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ADVANCED PROCESSES FOR GENERATION OF ELECTRIC POWER:  
SOLVENT REFINING OF COAL AND COMBINED CYCLE PLANTS

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SOLVENT REFINING OF COAL AND COMBINED CYCLE PLANTS

by

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*ABSTRACT*

An assessment of the status of technology of solvent refined coal (SRC) production and utilization and low Btu gasification/combined cycle power generation (LBG/CCPG) systems was made. The assessment included an analysis of, among other things, the relative potential for commercial application, energy conversion efficiencies and economics. The potential for commercial application of these two technologies was found to depend on certain institutional barriers and solution of a few technological problems. Energy conversion efficiency for SRC production and utilization for generation of electricity was found to be comparable to conventional plants with flue gas desulfurization systems. Energy conversion efficiency for combined cycle plants was found to be higher than that of conventional plants. Cost of electricity generated by plants based on these two technologies was found to be higher at present but in the future it was projected to be comparable.

INTRODUCTION

Until 1970 R&D activity associated with coal based electricity generation was linked to the development of more efficient boilers and other systems with relatively low heat rates (Btus in coal to kWhr of electricity). However, after the enactment of the 1970 Clean Air Act Amendments and the ecological movement picking up steam, this R&D effort slowly started shifting toward not only more energy efficient but also environmentally clean electricity generation systems. An analysis of such advanced systems shows that beyond 1980 four of the technologies that hold varying potential for commercial application are:

1. Production and utilization of solvent refined coal (SRC);
2. Low Btu gasification/combined cycle power generation (LBG/CCPG);
3. Fluidized bed combustion (FBC); and
4. Magneto-hydro dynamics (MHD).

The four technologies are being evaluated under the Environmental Control Technology program at Argonne National Laboratory. However, this paper deals only with the assessment of status of technology of SRC and LBG/CCPG plants. The relative potential for commercial application, energy conversion efficiencies and economics are discussed.

## SOLVENT REFINING OF COAL

Solvent refining of coal (SRC) generally refers to a process of initially dissolving coal in a coal derived solvent and then hydrogenating, in the absence of an externally added catalyst, some of the natural constituents of coal. The coal derived solvent is the hydrogen donor and the hydrogenation takes place under high pressures (1500 to 2500 psia) and temperatures of around 850°F. The donor solvent is rehydrogenated, within the main process at present, using essentially pure hydrogen from a hydrogen manufacturing plant.

Figure 1 shows the process flow diagram for a 6000 ton per day SRC plant. In this diagram the filter cake containing some carbon in the form of char is shown as being used along with some raw coal in the hydrogen plant. In commercial scale plants this would be the desirable route since manufacture of hydrogen from other raw materials would be quite expensive.

Table 1 shows the analysis of SRC that can be expected from Kentucky coal. This SRC when burned in a fuel combustion source would allow compliance with the present new source performance standards without additional controls. It should be noted that in calculating plant efficiency the hydrogen plant was assumed to be only 60% efficient and the filter cake was not used in the hydrogen plant.

Table 1 SRC from Kentucky Coal

	Feed Coal wt. %	Product SRC wt. %
Carbon	71.0	87.5
Hydrogen	5.3	5.7
Nitrogen	1.1	2.1
Sulfur	3.9-4.2	0.7 <sup>a</sup>
Ash	11.0	0.1-0.2 <sup>a</sup>
Calorific value, Btu/lb	13,000	16,000
Coal feed rate	9,336 TPD	-
SRC produced	-	6,000 TPD
Plant energy efficiency <sup>b</sup>	68 to 75%	

<sup>a</sup>Compliance with NSPS requires:

Sulfur < 0.96%

Ash < 0.16%

$${}^b\text{Eff.} = \frac{H_{hg} + H_{lo} + H_{ws} + H_{src} - \text{Plant fuel} - \text{Power}}{H_{\text{Coal}} + [H_h \times 0.6] - H_{\text{char}}}$$

$H_{hg}$  → heat content in byproduct hydrocarbon gases

$H_{lo}$  → heat content in byproduct light oil

$H_{ws}$  → heat content in byproduct wash solvent

$H_{src}$  → heat content in product SRC

$H_h$  → heat input to the hydrogen plant

LOW BTU GASIFICATION/COMBINED CYCLE POWER GENERATION PLANTS

Figure 2 shows a block process flow diagram of a LBG/CCPG system. Coal is delivered from the coal pile to a coal preparation section where it is crushed, dried, and conditioned so as to be an acceptable feed to the gasifier.

