economy, reliability, and availability.

Exhibit 1. APFBC Power System Sketch



burning coal:

- ***All New:*** **46% HHV Net Plant Efficiency**
- ***Repowering:*** **42%+ HHV Net Plant Efficiency**

apfbc-4.5 / 98d08-04

There is enough flexibility with APFBC technology that it can be adjusted easily to adapt to any size coal-fired plant. The range of sizes of steam plants that can be repowered depends on the size of the gas turbine selected. Once that gas turbine is selected, relatively inexpensive changes in the size of the PFB combustor and fluid bed heat exchanger steam generation surfaces allow adaptation to fit a wide range of steam plant sizes. An APFBC system can even repower two steam turbines at a site, even if those turbines have different steam conditions and configurations.

A particular advantage of the technology for repowering applications is that steam is generated in the hot fluid bed heat exchangers of the APFBC system. This means that there is sufficient temperature in the beds, about 1600 ºF, to assure that the steam conditions of an existing steam turbine, usually a 1000 ºF superheat and 1000 ºF reheat, can be met. Since the PFBC combustor can be fed supplemental coal in addition to the char from the economizer, it is easy to match the steam demand and conditions of an existing steam turbine. Since an APFBC is entirely coal-fired, this means that an APFBC repowering can have nearly combined cycle energy efficiency levels, while having the very low production costs possible with low coal fuel price and high energy efficiency.

Evaluation Results

APFBC repowering concepts were assessed for several different steam units located at steam power stations owned by the five cooperating electric generating companies. Based on earlier DOE evaluations, 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. A large number of plants of similar size to five different plants exist in the U.S., so there is potentially a large market for the technology if its technical and economic feasibility in commercial service is proven. The five plant sites evaluated in this paper are the following:

- Carolina Power & Light Company's L.V. Sutton station Unit 2, and Unit 1 plus Unit 2

- Duke Power's Dan River station Unit 3

- AES Greenidge LLC's AES Greenidge steam plant Unit 4

- Nebraska Public Power District's Sheldon station Unit 1 and Unit 2, and Unit 1 plus Unit 2

- Arizona Public Service's Four Corners station, Unit 1, Unit 2, and Unit 3

photos courtesy of each respective plant owner

This study this paper is drawn from screened a number of preliminary concepts.[5] Some of these alternative candidate cycles were dismissed as less practical than those selected. In addition to this study's results, several related APFBC repowering concept studies are complete, and yet others are underway. These related studies are for APFBC repowering at the L.V. Sutton station[1], Dan River station[2], AES Greenidge steam plant[3], Sheldon station[4], and Four Corners station. There are many U.S. and international coal-fired units that could benefit from APFBC repowering. There is enough flexibility with APFBC technology that it can be adjusted easily to adapt to any size coal-fired plant. The range of sizes of steam plants that can be repowered depends on the size of the gas turbine selected. Once that gas turbine is selected, relatively inexpensive adaptations in the size of the PFB combustor and fluid bed heat exchanger steam generation surfaces allows adaptation to fit a wide range of steam plant sizes. An APFBC system can even repower two steam turbines at a site, even if those turbines have different steam conditions and configurations. Exhibit 2 shows the results of the several APFBC repowering evaluations.

Each Site Is Unique

Unlike "greenfield" designs, which can often be extrapolated to a number of sites, repowering studies are very specific, with results unique to each application. Certain of the conclusions are general: for example, it appears that APFBC repowering makes sense at a number of sites, and that a range of gas turbines might be used at those locations. However, one must be very careful not to make integration conclusions or judgments about any particular gas turbine's potential improvement in energy efficiency or output from APFBC repowering.

A good example of this is the Rolls-Royce Trent integration with the AES Greenidge steam plant Unit 4. That integration is one of the several that are possible at that site. Some of the integration schemes at that plant show only a modest gain in energy efficiency compared to some of the other APFBC repowering integrations at that site. This is because of a high velocity in the existing low-pressure steam turbine exhaust that leads to compromises in integrated APFBC performance unless new low-pressure steam capability is added. This is no reflection on the Trent; rather, it is a real problem with one particular integration scheme that requires a different approach.

Each repowering site requires specific evaluation before making judgments on the best choices for that location. Site differences affect the practicality of repowering with any technology, not just APFBC. Because each site has unique characteristics, the results summarized in Exhibit 2 cannot be used to assess the relative merits of one combustion turbine versus another, EXCEPT at that site for which it was evaluated. Unique circumstances at a different site might mean that a another integration scheme and different gas turbine would be the better integration choice.

