# ELECTRICITY INDUSTRY ASSESSMENT OF LOW BTU GAS FOR POWER GENERATION

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## Introduction

Gasification of coal with air or oxygen to produce low Btu (80-180 Btu/SCF) or intermediate Btu (200-350 Btu/SCF) gas represents a technology that is being given close scrutiny by the electric power utility industry. Recent legislation has precluded the use of natural gas as fuel for baseload power generation. Fuel oil is following closely on the heels of natural gas and will not be available to the electric utility industry for baseload applications in the near future. Coal, therefore, represents the last remaining fossil option available to the utility industry for baseload power generation in the last decade of the twentieth century and on, into the twenty first century.

Coincident with the fuel crunch, the utility industry is being confronted by an equally serious and difficult to handle environmental crunch. Coal gasification offers the potential for controlling $SO_x$, $NO_x$ and particulate emissions in a far more efficient and less costly manner than can be achieved in pulverized coal boilers.

There are a variety of different ways in which the utility industry can employ the concept of coal gasification for electric power generation. Some of the more obvious options are shown in Table 1. It is important to realize that most of the cost and performance figures presented in Table 1 represent estimates generated by the authors. Specific engineering studies addressing each option in detail are currently underway or are in the process of being initiated. It must be pointed out, however, that the Electric Power Research Institute (EPRI) has been funding engineering and economic studies of gasification and combined cycle systems with Fluor Engineers and Constructors, Inc., Stone and Webster Engineering Corporation, R. M. Parsons, the Bechtel Corporation and C. F. Braun for many years. Therefore, the estimates presented in Table 1 are based on a substantial body of cost and performance information (1) (2) (3) (4) (5) (6) (7).

A cursory glance at Table 1 indicates that option 7 (methanol production) is too expensive to be considered for baseload fuel production. Considering the other six alternatives presented in Table 1, EPRI has identified options 5 and 6 (integrated gasification-combined cycle plants and integrated gasification-gas turbine power systems) as the most attractive options for baseload power generation. Table 2 presents cost and performance estimates for a variety of gasification-combined cycle power plants(3). It can be seen from this table that, in general, integrated gasification based power systems have the potential for more efficient operation and lower cost of electricity than conventional coal fired power plants with flue gas desulfurization. Keeping in mind the fact that integrated gasification based power plants have the potential to meet more stringent environmental control

TABLE 1

UTILITY OPTIONS FOR COAL GASIFICATION

| Option | Time Frame for Initial Introduction | Capital Requirements[a] | Heat Rate Btu/kWh |
|---|---|---|---|
| 1. Retrofitting existing gas/oil fired boilers | 1982-1990 | 0.70 - 1.0 | 13,000 - 17,000 |
| 2. Retrofitting existing combined cycle equipment | 1982-1990 | 0.60 - 0.9 | 12,500 - 15,000 |
| 3. Centralized gas production including distribution to a number of utility plants | 1982-2000 | ($3.50/MMBtu - | $5.00/MMBtu)[b] |
| 4. Integrated gasification-steam boiler power plants | 1982-2000 | 0.90 - 1.2 | 9,600 - 11,000 |
| 5. Integrated gasification-combined cycle power plants | 1990-2000 | 0.85 - 1.1 | 8,400 - 9,500 |
| 6. Integrated gasification-gas turbine power plants | 1995-2010 | 0.75 - 1.1 | 7,500 - 8,500 |
| 7. Syngas generation for methanol production | 1982-2000 | ($5.00/MMBtu - | $7.00/MMBtu)[b] |

(a) A pulverized coal boilder with stack gas scrubbers costs 1.0.

(b) These selling prices based on utility financing, instantaneous 1976 dollars with no escalation, and coal costing $1.00/MMBtu.

