INTEGRATED COAL GASIFICATION COMBINED CYCLES (IGCC)
AN EMERGING COMMERCIAL OPTION FOR THE POWER INDUSTRY

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Introduction

The very successful initial operation of the 100 MWe Cool Water Coal Gasification Combined Cycle Power Plant during 1985 has stimulated a great deal of interest in IGCC technology within the U.S. and foreign electric power industries. The Cool Water plant has clearly shown that IGCC plants, based on Texaco Partial Oxidation technology, can greatly reduce environmental emissions from coal utilization facilities and simultaneously meet normal electric utility load following requirements. In addition, inspections of Cool Water components, after nearly 7000 hours of operation, have shown that critical units are withstanding the service conditions very well. As a consequence, electric utilities are now developing confidence that such systems can be operated and maintained with little change in normal utility practice.

In parallel, electric load growth in the U.S. has been spurred by economic recovery and electric end use substitution; therefore, electric utilities are again beginning to plan unit additions for the early- to mid-1990's. Since many electric utilities have excess baseload capacity, initial generation additions are likely to be combustion turbines or combustion turbine combined cycle power plants. It is likely that these systems will first be used for peaking and mid-range duty and be fired with premium fuels such as natural gas and distillate. However, in the longer term, they are likely to be phased into baseload operation utilizing coal gasification technology. It is this planning flexibility which adds another important benefit and "degree of freedom" to IGCC power plants.

As a consequence, Potomac Electric Power Company has announced that it is considering the addition of a 350-400 MWe phased IGCC plant at the Dickerson Station. Virginia Power Company is proceeding with a full 200 MWe commercial module IGCC plant for repowering their Chesterfield Station. At least ten other electric utilities are currently conducting or planning site specific IGCC plant designs.

Although it is too early to judge the ultimate penetration potential of IGCC power plants in the U.S., it appears that this option may become the leading new coal technology for the 1990's.

Coal Gasification Systems Status

Development of a number of advanced coal gasification systems has been progressing at a rapid pace. Uncertainty regarding conventional fuels, i.e., natural gas and oil, environmental regulations that represent increasingly tight standards, and uncertainty regarding nuclear power deployment in a number of countries has spurred commercial development of coal gasification systems for diverse applications such as electricity generation; fertilizer, hydrogen and organic chemicals production; generation of hot water for district heating; etc.

Characterization of Gasification Systems

Coal gasification systems are usually classified by the type of gasifier which contacts and reacts coal with an oxidant (air or oxygen) to produce the desired fuel gas. If the system is blown with air, the fuel gas is low Btu gas and if the system is blown with oxygen, the fuel gas is medium Btu gas.

Three types of contacting devices are:

- moving beds
- fluidized beds
- entrained beds

In moving beds a descending bed of coal, usually 1/8 to 1 inch in size, is fed by a pressurized lockhopper system to the top of a shaft. Reactant gaseous oxygen (or air) and steam enter the bottom of the vessel. As coal descends it is devolatized, then pyrolysis reations occur and finally carbon is gasified. The raw product gas contains tars, and oils which need to be condensed and removed. The ash may be withdrawn as a dry solid or as molten slag. In some moving bed versions, tars, oils, and coal fines are recycled to extinction.

In fluidized bed reactors, coal is ground to produce a fluid bed grind (ca 8 mesh or less). The oxidant gas (and some steam) are introduced through a perforated deck or grid at the bottom of a vessel. The flow rate of the reactants is high enough to suspend the coal particulates but not blow them out of the vessel. A uniform temperature is obtained by the mixing that occurs. Depending on the temperature, tars and oils can be avoided but fines carryover and ash slagging limit conversion of some coals to 80%-90% of the carbon. In order to overcome this limitation, the carbon containing ash can be processed in an additional vessel or the unconverted carbon can be recycled to the gasifier.

In entrained flow systems, a relatively fine grind of coal (ca 75% through 200 mesh) is fed either as a dry solid or as a water and coal mixture to a short residence time reactor. Contacting with the oxidant is achieved by means of a nozzle arrangement. At the high velocities and temperatures used in entrained systems (2000 to 3000°F) no tars or oils are produced. Carbon burn-out is nearly complete and the product gas is essentially carbon monoxide and hydrogen.

In the U.S. and abroad, advanced coal gasification technologies have been under development for the last decade. Several technologies have been supported by EPRI's program.

1. Texaco technology, represents an entrained system that features a coal water slurry feeding the pressurized, oxygen-blown gasifier. It is the farthest advanced in that three commercial or demonstration plants are in operation. Two of these plants are located in the U.S. and one in Japan. A plant in the Fedeal Republic of Germany will start up in late 1986 to produce organic chemicals and hot water for district heating. Projects have also been announced for China and Sweden.

2. Shell coal gasification has under construction a 250/400 ton/day pilot plant at their research center in Deer Park, Texas that will lead to commercial designs in the late 1980s. The Shell process features a dry fed entrained gasifier system that operates at elevated temperature and pressure. Current studies with U.S. electricity companies are defining commercial opportunities.

3. The British Gas Corporation and Lurgi GmbH have jointly developed a slagging, moving bed gasifier system. A commercial gasifier prototype (600 ton/day) will be started up at Westfield, Scotland in early 1986. Virginia

Power is considering installation of a coal gasification system for a 200 MWe IGCC power plant based on the BGC/Lurgi technology.

4. An air-blown rotary ported kiln (similar to a moving bed device) is under development by Allis Chalmers Corporation. A 600 ton/day prototype is located at an Illinois Power Co. power station.

The Dow Chemical Co. is installing a 160 MWe IGCC plant in Louisiana that will produce electricity and synthesis gas for industrial chemicals. Details of the system are proprietary, but the system features a coal water slurry fed entrained gasifier. Price supports of $620 million from the Synthetic Fuels Corporation have been obtained for the project.

Other gasification systems technologies have been evolving, including the Kellogg Rust Westinghouse gasifier and Institute of Gas Technology U-Gas system that are representative of ash agglomerating fluid bed systems. Advanced fluid bed systems are also being developed in Japan. A Winkler demonstration fluid bed system operating at elevated temperature and pressure is being started up in the Federal Republic of Germany by Rheinesche Braunkohle. The Winkler system will handle 700 tons/day of coal to produce industrial chemicals and electric power.

Other projects that are at the pilot plant stage of development include a 50 ton per day pressurized pilot plant by GKT-Krupp. The Vereinegte Elektricitatswerke Westfallen (VEW) has started up a 250 ton per day pressurized pilot plant that partially converts coal (60% conversion) to low Btu gas for power generation. Lurgi has gasified lignite in an atmospheric pressure circulating fluid bed in their 15 ton per day pilot plant in Frankfurt, West Germany.

In Japan, several pilot plant programs are also underway including development of a molten iron gasifiation system. A 250 ton per day pilot plant is under construction in Sweden by Sumitomo-KHD in which sulfur is captured in the slag.

Combustion Turbines

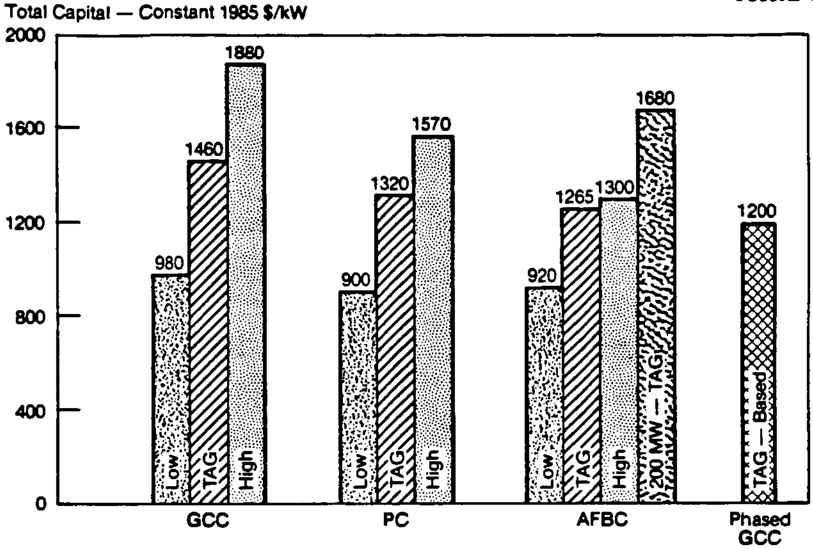
Develoment of advanced combustion turbines is proceeding rapidly. Efficiency of combined cycle equipment is increasing from the ability to operate at higher firing temperatures. In utility applications, firing temperatures of 2,000°F are conventionally used and higher temperatures of 2,300°F can be expected before 1990. Developments in the areas of reheat, materials, and advanced cooling methods promise additional improvements in efficiency in the 1990's.