Exhibit 2 shows the estimated energy efficiency improvement found when APFBC repowers a number of different existing coal-fired steam plant units. These studies evaluated each of the gas turbines discussed earlier, and show that the potential energy efficiency improvement is dramatic, generally from 5 to 10 percentage points better than the existing unit presently exhibits.

Exhibit 2 Listing of Gas Turbines Evaluated for APFBC Service

Owner / Station	Unit(s)	notes	Unmodified Nameplate Rating	Gas Turbines Configuration for Repowering	Temperature Syngas filter / Vitiated air filter	Repowered Net Plant Output	Repowered Net Plant HHV Efficiency	Points Improvement With APFBC	Percent of Coal to Carbonizer	Boost Driver
Carolina Power & Light Company	Unit 1** + Unit 2 97+106 MW=	a,e,f	203,000 kW	1 x Adv. GT"C17"	1430F/1400F	359,509 kW	43.5%	12.7%	63.4%	motor
L.V. Sutton station Wilmington, NC	Unit 1** + Unit 2 97+106 MW=	a,e	203,000 kW	1 x W501F	1430F/1400F	340,736 kW	39.7%	8.9%	57.9%	motor
Non-RH Unit 1: 1450 psia / 1000°F	Unit 2	a	106,000 kW	1 x Adv. GT"B17A"	1430F/1400F	251,644 kW	45.7%	13.7%	100.0%	motor
RH Unit 3: 1815 psia / 1000°F / 1000°F	Unit 2	a	106,000 kW	1 x W501F	1430F/1400F	226,491 kW	42.4%	10.4%	100.0%	motor
	Unit 2	b	106,000 kW	2xTwinPacs 4xFT8	1700F / 1650F					
	Unit 2	b	106,000 kW	3xTwinPacs 6xFT8	1700F / 1650F	244,489 kW	43.4%	11.4%	78.3%	motor
	Unit 2	b	106,000 kW	1 x V64.3	1430F/1400F					
	Unit 2	b	106,000 kW	2 x V64.3	1430F/1400F	207,456 kW	42.7%	10.7%	100.0%	motor
	Unit 2	b	106,000 kW	1 x V84.2	1430F/1400F					
	Unit 2	b	106,000 kW	1 x V84.3	1430F/1400F					
	Unit 2	b	106,000 kW	1 x V84.3, derated	1430F/1400F	244,730 kW	41.2%	9.2%	100.0%	steam
Duke Power	Unit 3	a	143,470 kW	1 x W501F	1430F/1400F	290,409 kW	43.2%	6.8%	78.2%	steam
Dan River station Eden, NC										
RH Unit 3: 1815 psia / 1000°F / 1000°F										
AES Greenidge LLC AES Greenidge Dresden, NY	Unit 3** + Unit 4 55+108 MW=	b,e	163,000 kW	2 x Trent	1430F/1400F					
Non-RH Unit 3: 865 psia / 900°F	Case 1 Unit 4	b	106,310 kW	2 x Trent	1430F/1400F	207,460 kW	39.9%	5.3%	100.0%	steam
RH Unit 4: 1490 psia / 960°F /1000°F	Case 2 U-3** + U-4 55+108 MW=	b,e	163,000 kW	2 x Trent	1430F/1400F	211,290 kW	38.8%	4.2%	95.0%	motor
	Case 3 New Unit 4 LPT only	b	106,310 kW	2 x Trent	1430F/1400F	209,020 kW	40.3%	5.7%	100.0%	steam
	Case 4 Add New Aux. LPT	b	106,310 kW	2 x Trent	1430F/1400F	213,730 kW	41.2%	6.6%	100.0%	motor
	Case 5 All New U-4 1800/1000/1000	b	106,310 kW	2 x Trent	1430F/1400F	224,330 kW	41.2%	6.6%	95.0%	motor
	Case 6 New U-4 1800/1050/1050	b	106,310 kW	2 x Trent	1430F/1400F	226,450 kW	41.8%	7.2%	95.0%	motor
	Case 7 New U-4 1450/1000/1000	b	106,310 kW	2 x Trent	1430F/1400F	222,670 kW	40.9%	6.3%	95.0%	motor