TABLE 2

COST ESTIMATES FOR GASIFICATION-COMBINED CYCLE POWER PLANTS

| Gasifier | BGC Slagger (b) | Lurgi (a) | Foster Wheeler (b) | Texaco (b) | Texaco (b) | PC Boilers With Stack Gas Scrubbers (b) |
|---|---|---|---|---|---|---|
| Oxidant | $O_2$ | Air | Air | $O_2$ | $O_2$ | Air |
| Power System | CC (c) | CC (c) | CC (c) | CC (c) | gas turbine (f) | steam turbine |
| Heat Rate, Btu/kWh | 8,410 | 9,762 | 8,428 | 8,813 | 7,500 - 8,500 | 9,928 |
| Make-up Water, gpm/1000MW | 6,716 | 7,905 | 6,622 | 7,950 | 1,500 - 3,500 | 13,000 |
| Total Capital Requirement, $/kW (d) | 711 | 906 | 705 | 816 | 650 - 900 | 838 |
| Cost of Electricity, mills/kWh (e) | 32.8 | 41.2 | 32.5 | 37.2 | 29 - 35 | 40.9 |

(a) Western coal

(b) Illinois #6 coal

(c) Combined cycles based on 2400°F gas turbine and 1450 p/900°F/1000°F steam turbine

(d) Mid-1976 dollars, no escalation, 1000MW, including construction loan interest, paid up royalties, initial catalyst and chemicals cost, preproduction costs, working capital, wet cooling towers, and emissions of < 1.2 lbs $SO_2$/MMBtu

(e) Coal costing $1.00/MMBtu

(f) These estimates not included in Fluor report. Detailed performance and cost estimates for these systems are not yet available.

requirements as well as consuming substantially less water than conventional plants, it is evident why such systems represent a most attractive option for intermediate term baseload power generation.

It should be noted that gasification-combined cycle power systems have not yet been developed to the point where a utility company can order and install one with confidence. Such systems need to be demonstrated at sufficiently large scale (100MW - 200MW) such that the utility industry will have confidence that these plants can generate electricity reliably at the costs projected by the engineering studies.

Table 1 indicates that integrated baseload gasification-combined cycle power plants will only be available for utility use in the 1990's. A major question that must be addressed is: "Can coal gasification technology be utilized to alleviate utility needs for clean fuel prior to the 1990's?" The answer to this question has to be supplied in two parts i.e. a) an investigation of the development status of near term coal gasification technology and, b) identification of the technical possibilities and cost potential for rapid introduction of gasification systems for utility power generation.

Status of Near Term Gasifiers

Table 3 presents a summary of the development status of near term coal gasification options. It can be seen from this table that the suitability of the three commercially available gasifiers for combined cycle power generation is not good. Reasons for the lack of suitability range from low pressure operation to excessive by-product production - all of which result in an unacceptably high cost of electricity. It is the judgement of these authors that the gasifiers offering the greatest near term potential for combined cycle power generation at this time are the Texaco and Shell/Koppers partial oxidation units. This judgement is based on the extensive experience of the particular organizations in partial oxidation of oil, the simplicity of the gasifiers, their feedstock flexibility (ability to handle any coal as well as oil), absence of byproducts in the make gas, capability for high pressure operation, and the results of extensive engineering and economic studies. Information concerning the Shell/Koppers device is sparce. Texaco claims that based on successful operation of the 150 ton/day gasifier to be operated in Germany in 1978, they could scale-up to 1,000 tons coal/day capacity with confidence. Therefore, it appears that the Texaco gasification option could be available for utility use in the early 1980's.

Technical Possibilities for Near Term Introduction

It has already been mentioned that integrated gasification-combined cycle systems have not yet been demonstrated to the point where they would represent viable commercial options for the electric utility industry. Although all of the subsystems (i.e. gasifiers, gas clean-up modules, and combined cycles) have been operated at large scale independently, they have never been operated in an integrated mode for power production. Questions concerning the ability to control such integrated systems in a power plant environment can only be satisfactorily answered by building and operating an integrated test facility. One of the major control problems for these systems is posed by integrating the rapidly responding gas turbine and steam system with the more sluggish fuel production plant.