Economics of IGCC Power Plants

The three major candidates for advanced coal utilization in the 1990s are integrated coal gasification combined cycle (IGCC) power plants, atmospheric fluidized bed combustion (AFBC) systems, and improved pulverized coal (PC) power plants. In order to assess the relative benefits of IGCC, AFBC, and PC plants, EPRI in conjunction with numerous engineering/construction firms have estimated the expected range of capital and busbar power costs for such plants using 3.5% sulphur Illinois bituminous coal. Figure 1 shows a comparison of the estimated range of capital costs from various studies placed on as consistent an estimate basis as possible. The estimates shown are low and high estimates, as well as those shown in EPRI's Technical Assessment Guide (TAG) for the three competing technologies. Also shown for the IGCC plant is the benefit of utilizing phased construction of the plant rather than committing all plant capital at once. The expected cost of a 200 MWe AFBC unit has been included because it is unclear whether single 500 MWe AFBC units can be constructed. In general, there is little difference in the expected range of capital costs for these three plant types, with perhaps a small capital advantage to AFBC and PC plants.

CAPITAL INVESTMENT ESTIMATES FOR SINGLE 500 MW UNITS
AFBC HAS ONE 200 MW UNIT CASE

FIGURE 1



COST OF ELECTRICITY ESTIMATES USING
TAG ECONOMIC CRITERIA

FIGURE 2

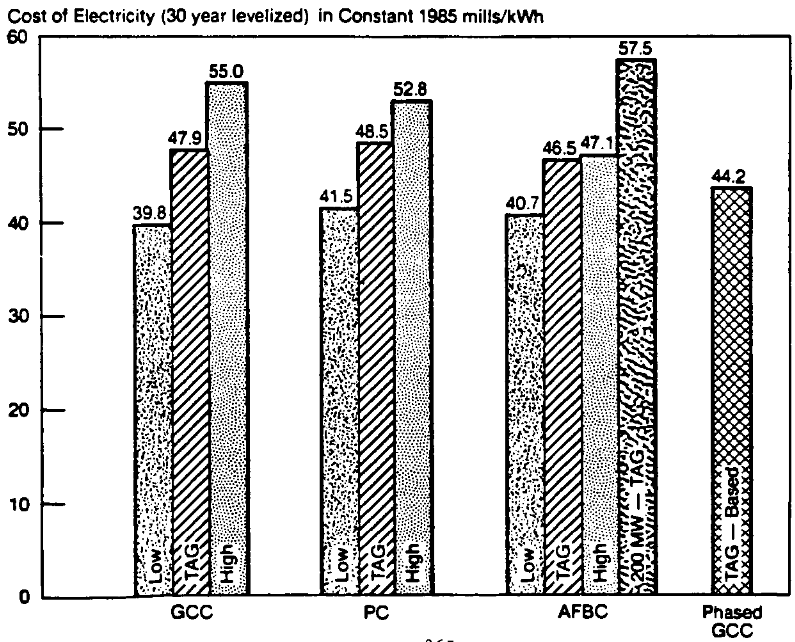


Figure 2 compares the 30 year levelized, constant 1985 dollar busbar energy costs for these same alternatives. As may be seen, all 500 MWe plants are projected to produce power costs of approximately 4¢/kWhr to 5.5¢/kWhr. There is no clear advantage for any of the technologies, considering the present uncertainties in these cost estimates. Phased construction of IGCC plants does show promise of producing some reduction in power costs.

It is in the area of environmental emissions control that coal gasification combined cycles demonstrate their true benefits. Table 1 shows typical effluent streams from the three coal-based technologies, using a 3.5% sulphur Illinois coal. The IGCC plant emits approximately one-tenth the acid rain precursors (SO_2 and NO_x) than a pulverized coal plant and produces 40 percent of the solid wastes from a PC plant. In comparison, the AFBC plant emits about 50 percent of the acid rain precursors from a PC plant, but produces 60 percent more dry solid waste for disposal. Although solid waste disposal costs were factored into the previous electricity estimates, very low costs for disposal were assumed. In many areas of the U.S., there just is not landfill area available for such large amounts of waste.

Table 1

Typical Effluent Streams
From Coal Based Power Plant Types
(Using 3.5% S. Illinois Coal)

Plant Type	SO_2 Emissions (Tons/MWe Yr)	NO_x Emissions (Tons/MWe Yr)	Solid Wastes (Tons/MWe Yr)
Pulverized Coal Plant (Precipitators Only)	140	25	240
Pulverized Coal Plant With FGD (90% Removal)	14	8	750
Integrated Gasification Combined Cycle Plant	0.14-4	3	300
Atmospheric Fluidized Bed Combustion	7	4	1200

Therefore, we believe that coal gasification combined cycle power plants show the greatest potential for meeting stringent emission control requirements, yet remaining economically competitive with alternative coal technologies.

