ECONOMIC EVALUATION OF ELECTROSTATIC PRECIPITATOR RETROFIT OPTIONS

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Abstract

Sargent & Lundy (S&L), under Electric Power Research Institute (EPRI) Project RP 3083-4, was commissioned to perform an engineering and economic analysis of electrostatic precipitator (ESP) upgrade retrofit options. This paper compares the installed capital and operating and maintenance (O&M) costs of various option to upgrade an existing ESP. The costs were derived from three sources: operating conditions and performance determined from EPRI's survey of users; design and pricing supplied by equipment vendors; and economic assumptions used in EPRI's Technical Assessment Guide. The economic analysis is based on retrofitting an existing ESP (base case - 277 SCA, 0.95 Macfm, 250 MW) with options that include wide plate spacing, taller plates, an additional field, pulse energization, temperature-controlled electrode precharging, SO_3 conditioning, and a pulse-jet baghouse inserted into an ESP casing. The capital and incremental O&M cost models were developed for all these options as functions of flue gas flow rate, plate area to be retrofitted, and other design or operating parameters. The performance (emission limits) of these retrofit options for six different coal ashes is also analyzed.

Introduction

Until recently, the options available to the utilities equipped with cold-side electrostatic precipitators have been to add new precipitator plate area or to install SO_3 injection systems to improve upon the existing performance. Many plants have been retrofitted with each of these two options. Advances in precipitator technology have resulted in more options for upgrading existing electrostatic precipitators (ESP). These options include pulse energization (PE), temperature control electrode precharging (TCEP), and in situ SO_3 conditioning (EPRICON).

The Clean Air Act Amendments (CAAA) of 1990 require utilities to reduce sulfur dioxide (SO_2) emissions significantly. Certain approaches that could be cost-effective for specific sites, such as fuel switching and sorbent injection, can severely affect the particulate collection performance of existing ESPs. Pulse-jet baghouses are an attractive upgrade option for under-performing precipitators because of their compactness and their ability to meet stringent particulate emission limits, regardless of variations in coal type or fly ash properties. These baghouses can be retrofitted into the casing of many existing precipitators (provided the casing is large enough—typically equal to or greater than 275 SCA with 9-inch spacing) by removing the ESP internals and penthouse. These baghouses are also a very promising option for compliance with possible future emission regulations on fine particulates and air toxics.

The following options analyzed for retrofitting an existing ESP are discussed in this paper:

- Wide plate spacing (12 inches and 16 inches)
- Taller plates (35-foot plates)
- Addition of a 9-foot field
- Pulse energization
- Temperature-controlled electrode precharging
- SO_3 conditioning
    - Conventional
    - In situ (EPRICON)
- Pulse-jet baghouse in an ESP casing
- New pulse-jet baghouse
- Compact baghouse (COHPAC)

The impacts of six U.S. coals on these options to meet a 0.1 to 0.01 lb/MBtu emission limit is also presented.

Process Design Premises

The base design premises were used to retrofit an existing ESP at a typical site listed in Table 1. A 250-MW unit size (950,000 acfm gas), with a 277-SCA precipitator was used as a base case unit. The specific design premises and conceptual design bases for ESP retrofits are presented in Table 2.

Retrofit with Wide Plate Spacing, