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REPOWERING WITH CLEAN COAL TECHNOLOGIES

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INTRODUCTION

At this time, little coal-based generating capacity is being added or planned in the United States. The current environment of low natural gas prices, adequate capacity, low load growth, and anticipated deregulation, results in the current condition. However, by the year 2000, this situation may change. In addition, an increasing percentage of the existing coal-fired baseload capacity will be over 35 years old.

Many of these plants will be candidates for repowering in the year 2000 to 2010 time frame with advanced coal-fired technologies being developed with the support of the U.S. Department of Energy's (DOE) Morgantown Energy Technology Center (METC), or being demonstrated in the DOE's Clean Coal Technology Demonstration Program.

Repowering with clean coal technology can offer significant advantages, including lower heat rates and production costs, environmental compliance, incremental capacity increases, and life extension of existing facilities. Significant savings of capital costs can result by refurbishing and reusing existing sites and infrastructure relative to a greenfield siting approach. This paper summarizes some key results of a study performed by Parsons Power Group, Inc., under a contract with DOE/METC, which investigates many of the promising advanced power generation technologies in a repowering application.

The purpose of this study was to evaluate the technical and economic results of applying each of a menu of Clean Coal Technologies in a repowering of a hypothetical representative fossil fueled power station.

Motivations for repowering may include the following:

-Emissions Reduction/Environmental Compliance

-Heat Rate Improvement/Reduction in Production Cost

-Net Power Increase

-Life Extension/Capacity Factor Enhancement

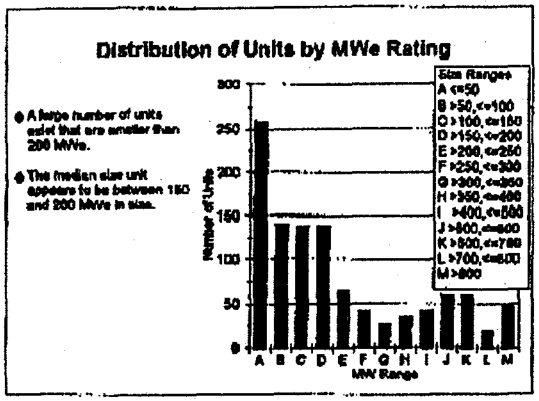
The guidelines adopted for this study were based on the potential to repower some of the aging fleet of existing fossil power stations in the continental US. in the first decade of the next century Each technology was configured the same way it is utilized in its demonstration project, with some exceptions prevailing.

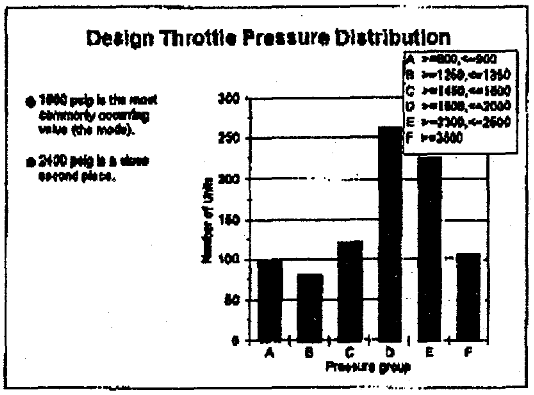
Pittsburgh No. 8 coal is used as the fuel for most of the cases evaluated herein, as well as serving as the fuel for the original unrepowered station. The steam turbine-generator, condenser, and circulating water system are refurbished and reused in this study, as is most of the existing site infrastructure such as transmission lines, railroad, coal yard and coal handling equipment, etc.