TABLE 3

DEVELOPMENT STATUS OF NEAR-TERM GASIFIERS

| Technology | Operational Mode | Suitability for Combined Cycle Operation | Current Status | Future |
|---|---|---|---|---|
| Lurgi | Moving Bed | Intermediate | Commercial | --- |
| Koppers Totzek | Entrained | Poor | Commercial | --- |
| Winkler | Fluidized Bed | Poor | Commercial | --- |
| Texaco | 1 Stage Entrained | Good | 15 ton/day running | 150 ton/day 1978 |
| Shell/Koppers | 1 Stage Entrained | Good | 5 ton/day running | 160 ton/day 1978 |
| BGC Slagger | Moving Bed | Intermediate - Good | 360 ton/day running | 1,000 ton/day 1983 |
| Combustion Engineering | 2 Stage Entrained | Intermediate | 120 ton/day 1978 | ? |

The influence of control problems on the operability of the system can be deemphasized by decoupling the fuel plant from the power equipment i.e. the gasification plant would operate independently of the power plant and would simply produce "over the fence" fuel gas to be consumed by the power system. The major penalty to be paid due to system decoupling is a significant decrease in power plant efficiency with a resultant increase in the cost of electricity (compare the heat rates of options 1 and 4 as well as options 2 and 5 from Table 1). The main advantage to be derived from decoupling the system is the fact that engineering for the first of such power plants could be started in 1978.

Non-integrated gasification based power systems of the type discussed above could most readily be achieved by retrofitting existing power plants which in the near future will have difficulty securing adequate fuel supplies i.e. gas and oil fired boilers as well as conventional combined cycle power plants. Such retrofitting can be acccomplished in one of two different ways. Centralized gasification plants can be constructed to produce intermediate Btu fuel gas for limited distance pipeline distribution to one or more power plants. Alternatively, on-site retrofitting of individual power plants can be affected. The remainder of this paper will address the above two retrofit options and will attempt to highlight the advantages and disadvantages of each.

Centralized Gasification Plants

Large (10,000 tons/day coal - 30,000 tons/day coal) centralized gasification plants could be constructed to produce intermediate Btu gas for transmission to a number of power plants. Such gasification plants would have to produce 250 Btu/SCF to 300 Btu/SCF gas for two major reasons. First, the cost of pipeline distribution for low Btu gas is excessively high. Also, it has been shown by both Babcock and Wilcox (8) and Combustion Engineering (9) that retrofitting gas and oil fired boilers with fuel gas having a heating value much below 250 Btu/SCF will result in a rather serious derating of the existing boilers.

Some of the major advantages and disadvantages of large centralized gasification plants are shown in Table 4. Based on the high cost of fuel gas and the political and environmental problems associated with intermediate Btu gas transmission shown in Table 4, the option of large centralized gasification plants does not appear to offer sufficient economic incentive to be given major consideration by the electric utility industry at this time.

Gasification Plants For On-Site Retrofitting

There is an entire category of generic questions associated with on-site retrofitting of conventional steam electric power plants as well as combined cycle facilities with gasification systems that are site specific i.e. space availability, rail access, coal supply, environmental requirements (non degradation standards), etc. that need to be closely examined before any retrofit decision can be made. The purpose of this paper is to point out some of the technical opportunities and constraints associated with on-site retrofitting assuming that the answers to the above mentioned generic questions are all positive.

TABLE 4

ADVANTAGES AND DISADVANTAGES OF LARGE CENTRALIZED GASIFICATION PLANTS

| ADVANTAGES | DISADVANTAGES |
|---|---|
| 1. Fuel gas production decoupled from power plant operation. | 1. The cost of fuel will be high, i.e., $3.50/MMBTU to $5.00/MMBTU in 1976 dollars (see Table 1) and utility financing. If private financing is used, the gas cost will increase by approximately $1.00/MMBTU. |
| 2. Gasification plant can operate in steady state mode most of the time. | 2. Environmental and Right of Way problems associated with the installation of large underground pipelines. |
| 3. Transmission pipelines offer a minor form of fuel storage. | 3. Safety problems associated with the transmission of gases containing high concentrations of carbon monoxide. |
| 4. Ownership of the fuel production plant does not have to reside in the electric utility industry. | 4. Ownership If the electric utility industry does not own the gasification plant, the owner will require long term take-or-pay fuel contracts to insure the integrity of the large capital investment required. |
| 5. The gasification plant (and its emissions) can be remote from large population centers. | |