Phased Construction of IGCC Power Plants

The modular structure of IGCC power plants provides utility companies with a major flexibility not available to them in the past. The capability to "phase-in" a plant in relatively small increments would allow a utility to more closely match load growth requirements by bringing a sequence of combustion turbines on line (shown in Figure 3 as Phases 1 and 2); converting these turbines into a combined cycle plant in Phase 3 and finally adding the gasification facility in Phase 4. The excess capacity at any time is shown as the crosshatched areas in Figure 3. This can be compared to the addition of an unphased, substantially larger power plant depicted in Figure 4. It is evident from Figures 3 and 4 that at any point in time, the phased addition approach results in substantially less excess system capacity than the conventional unphased plant construction approach. This means

FIGURE 3

PHASED CAPACITY ADDITION

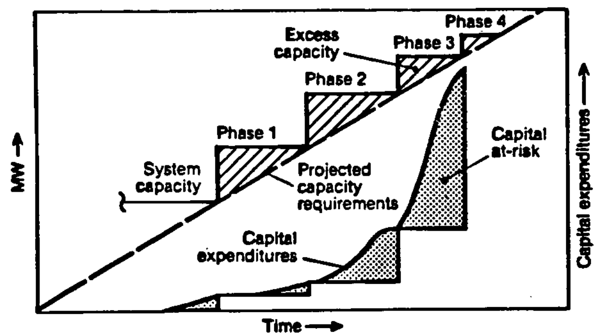
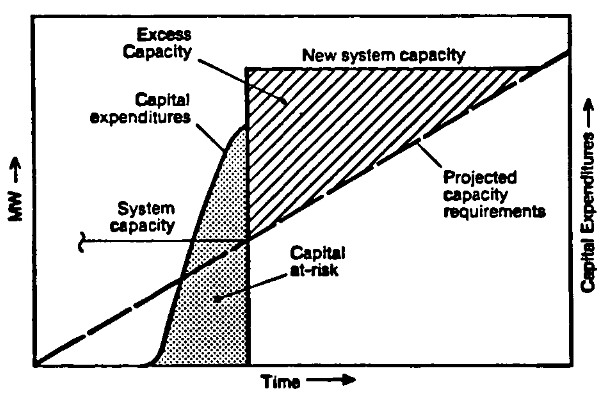


FIGURE 4

UNPHASED CAPACITY ADDITION



that the rate payer does not have to pay for unnecessary capacity ahead of time and the electric utility company does not have to place "at-risk" for an extended period of time the vast amount of capital required to construct a large, unphased power plant.

The major potential benefits to be associated with the phased addition of IGCC power plants are summarized below:

- o It allows the utility to delay and stretch out large capital outlays by more evenly matching load growth requirements without taking the full cost penalty of diseconomy of small scale.
- o It minimizes "at-risk" capital due to short construction periods for modules, i.e., capital becomes part of the rate base significantly earlier. A combustion turbine can be installed in approximately one year whereas it could take up to five years to construct a large coal-fired steam plant.
- o Phased construction provides the flexibility to take advantage of "low-cost" and "available" fuels for as long as this situation persists, i.e., a utility does not have to predict fuel prices or availability ten or fifteen years into the future. The phased plant can switch to coal whenever appropriate.
- o Phasing in an IGCC power plant provides a utility the flexibility to respond rapidly (and, therefore, at minimum cost) to changes in system load growth and/or fuel prices.
- o Finally, this procedure provides the potential for the utility to take advantage of non-utility company ownership of the coal gasification plant, thereby dramatically reducing the capital required for new capacity additions.

These potential benefits to be associated with the phased construction of IGCC power plants have already been recognized by major equipment suppliers and utilities alike. General Electric (GE) has investigated the system expansion benefits of phasing in an IGCC power plant (a procedure that they have termed PROGEN) instead of constructing conventional coal-fired steam plants. Sixteen scenarios of load growth and fuel prices were investigated. The GE results indicated that for all sixteen cases, fixed charges and production costs were significantly reduced due to phased construction. Capitalized savings for the phased construction approach ranged from \$350/kW to \$800/kW.

Potomac Electric Power Company (PEPCO) has conducted a preliminary phased construction study (comparing one IGCC plant to a coal-fired steam plant). Results of this study show a cumulative present worth saving in revenue requirements of approximately \$100 million attributable to the phased IGCC plant. Approximately one year ago, ten member companies (see Table 2) of the Utility Coal Gasification Association began an evaluation of the benefits of phased construction of IGCC plants on their systems. Preliminary results of some of these studies have confirmed the potential for financial benefits that have been claimed for this phased construction approach.

IGCC power plants clearly show promise of being the truly environmentally benign, economically competitive method of utilizing high-sulphur coal for power generation in the 1990's and beyond.

Table 2

Phased IGCC Construction Study Team

Baltimore Gas & Electric Co.	Northeast Utilities
Cleveland Electric Illuminating Co.	Potomac Electric Power Co.
Consumers Power Co.	Public Service Electric & Gas Co.
Illinois Power Co.	Virginia Power Co.
Nevada Power Co.	Public Service of Indiana