(table continued on next page)

notes: no marks= reheat steam turbine
** = non-reheat steam turbine

a. Old Spider, with 57.2% carbon conversion (obsolete conversion)
b. New Spider with 53.76% carbon conversion
c. This repowering evaluation uses a related fluidized bed system concept, GFBCC; unless otherwise marked, all others are APFBC repowered
d. This repowering evaluation uses a related fluidized bed system concept, a 1st-generation unfired PFBC; unless otherwise marked, all others are APFBC repowered
e. Numbers shown for multiple steam turbines in combination are MW-weighted averages
f. The gas turbine used is a hypothetical, ultra-high efficiency concept, not an actual commercial offering

Exhibit 2 Listing of Gas Turbines Evaluated for APFBC Service *(continued)*

Owner / Station	Unit(s)	notes	Unmodified Nameplate Rating	Gas Turbines Configuration for Repowering	Temperature Syngas filter / Vitiated air filter	Repowered Net Plant Output	Repowered Net Plant HHV Efficiency	Points Improvement With APFBC	Percent of Coal to Carbonizer	Boost Driver
Nebraska Public Power District	Unit 1	b	109,000 kW	1 x PG7121EA	680F/1000F	189,694 kW	37.1%	6.2%	70.0%	steam
Sheldon station Hallam, NE	Unit 2	b	125,000 kW	1 x PG7121EA	680F/1000F	213,711 kW	36.9%	5.9%	62.0%	steam
RH Unit 1: 1450 psia / 1000°F / 1000°F RH Unit 2: 1800 psia / 1000°F / 1000°F	Unit1+Unit2 GFBCC 109+125	c,e	234,000 kW	1 x PG9341FA	600F / none	213,711 kW				steam
Arizona Public Serice Company Four Corners station Fruitland, NM	Phase I 1st gen Unit 1	b,d	190,100 kW	1 x 1750F unfired Dresser-Rand	none / 1550F					motor
RH Unit 1: 1815 psia / 1000°F / 1000°F RH Unit 2: 2015 psia / 1000°F / 1000°F	Phase II 1st gen Unit 2	b,d	190,100 kW	1 x 1750F unfired Dresser-Rand	none / 1550F					motor
RH Unit 3: 2015 psia / 1000°F / 1000°F	Phase III 2nd gen Unit 3	b	253,400 kW	1 x 1950F fired Dresser-Rand	1430F/1400F					motor
	Phase IV 2nd gen Unit 2	b	190,100 kW	1 x 1750F fired Dresser-Rand	1430F/1400F					motor
	Phase V 2nd gen Unit 1	b	190,100 kW	1 x 1750F fired Dresser-Rand	1430F/1400F					motor

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Environmental Emissions Expectation. An APFBC plant has exceptionally clean operation. This comes from two characteristics: first, it employs a number of low environmental emission design features that reduce pollution for each pound of gas flow; and second, an APFBC plant has high energy efficiency, so less coal is used to produce each kWh of electricity. These combine so that emissions per kWh are excellent. Limestone in the fluid beds removes sulfur, so SO_2 can be 96 percent less than that emitted by the existing station. Combustion temperatures are low and uniform to minimize NOx production. Additionally, the gas turbine topping combustor burners are specifically designed for low NOx production, and an APFBC can be fitted with SCR in non-attainment regions. NOx can be 67 percent less per kWh than the existing station. The ceramic high-temperature filters that protect the gas turbines from dust are extremely effective in reducing particulate emissions. An existing steam unit with well-performing electrostatic precipitators (ESPs) significantly reduces particulate emissions, but the APFBC filters are so much more effective in particulate reduction that particulate removal is 95 percent less per kWh than a conventional plant with an ESP; hardly any particulate matter escapes from an APFBC plant.

While not a pollutant, some segments of the public have concerns about carbon dioxide as a “greenhouse” gas. The high energy efficiency of APFBC means that there is 25 percent less CO_2 per kWh.

Depending on repowering design choices made, water use and steam condenser thermal discharge can remain unaffected, so existing water use permits often can remain unchanged. However, since feedwater heaters are taken out of service in some repowering applications where the back-end of the steam turbine has adequate capacity for higher flow, there can be advantages in increased output that could result in a modest increase in condenser duty.