## A. Retrofitting Existing Gas and Oil Fired Boilers

In order to fire coal derived fuel gas in an existing boiler designed for natural gas or oil firing, Combustion Engineering (9) and Babcock and Wilcox (8) both claim that the heating value of the gas should be above 250 Btu/SCF in order not to derate the steaming capacity of the boiler. Summary results of the Combustion Engineering (9) study are shown in Table 5. The heating value requirement of the gas employed for this situation dictates that the gasifier be oxygen blown. As fuel gas for this application is not needed at high pressure, an atmospheric pressure gasifier could be utilized. Therefore, for boiler retrofitting, either an oxygen blown Texaco gasifier or an oxygen blown Combustion Engineering gasifier could be employed. EPRI has retained the Bechtel Power Corporation to study the cost of electricity from this type of retrofit.

It is the opinion of these authors that the electricity generated by this technique will be expensive due primarily to the excessively high heat rates anticipated for such systems (see Table 1, option 1). Such heat rates are unavoidable for decoupled systems as the efficiency of the conversion of coal to intermediate Btu gas ranges from 65% to 75%. These gasification efficiencies are somewhat lower than the much quoted cold gas efficiencies as they include the firing of up to 10% of the clean fuel gas produced to supplement superheated steam requirements for the air separation plant or to superheat steam generated in the gas coolers following the gasifier. Dividing the existing steam plant heat rates (ranging from 9,500 Btu/kWh to 11,000 Btu/kWh) by the fuel production efficiencies (65% to 75%) results in overall system heat rates in the range 13,000 Btu/kWh to 17,000 Btu/kWh. Not only are these high heat rates costly from a fuel consumption point of view, they will also require excessively high capital expenditures as the gasification plant needed to produce 1000 MW at a heat rate of 17,000 Btu/kWh will be twice the size of the same capacity system having a heat rate of 8,500 Btu/kWh (i.e. an integrated gasification-combined cycle power plant).

Notwithstanding the promise of substantial tax incentives by the current administration for this type of retrofit, the fuel and capital utilization efficiencies are sufficiently poor to render this option of low long term interest to the bulk of the electric utility industry.

## B. Retrofitting Existing Oil Fired Combined Cycles

Most of the statements made concerning the retrofit of existing steam electric power plants apply to the decoupled retrofitting of oil fired combined cycle equipment with three differences:

(i) For this application, a pressurized gasifier such as the Texaco unit would be preferred as fuel gas must be delivered to the gas turbine combustor inlet system at pressures ranging from 230 psia to 280 psia.

(ii) Air or oxygen blowing of the gasifier would be acceptable as gas turbine combustors can be modified to fire either low Btu gas or intermediate Btu gas. This statement must be treated with extreme caution. If, for example, the gasifier is air blown and the air is not extracted from the gas turbine air compressor, the turbine would suffer a major derating due to the mismatch between compressor and expansion turbine sections resulting from the high mass flow rate of low Btu fuel gas. Modification of an existing gas turbine for air extraction is not simple and could result in a high capital cost.

TABLE 5

SUMMARY RESULTS OF COMBUSTION ENGINEERING BOILER RETROFIT STUDY (9)

With existing steam generating unit and auxiliary components, the approximate maximum rating that can be achieved firing low BTU gas with only minor modifications to the windbox and firing system equipment is:

| | Original Design Fuel | |
|---|---|---|
| Fuel Gas HHV | Oil | Gas |
| 396 BTU/SCF | 100% | 100% |
| 292 BTU/SCF | 100% | 100% |
| 179 BTU/SCF | 70% | 70% |
| 128 BTU/SCF | 65% | 60% |
| 105 BTU/SCF | 50% | 50% |

(iii) The overall system heat rate would be approximately 10% better than that for the steam electric power plant due to the higher efficiency of the combined cycle system (see Table 1, Option 2).

Although the decoupled retrofit of existing combined cycle systems appears to be somewhat more attractive from a cost and heat rate point of view than the retrofit of existing steam electric power plants, the heat rates and capital requirement estimates shown in Table 1 are still too high to make this a high priority option for the electric utility industry.

To this point, the entire retrofitting discussion has been based on the premise that the power production plant (i.e. the steam boiler or the combined cycle system) has already been constructed and operated at a specific site. Based on the preceding discussions, none of the retrofit scenarios involving total decoupling of the gasification plant and the power system appears to offer an attractive baseload option to the electric utility industry.