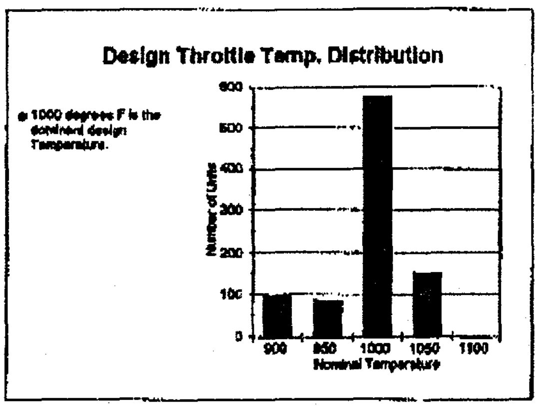
REFERENCE PLANT DEFINITION

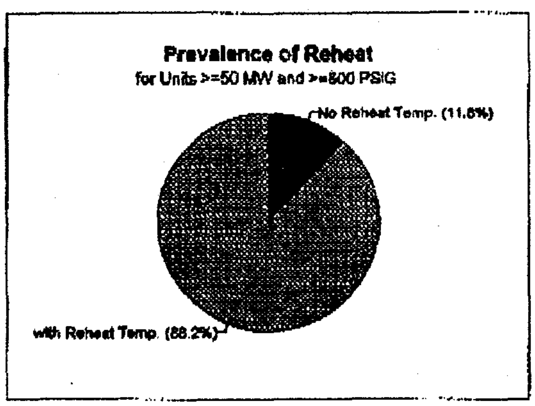
The objective in defining the reference plant was to provide a consistent basis for applying the advanced technology repowerings. Therefore, the reference plant was defined to be representative of a large portion of the aging existing fleet of fossil power stations in the US.

A data base representing the fleet of US power stations was obtained from UDI (Ref. 1). The data base was evaluated on a statistical basis to illustrate selected parameters of interest such as unit size, steam pressure and temperature, and the presence of reheat in the steam cycle. The accompanying figures show that a large number of units exist that are between 100 and 200 MWe in size, have main steam conditions between 1450 and 2400 psig at 1000F, and use reheat. Other data, (not shown), confirmed that a large number of these units were commissioned in the decade of the 1950's, and often appear as twin or multiple units on a site.









Based on the above data, the reference plant for this study was defined as a twin unit station, 150 MWe each, with steam conditions of 1800 psig/1000F/1000F. The station is located on a flat site in the eastern part of the US, with existing rail access, once through cooling from a lake or river, and sufficient space to site the new equipment and structures associated with the repowering. The station has existing particulate and NOx controls (electrostatic precipitator and low NOx burners), but does not incorporate any means of SO2 reduction.

A complete refurbishment of the reused portions of the reference plant was considered to be performed as part of the repowering. This included a complete overhaul of the steam turbine-generator, which incorporates a new nozzle ring and first stage buckets for the HP turbine, new buckets for the first stage of the IP turbine and last stage of the LP turbine, and new variable clearance shaft seal packing. These turbine upgrades are expected to improve turbine adiabatic efficiency by about 1-1/2 % relative to the original machine in new condition.

EVALUATION APPROACH

The technologies evaluated in this study consisted of an atmospheric fluidized bed combustor, several varieties of pressurized fluid bed combustors, several types of gasifiers (including air and oxygen blown), a refueling with a process derived fuel (PDF), and, for reference, a natural gas fired combustion turbine-combined cycle.

For each technology, a heat and mass balance was modeled on a modified version of ASPEN-SP, a flow sheet simulator program. This program was modified in-house to incorporate steam turbine performance computations per Spencer, Cotton, and Cannon, (Ref. 2), and other enhancements. Each heat and mass balance is presented diagramaticaly in the complete report.

A description of each technology and its integration with the existing reference station was prepared, along with an auxiliary load estimate, a list of major items of equipment, and a conceptual site physical arrangement drawing. Each section of the report also contains a comparison of emissions for the reference station, before and after repowering.

TECHNICAL ISSUES

A repowering involves consideration of many important technical issues involving the application of the specific technology that is used, the selection and modification of the gas turbine used in the repowering (where applicable), and the adaptation of the existing steam turbine. Several of these issues are briefly discussed below.

Scaling vs. Modularity: This issue relates to the selection of the appropriate number of modules or trains required for the level of capacity chosen. A smaller number of large modules or trains may result in lower capital costs, unless a threshold is crossed that limits shop fabrication and shipment to the site. For the repowerings reported on herein, the size of individual modules was selected to be comparable to that used in the comparable Clean Coal Demonstration project.

Gas Cleanup/Filtration: In this study, gas streams were filtered using cyclones and/or ceramic filters in most cases. The Destec gasifier uses a proprietary type of filter media, while the British Gas/Lurgi gasifier does not require particulate removal since the gas is cleaned in the quench tank by a water spray. The Circulating Pressurized Fluid Bed (CPFB) Combustor cases described herein utilize ceramic candle filter technology, whereas the Bubbling Bed PFB Combustor relies on several stages of cyclones and the ability of the specific gas turbine to tolerate a certain amount of particulates, which are captured in the heat recovery equipment in the turbine exhaust.

Sulfur Removal: The oxygen blown gasifiers in this study use processes that yield a salable sulfuric acid byproduct. The air blown gasifiers and the fluidized bed combustors use limestone sorbent to remove sulfur in the bed. The typical byproduct is a calcium sulfate bearing ash which is disposed of in a landfill.