CP&L production costing evaluations show that APFBC technology can promote a low-use unit from 10 to 20 percent capacity factors to first-dispatched baseload status with projected capacity factors in excess of 80. With APFBC repowering, energy efficiency improvement of an existing unit is dramatic, so less coal is needed — and less CO_2 emitted — for each kilowatt generated.

The ease with which an APFBC can match existing steam conditions must be contrasted with attempting to repower these units with heat recovery boilers in a natural-gas-fueled gas turbine. The exhaust temperature serving a natural gas turbine heat recovery unit is so close to the needed steam conditions that it is difficult or impossible to match the steam demand and fully repower an existing steam turbine.

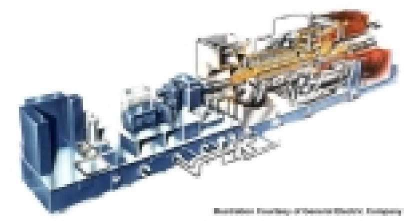
The Gas Turbines Evaluated

The DOE completed a screening concept evaluation of a range of gas turbine equipment from a number of manufacturers, to assess how their equipment might operate over a range of different APFBC plant applications using Foster Wheeler PFBC and APFBC equipment, and Siemens Westinghouse ceramic filters.[5] While the equipment manufacturers and host power companies cooperated in supporting these feasibility evaluations, this does not mean they necessarily plan to develop equipment for this type of duty, nor that they necessarily endorse the results.

- **Dresser-Rand**: Dresser-Rand turbomachinery derived from their compressed air energy storage (CAES) plant designs. This system was also screened for a number of possible similar barge-based PFBC systems.

Dresser-Rand expander train for APFBC service

- **General Electric E and F Series**: The PG9341FA is under evaluation for the GFBCC repowering of Nebraska Public Power District's Sheldon station, with a single PG9341FA repowering both Unit 1 and Unit 2. An alternative evaluation investigated APFBC repowering, with a single PG7121EA and APFBC train repowering Unit 1, and a second train repowering Unit 2.

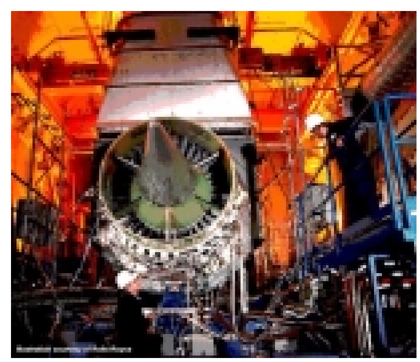


GE PG7121EA

- **P&W Twin-Pac**: Three aeroderivative Pratt & Whitney Turbo Power FT8 Twin-Pacs (6 x FT8 gas turbines [24 MW, 20:1]) were evaluated in a "dry gas" (1700 °F carbonizer and 1600 °F vitiated air) application, for repowering Unit 2 of the Carolina Power & Light L.V. Sutton station.

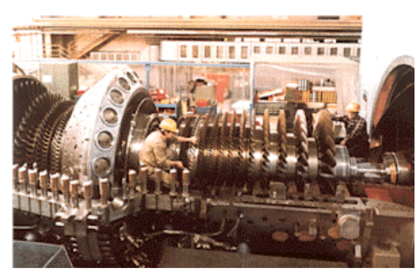
Pratt & Whitney FT-8

- **R-R Trent**: Two APFBC-modified aeroderivative Rolls-Royce Trent gas turbines (51 MW, 35:1) were evaluated for suitability for the APFBC repowering of the AES Greenidge steam plant. This concept uses 1400 °F carbonizer and vitiated air. The APFBC-modified Trent would repower one of the two existing steam turbine units at the station: Unit 4, a 106 MW 1450 psig / 1000 °F / 1000 °F reheat turbine generator was APFBC-repowered in this concept. Unit 3, a 55 MW, 850 psig/900 °F non-reheat steam turbine/generator also at the site was evaluated in a repowering combination with Unit 4.