There are, however, at least two additional possibilities for retrofitting combined cycle power plants with gasification systems that offer the potential for lower heat rates and lower costs than the decoupled retrofit discussed previously. These new situations will be termed integrated retrofits.

Potential for Integrated Retrofits

Two types of integrated retrofit possibilities will be discussed i.e.
1) Constructing the gasification plant first and firing the clean fuel gas in an existing boiler. When the gasification plant has been demonstrated to operate reliably and efficiently, it can be retrofit and integrated with a combined cycle power plant.
2) Constructing an oil fired combined cycle power plant initially to be retrofit and integrated with a gasification plant at some later date.

A) Integrated Retrofit - Gasification Plant Initially

The major attraction of this option is that it provides for the earliest possible introduction of coal gasification as a source of clean fuel for the utility industry without the disadvantage of having to suffer major thermal inefficiencies for the entire life of the gasification plant.

This could be achieved technically at an early time by constructing a self sufficient oxygen blown Texaco gasification plant at a utility site having the necessary space requirements as well as an oil or gas fired steam electric power plant. For the initial design, steam to power the air separation plant as well as the oxygen compressors would be generated in the gasifier gas coolers and could then be superheated in a furnace fired with clean fuel gas. The clean intermediate Btu fuel gas produced could be fired in the existing boiler for power production (at an overall system heat rate of 13,000 Btu/kWh to 17,000 Btu/kWh). The purpose of this phase of the project would be to demonstrate the operability of the gasification - gas clean-up system under utility operating conditions.

The second phase of the project would involve retrofitting and integrating the gasification plant with a combined cycle system. Major integration features would include:

- superheating steam produced in the gasification gas coolers in the new heat recovery steam generator (HRSG) for introduction into the new steam turbine.

- extraction of steam from the new steam turbine or HRSG to power the air separation plant, oxygen compressors and gas clean-up system.
- possibly reheating clean fuel gas in the new HRSG
- supplying hot boiler feed water from the new HRSG to the gasifier gas coolers.

The major purpose of this phase of the project would be to demonstrate the operability of an integrated gasification-combined cycle power plant (the major incentive for coal gasification) under utility operating conditions.

Some of the advantages and disadvantages associated with this option are shown in Table 6. In summary, this form of retrofit provides for the earliest low risk introduction of coal gasification for environmentally acceptable electric power generation. The penalties to be paid are high cost, limited capacity and a relatively short plant life.

B. Integrated Retrofit - Combined Cycle Plant First

The major attraction of this option is that it provides for extremely rapid introduction of new oil fired baseload capacity without any initial risk being taken concerning the integrability and operability of gasification-combined cycle power plants.

Initially, conventional oil fired combined cycle equipment would be installed. Salable electricity could be produced approximately three years after initiation of project engineering. At some later date, after demonstration of the viability of integrated gasification-combined cycle power plants, the existing combined cycle facility could be retrofit and integrated with a coal gasification plant. One of the major advantages of this scenario is based on the fact that knowing that the integrated retrofit is to take place some time in the future, the initially installed combined cycle plant could be designed to minimize the cost of the future retrofit. Some key technical questions concerning this type of retrofit are:

- can the gas turbine combustor cans be designed for dual fuel capability i.e. for firing oil initially and switching to low Btu or intermediate Btu gas at some later time? Such combustors are currently being designed by General Electric.

- If the gasification plant is to be air blown, can the gas turbine wrapper be designed to accommodate air extraction at some later date? If not, what would be the cost of changing the wrapper at the time of the retrofit?

- If the gasification plant is to be oxygen blown, will the compressor/turbine mismatch after retrofitting result in a significant derating of the gas turbine?

- A conventional combined cycle HRSG is balanced with respect to steam generation. For the integrated retrofit with a Texaco gasification plant, much interchange of boiler feed water and steam must take place between the gasification plant and the HRSG. Can the HRSG be designed initially to accommodate the retrofit? If not, what type of modifications will have to be made to the existing HRSG? Will it be cheaper to modify the existing HRSG than to scrap it and construct a new HRSG?