Gas Turbine Selection and Adaptation: The Westinghouse 501G machine was selected for the majority of the repowerings in this study since it represents the current state of the art in large power generating equipment of this type and is sized so that only one machine is required to achieve the overall power generation desired. Although not in service as of this writing, this machine will have developed some service history by the time repowering decisions will be made for the time frame assumed for this study. The Westinghouse 501D5 machine was utilized for several of the CPFB cases where a smaller machine and lower firing temperatures were required. Adaptation of these, or any other gas turbine for gasifier or CPFBC applications must consider the requirements to increase the turbine nozzle areas and provide modifications to the outer envelope of the machine to accommodate the increased gas mass flows, and, in the case of the CPFB's, the need to move air/gas off and back on to the machine.

Steam Turbine Adaptation: Repowerings that use a gas turbine to create a combined cycle, with the steam turbine in the bottoming cycle, must deal with the increase in steam flow through the lower pressure portions of the machine. This consequence arises due to the abundant heat recovery from the gas turbine exhaust by condensate and feedwater, which reduces or eliminates the need for extracting steam from the steam turbine for condensate/feedwater heating. Steam turbine throttle flow may, in some cases, be limited by the need to avoid choking the last LP stage, or by blade loading in the last several stages of the machine.

Steam Cycle Configuration: Modifications to the existing steam cycle may be conceived that offer potential performance improvements, at the cost of increased capital and complexity. The use of a topping turbine at an elevated pressure such as 4500 psig, exhausting to the present HP turbine is one such concept. The use of a LP steam drum in the HRSG to essentially convert the existing machine into a triple admission type is another potential concept that could enhance efficiency. These and other concepts were rejected in favor of retaining and matching the original steam cycle in order to reduce capital costs and maintain simplicity.

SUMMARY DESCRIPTION OF TECHNOLOGIES

The following represent summary descriptions of the technologies evaluated: *Note-All heat rate values presented below are based on HHV of the fuel used.*

1. Atmospheric Fluid Bed Combustor, represented by a Foster Wheeler design quite similar to the equipment designed for the York County Energy Partners Cogeneration Project. The fluid bed combustor has a large footprint, relative to the original powerhouse, and is sited adjacent to the existing station. The existing coal handling equipment and other infrastructure are considered to be refurbished and reused. Plant performance is relatively unchanged except for emissions, which are significantly reduced. Plant solid waste production is increased.

2. Pressurized Fluid Bed Combustor (Bubbling Bed); this technology is represented by the ABB P-800 commercial module, incorporating an ASEA Stahl GT-140 gas turbine. The combustor is located inside a pressure vessel that is 57 ft in diameter and 160 ft high, operating at a nominal pressure of 245 psig. The new equipment comprising the PFBC package and the gas turbine and its associated equipment are arranged adjacent to the original powerhouse. Net plant output is increased to 348 MWe, while net plant heat rate is reduced to 8729 Btu/kwh.

3. Pressurized Fluid Bed Combustor (Circulating Bed, First Generation);based on Foster Wheeler technology. This concept utilizes the circulating pressurized bed for complete combustion of the coal. The hot air/gas mixture leaving the bed is cleaned in a series of cyclone and ceramic candle filters, and is then ducted to a gas turbine for expansion. Most of the gas turbine compressor discharge air is used in the circulating bed; the hot gases returning to the turbine for expansion are limited in temperature to 1650F. A machine based on the Westinghouse 501D5 is used in this arrangement, with a single drum HRSG in the exhaust to supplement the steam production in the circulating bed heat exchanger. Plant net output is increased to 314 MWe, while heat rate is reduced to 8506 Btu/kwh.

4. Pressurized Fluid Bed Combustor (Circulating Bed, One and One-Half Generation); this version of CPFBC technology is similar to the first generation scheme mentioned above. However, in this case, natural gas is fired in the combustion turbine to reach the original design turbine inlet temperature of the machine. An external, motor driven boost compressor is used to compensate for the unrecovered pressure drop in the CPFB circuit external to the gas turbine. The W501D5 is again selected, exhausting through economizer coils for condensate and feedwater heating. Steam is produced in the CPFBC heat exchanger to drive both of the existing steam turbines. Plant net output is increased to 368 MWe, while heat rate is reduced to 8087 Btu/kwh.

5. Pressurized Fluid Bed Combustor (Circulating Bed, Second Generation). In this version of the CPFBC technology, a pyrolizer is added to the process upstream of the circulating bed combustor. A low Btu fuel gas is produced by the pyrolizer, which is conveyed to the gas turbine where it is mixed with the returning vitiated air from the CPFBC and combusted to produce the design basis firing temperature of the turbine. This configuration is based on the use of a modified W501G machine, with an external, motor driven boost compressor as in the previous case. Steam is produced in a HRSG and in the CPFBC heat exchanger to drive both of the steam turbines in the existing station. Net output is increased to 433 MWe, while net heat rate is reduced to 7043 Btu/kwh.