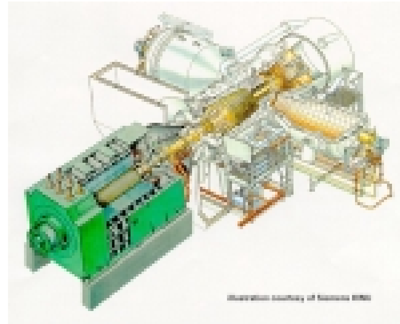
Rolls-Royce Industrial Trent

- **SW V-series and W-series**: An APFBC-modified Siemens Westinghouse V64.3 (63 MW, 16:1) was evaluated for APFBC service, and was too small for the size power plants considered. In this evaluation, L.V. Sutton Unit 2 was evaluated as a candidate plant repowered with APFBC using two Siemens Westinghouse V64.3 units, or the selected cycle, a single, larger V84.3 gas turbine (153 MW, 17:1) modified for APFBC operations, or an APFBC modified W501F. These use 1400 °F carbonizer and vitiated air



Siemens Westinghouse W501F

temperatures. The V64.3 and V84.3 gas turbines are the older model 3 series units with off-board combustors, (not the most recent 3A series, which has hybrid ring burners™).



Siemens Westinghouse V84.3

photos / illustrations courtesy of their respective manufacturers

Gas Turbine Modifications Needed for APFBC Operations

The applicability of different combustion turbine systems requires consideration of several important criteria needed as unit modifications that would allow the combustion turbines to operate in an APFBC environment. These include the following, and are discussed below:

- **Export of High Compressor Air**. The easier it is to modify the casing for the export of large quantities of high compressor discharge air, the more suited the engine is for APFBC applications. The APFBC hardware has pressure drops that are larger than those of the short path in natural gas combined cycle turbines. To minimize the need for specially designed equipment, it is prudent to make design choices where direct use should be made of the standard design for the flow cross sections as well as the external airfoil blade geometry. This is eased by the decision to employ a boost compression system to restore the volumetric flow levels and pressure at the turbine face to about the same conditions that exist in the standard design.

- **Ability to Burn Low-Btu Syngas**. Manufacturers who already have low Btu content (130 Btu/scf) syngas combustor designs proven to have low NOx production will have an easier transition to APFBC operations. The burner must be capable of sustaining stable combustion and low-NOx operations throughout the load range on syngas. Burners must be capable of starting and operating on natural gas, and capable of smooth transition to full syngas/vitiated air firing.

- **Ability to Burn Using Low Oxygen 1400 °F or Higher Vitiated Air**. A unit is better suited for APFBC if the combustor design has features that make it easier to make modifications for the differing combustor conditions in the burner cans imposed by 1400 ºF+ low (8 to 17 mole percent O_2) oxygen content vitiated combustion air. The nozzles, manifolds, and connectors to the APFBC system fuel gas and vitiated air piping must be capable of handling the thermal growth loads imposed on them at the high delivery temperatures of these gases.

- **Topping Combustor Capable of Import of 1400 °F or Higher Syngas and Vitiated Air**. The easier it is to modify the casing for the import of large quantities of high temperature syngas and vitiated air, the more suited the engine is for APFBC applications.

- **Single/Multi Unit Concerns**. If multi-combustion turbines feed a single APFBC train, there is the added control complication of matching the gas turbine discharge conditions, and metering the returned syngas and vitiated air between the gas turbines.

- **Aeroderivative vs. Large Frame**. Cycle pressure ratios for aeroderivative combustion turbines are higher than for large-frame stationary turbines. This has a number of implications for operations and energy efficiency. Fluid bed designs to date have been for gas turbines below about 16:1 overall pressure ratio; fluidization velocity considerations, process chemistry, and heat transfer characteristics change with increasing pressure, and would require design evaluation if higher pressure ratio gas turbines are chosen.

  Since the fluid bed heat exchanger in an APFBC repowering raises the superheat and reheat steam instead of a heat recovery boiler, APFBC is an acceptable plant repowering and combined cycle application for high pressure-ratio aeroderivative gas turbines. Unlike with natural gas firing, a high pressure ratio aeroderivative combustion turbine (which has lower exhaust temperature) used in an APFBC application can provide a good match to the existing steam turbine. An APFBC-modified aeroderivative can do this without compromising steam plant performance or requiring supplemental firing as might be required when a natural gas fired aeroderivative is assessed in repowering designs.

- **Other Issues**. There are other issues that might influence the gas turbine applicability. Does it employ intercooling or other features that enhance or discourage modification for use in an APFBC application? Are there test programs underway that relate to APFBC operations?

Fuel Control and Protection Valves

The valves and control system are different with APFBC than with natural gas operations.

- High temperature valves are needed with actuators sized to close with sufficient margin to provide the required overspeed and safety protection.
- Gas turbine syngas control valve.
- Gas turbine emergency vitiated air bypass valve.
- Gas turbine emergency syngas bypass valve.
- Gas turbine emergency fuel trip valve.