TABLE 6

ADVANTAGES AND DISADVANTAGES OF INTEGRATED RETROFIT - GASIFICATION PLANT FIRST

| Advantages | Disadvantages |
|---|---|
| 1. Allows for the earliest possible introduction and demonstration of coal gasification technology for electric power production. | 1. Limited site availability as a site is required having an existing gas or oil fired boiler with sufficient space for the new project. |
| 2. The integrated retrofit provides an opportunity to dramatically improve the heat rate of the initially installed plant at an early date. | 2. Limited ultimate capacity of 100MW-150MW dictated by prudent engineering scale-up of gasification plant. |
| 3. Provides for the lowest risk demonstration of an integrated gasification-combined cycle power plant as the gasification plant will have been debugged prior to operation in an integrated mode. | 3. Anticipated project cost will be higher than the cost of building an integrated system initially due to the two phase nature of the project. |
| 4. Project risk can be further minimized by designing the Texaco gasification plant to fire coal, coke and high sulfur heavy oil providing extreme fuel flexibility (risk is lowered as the Texaco gasifier has been commercially proven for oil firing). | 4. The resulting integrated plant will not be a commercial facility having a life of 20 years to 30 years due to the experimental nature of the project. |

- What is the incremental cost of initially sizing power plant auxiliaries (i.e. deaerator, water treatment, cooling towers, etc.) such that at the time of the retrofit only minor modifications would be required?

Answers to these and other technical questions should be developed as soon as possible if this form of retrofitting is to be given serious consideration by the electric utility industry.

Some of the advantages and disadvantages of this type of retrofit are shown in Table 7. In summary, this option provides the opportunity for rapid installation of new oil fired baseload capacity while awaiting the demonstration of the gasification-combined cycle power plant concept. The penalties to be paid are higher than normal costs associated with the original combined cycle equipment (which might be more than offset by the fact that the plant is being constructed at an early date, thereby eliminating inflation and escalation costs that would have been incurred if the entire plant had been constructed at some later date) as well as the possibility of owning a plant for which a guaranteed fuel supply cannot be assured if gasification-combined cycle power plants do not emerge as an economic option for electric power generation.

In conclusion, it can be stated that the information presented in Tables 6 and 7 indicates that the two forms of integrated retrofitting discussed in this paper have the potential for providing attractive options for the electric utility industry to replace oil and gas firing with coal gasification in a low risk and timely manner. A number of unanswered technical and economic questions have to be resolved before these options can be given serious consideration. During 1978, EPRI, in conjunction with a number of member utilities, will attempt to find answers to most of the major unresolved issues.

TABLE 7

ADVANTAGES AND DISADVANTAGES OF INTEGRATED RETROFIT - COMBINED CYCLE PLANT FIRST

| Advantages | Disadvantages |
|---|---|
| 1. Offers the opportunity to install new oil fired baseload capacity at an early date and an acceptable heat rate. | 1. Higher than normal initial cost of combined cycle equipment due to the added flexibility required for the retrofit at a later time. |
| 2. Provides maximum security for the initial investment as oil fired combined cycle plants can be considered to be minimum risk projects. | 2. Possibility of having to make major modifications to or scrap the existing HRSG at the time of the retrofit. |
| 3. Offers a low risk opportunity for the introduction of commercial scale coal gasification to the utility industry as the retrofit will only be attempted after large scale demonstration of the integrated concept has been achieved. | 3. Space required for the ultimate retrofit of the gasification plant must be available at the beginning of the project i.e. eight to ten years before the retrofit is actually accomplished. |
| 4. Provides the opportunity for rapid capacity expansion (500MW-1,000MW) as well as providing the potential for extending the time period in which oil is used for baseload generation. | 4. If gasification-combined cycle power plants do not emerge as an economic option for electricity production the host utility company is stuck with a large investment in equipment for which a stable fuel supply cannot be guaranteed. |
| 5. Project risk can be further minimized by designing the Texaco gasification plant to fire coal, coke and high sulfur heavy oil providing extreme fuel flexibility (risk is lowered, as the Texaco gasifier has been commercially proven for oil firing). | |
| 6. The oil fired combined cycle plant can be operated over most of the construction period for the gasification plant. The down time required to accomplish the retrofit can be minimized. | |

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