6. Combustion Turbine/Combined Cycle. A natural gas fired, state of the art combustion turbine is used in conjunction with a HRSG to repower one of the two existing steam turbines in this case. The W501G machine , is coupled to a multi-pressure HRSG, to provide a net station output that is 312 MWe, with a heat rate of 7080 Btu/kwh. Two gas turbines repowering both existing steam turbines were not used in this case, since the resulting net power would be more than double the original output, and in excess of that allowed by the study guidelines. The second of the two original steam turbines is placed in reserve status, pending a future decision to repower or otherwise dispose it.

7. Integrated Gasification Combined Cycle (Air Blown KRW Gasifier). This case utilizes the air blown, fluidized bed, KRW type gasification process, including hot gas cleanup and a transport type gas polisher (desulfurizer) to supplement the sulfur removal that occurs in the gasifier bed. The clean hot low Btu gas that is produced is fired in a modified W501G gas turbine, which is coupled to a HRSG for steam production. Both existing steam turbines are repowered in this example, providing a net station power increase to 407 MWe , and a reduction in net heat rate to 7355 Btu/kwh.

8. Integrated Gasification Combined Cycle (Oxygen Blown Entrained Bed Gasifier). In this example, a two stage, entrained flow gasifier is supplied with 95% pure oxygen from a dedicated air separation plant located on-site. A single gasifier module produces medium Btu fuel gas which is desulfurized in a GE moving bed cleanup system, and is then fired in a modified W501G machine. The turbine exhausts through a HRSG to produce steam to drive one of the two existing steam turbines. A

Monsanto type (H2S burning, catalytic conversion) sulfur recovery process produces commercial grade sulfuric acid for sale as a byproduct. The net station output is increased to 353 MWe, while net heat rate is reduced to 7379 Btu/kwh, (including the air separation plant and other auxiliary loads).

9. Integrated Gasification Combined Cycle (Air Blown Transport Reactor). This IGCC concept is based on the application of an air blown Transport Reactor. The hot low Btu gas is desulfurised in the reactor, followed by a polishing step in a transport desulfurizer, chloride removal in a chloride guard bed, and filtration in a ceramic candle filter array. The fuel gas is fired in a modified W501G machine and exhausted through a HRSG to produce steam for one of the existing steam turbines. The Transport Gasifier concept evaluated in this study is not based on a current Clean Coal Technology demonstration site, but rather on concepts being evaluated at the DOE Advanced Power Systems Wilsonville test facility. This concept may not be commercially available at the beginning of the reference time frame, but can be expected to be ready for service at the end of this time period. The overall performance of the transport reactor in this repowering application results in a predicted increase in net output to 368 MWe, and a reduction in heat rate to 6854 Btu/kwh.

10. Integrated Gasification Combined Cycle (British Gas/Lurgi Oxygen Blown Gasifier). This fixed bed gasifier is supplied with 95% pure oxygen from an on-site air separation unit. The gasifier produces a cold medium Btu gas which is desulfurized in a Purisol cleanup train. Tail gas from the Purisol unit is converted to commercial grade sulfuric acid for sale, in a Monsanto type H2S burning and catalytic conversion unit. The fuel gas is fired in a modified W501G machine, which exhaust through a HRSG to produce steam to drive one of the existing steam turbines. A portion of the compressor discharge air is supplied to the high pressure air separation plant, eliminating the need for a separate air compressor. This repowering example produces a net power increase to 313 MWe, and a heat rate reduction to 7669 Btu/kwh.

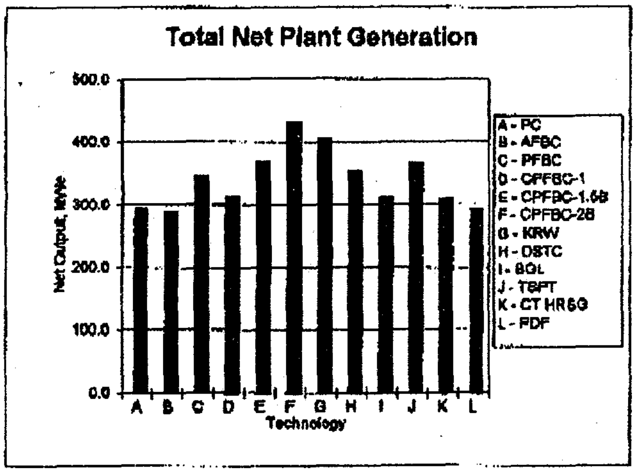
11. Refueling with Process Derived Fuel (Encoal Corp.). This case represents a refueling rather than a repowering. The original boilers are refurbished along with the steam turbines and other site equipment, and are fired with 100% Encoal Corp. PDF, which is a dried and mildly pyrolised Powder River Basin coal. The fuel is specified to contain low sulfur as delivered, (approximately 0.3% S, by weight). It is assumed, for the purposes of this study, that the original boiler capacity may be maintained, with some enhancement of soot blowing capacity, and other modifications to compensate for the somewhat different combustion characteristics of the Process Derived Fuel. These modifications would be accomplished as part of the refurbishment of the units. This refueling results in a slight reduction in net output to 293 MWe, and a slight reduction in net heat rate to 8890 Btu/kwh.