The general types of gasifiers that can be used in a combined cycle plant are moving bed, fluid bed and entrained flow gasifiers. The desired product from these is a clean combustible gas which can be used as gas turbine fuel. Oxygen is used for the partial combustion when pipeline quality gas is the desired product since dilution by nitrogen would introduce large amounts of essentially inert gas. However, when the product gas is to be used directly as fuel in a turbine air is preferred. Gas turbines are mass flow machines and, therefore, can recover energy efficiently from the nitrogen introduced with the air in the gasifier. Also gasifiers that operate at atmospheric pressure are considered not suitable since the economic and energy penalty for compressing raw fuel gas prior to combustion would be prohibitive. Based on this criteria the following three gasifiers, under the general categories mentioned above have been selected:

1. Lurgi's nonslagging moving bed;
2. IGT's U-Gas fluid bed; and
3. Foster Wheeler's entrained flow.

Raw gas from the gasifier is cooled and then directed to the raw fuel gas cleaning section for removal of particulates and sulfur compounds. Clean low Btu fuel gas is fired in the combustor and expanded in a gas turbine where the power produced in excess of that required for air compression is used to generate electricity. Hot exhaust gas from the gas turbine generates high pressure superheated steam in the heat recovery steam generator. This steam, after extraction of that required for fuel gas production, generates additional electric power via the steam turbine-generator set.

Table 2. Relative Potential for Commercialization

	SRC	LBG/CCPG
Present status	Pilot plant operation	Limited commercial operation
Scale up to 500 MWe	2 separate trains, 1 to 60 scale up for producing 6,000 TPD	1 to 5 gasifiers, multiple trains, scale up varies
Necessary process development	Solids separation and H <sub>2</sub> production	Raw fuel gas cleaning
Necessary equipment development	Pumps and filters	Gas turbines, instrumentation and control
Commercialization period	1982-1985	1985-1990

COMMERCIALIZATION POTENTIAL, ENERGY CONVERSION EFFICIENCY AND ECONOMICS

The assessment of the relative potential for commercial application of SRC and LBG/CCPG plants is of interest because of their capability to allow compliance with environmental standards and improve energy conversion efficiency thereby reducing the cost of electricity generated. Table 2 shows the important factors taken into consideration for determining, as shown at the bottom of this table, the expected commercialization period assuming of course the present rate of developmental work continues.

Table 3. Energy Conversion Efficiencies  
(Btu in Coal to kWh of Electricity)

	%
Conventional with Flue Gas Cleaning	32 to 37
SRC	
Process	68 to 75
Combustion	35 to 40
Composite	23 to 30
LBG/CCPG	30 to 42

Table 4. Economics

Technology	Capital Cost \$/kW	Mills/kWh
Conventional with Alkali Scrubbing		
EPRI (1975) (1)	485-625	28-34
FWEC (1977) (2)	886	49.9
Southern Co. (1980) (3)	912	54.6
SRC		
EPRI (1975) (1)	375-500	35-39 <sup>a</sup>
Southern Co. (1980) (3)	619	53.3 <sup>b</sup>
LBG/CCPG		
EPRI (1975) (1)		
Moving Bed	650-875	41-48
Entrained Flow	460-650	31-37
FWEC (1977, Ill. Coal) (2)		
Moving Bed	900	50.4
Fluid Bed	741	42.3
Entrained Flow	718	40.7
FWEC (1977, Mont. Coal)		
Moving Bed	953	55.3
Fluid Bed	747	44.6
Entrained Flow	748	42.8

<sup>a</sup>Cost of SRC - 2.50-2.75 \$/10<sup>6</sup> Btu

<sup>b</sup>First unit; cost of SRC - 3.08 \$/10<sup>6</sup> Btu

"Superior numbers refer to similarly-numbered references at the end of this paper!"

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Tables 3 and 4 show the energy conversion efficiencies and the cost of electricity generated for SRC and LBG/CCPG plants respectively. It should be noted that further improvements in conversion efficiencies can be expected because of developmental work presently underway.

The wide variation in the cost of electricity generated shown in Table 4 are due mainly to the use of various COE calculating procedures and assumptions regarding the type of financing, plant capacity factors, etc. However, the numbers represent best estimates and allow for a comparison of the economics of SRC and LBG/CCPG technologies with conventional combustion.

CONCLUSION

Results of the assessment have shown that in the 1980's the commercialization potential of SRC is good and that of LBG/CCPG is fair. Energy conversion efficiencies are good and very good for SRC and LBG/CCPG respectively and any specific conclusion is hard to reach about economics.

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