Control valve must be capable of load control modulation with minimum pressure drop, and be capable of transition from natural gas firing at startup through syngas operations at full load. The APFBC has large gas volumes and substantial thermal "inertia." Syngas and vitiated air flow rates are linked; adjusting fuel-air ratio takes combined action of the gas turbine fuel control with the APFBC system controls.

Control and Interaction with the Boost Compression System

The boost compression system restores the normal pressure balance of the combustion turbine. However, a boost compression system has its own independent driver. This means that the flow/pressure output of the booster must be balanced to the normal and emergency needs of the gas turbine during normal operations and any conceivable upset. This requires active control interaction, and fail-safe protection for key parameters. The combustion turbine/boost compressor system controls must provide control and safety during normal operations and upset conditions.

Anti-Surge Protection. Either the gas turbine's compressor or the boost compressor can surge if incorrect speed-flow conditions develop. Both possibilities need to be considered, and design and control strategies established so there is adequate anti-surge protection of these systems and their piping during normal operations, and any emergency situation.

Turbine and Seal Cooling Pressure Differential. The cooling air and seal air system for the gas turbine also needs review. With a boost compression system, the pressure differentials must be adequate to feed the cooling air for airfoil and seal cooling for all normal and abnormal conditions. The differentials must be maintained at a sufficient margin above the highest pressure that might be delivered from the boost system, even under system upset conditions.

Pressure Balance. The boost compression system restores the normal pressure balance of the gas turbine. This prevents different axial forces on the gas turbine generator than were initially designed into the unit. However, protection is needed to prevent out-of-range pressure differentials during system upset conditions. The possibility of reverse axial forces at abnormal operations or low load have to be considered. It may be necessary to check whether this is covered by the existing equipment mechanical design, or if automatic control system protection is needed if emergency conditions are detected.

Conclusions

APFBC is a high energy efficiency power generation technology that uses modern high-efficiency gas turbines to advantage. APFBC can operate on coal or opportunity fuels, or operate in modes that use a mix of coal and natural gas, if desired. It has proven particularly adaptable for repowering a wide range of existing steam units. Several conclusions about APFBC repowering can be drawn:

a. With APFBC, a single gas turbine unit can repower a wide range of steam plant sizes, and exactly match the existing steam conditions. This is because with APFBC, superheat, and reheat steam generation does not depend on gas turbine exhaust conditions for finishing superheat and reheat, as does a conventional natural gas combined cycle. The APFBC system PFBC combustor uses char from the syngas-producing carbonizer to raise superheat and reheat steam in the fluid bed heat exchanger. This char can be supplemented with added coal to make more steam if needed to exactly match steam turbine flow and temperature demands.

b. Aeroderivative gas turbines can make effective combined cycles when modified as APFBC units. Their high pressure ratios, which often result in low exhaust temperatures that are limiting when natural gas fired, are not significant with APFBC, since finishing superheat and reheat steam generation does not depend on gas turbine exhaust conditions in APFBC plants.

c. Preliminary assessment shows that a number of gas turbine units from various manufacturers are feasible candidates for APFBC operations.

d. Natural-gas-fired units from these manufacturers need modification and testing for APFBC operations to accommodate the export of air, and to import hot syngas and vitiated air. Each unit evaluated could be so modified, should the manufacturer choose to do so were they to perceive that a market for APFBC repowering sales is emerging.

e. APFBC repowering is projected to be economically competitive when coal-fired generation additions are needed.

f. APFBC repowering offers the owners added output, with significant improvements in energy efficiency, reduced environmental emissions, and low operating costs. The added gas turbine generation for those units that integrate well means that an appropriately sized gas turbine for APFBC repowering roughly doubles the output of the existing steam unit. This is done while improving the energy efficiency from 4 to 12 percent. The resulting APFBC repowering energy efficiency is excellent, as high as 43 percent HHV (HHV heat rate of 7,935 Btu/kWh). This means that fuel costs per kilowatt are significantly reduced; a unit repowered with APFBC would most likely be the lowest cost coal generation on the system, with a considerable operating cost advantage over other units.

g. APFBC repowering is feasible at a large number of sites. Still, every site is unique, and conclusions about the merit at any specific location need to be evaluated separately. It is unwise to assume results found at one site are applicable at others.

References

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