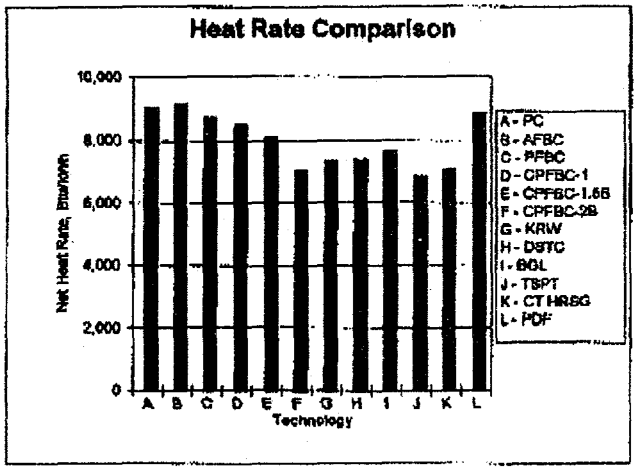
COMPARISON OF RESULTS

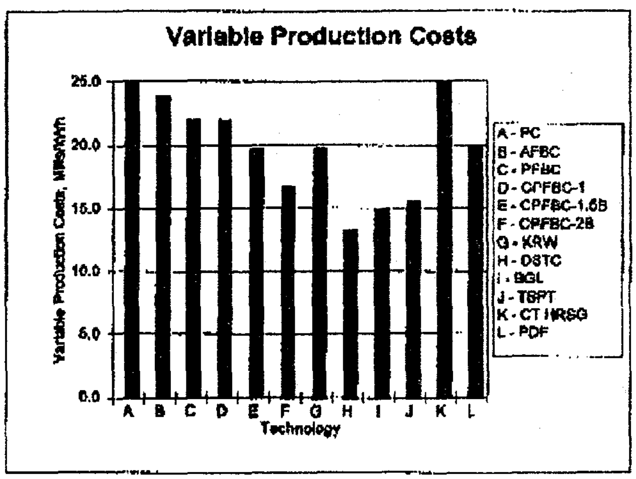
Review of the performance for each of the repowered stations reveals that the objectives originally set forth for repowering have, for the most part, been satisfied. All of the technologies reported on above result in a reduction in air borne emissions of SO2, NOx, and particulates to levels that meet or do better than currently projected federal standards. Regional requirements for lower emissions of NOx may be satisfied by the incorporation of Selective Catalytic Reduction and/or Selective Non-Catalytic Reduction technologies. These have not been included in this study since they are site specific.

The net power capacities of the repowered projects range from small reductions in power to substantial increases. In several cases, only one of the two existing steam turbines was repowered, in order to limit power output to about 135% of the original value. Net heat rates of the repowered stations varied from small deficits to very significant improvements. The net power and heat rates of the repowered stations are shown graphically in the following charts.

Production costs include fuel, sorbent, byproduct credits or charges, excess emissions credits or charges, and variable operations and maintenance costs. Consideration of production costs is more meaningful than consideration of heat rate alone in evaluating the attractiveness of a particular technology, in a repowering or in a greenfield facility. Technologies that produce salable byproducts, burn cheaper fuels, or reduce variable costs in some other manner realize these benefits in a production cost evaluation, but not in a simple comparison of heat rates or efficiencies.







CONCLUSIONS

The evaluation of the advanced technologies in repowering applications continues, with the focus now on definition of capital costs. The interplay of these costs and the consequent capital carrying charges vs. the predicted operating cost savings will determine the ultimate investment potential of each of the technologies evaluated in this paper. Site specific factors, fuel related variables, and other considerations will also influence the economics of selection for these and conventional technologies in the decades ahead.

This study concludes that most, if not all of the technologies examined herein show potential for technically and economically successful application in the developing future. The bottom line will govern.

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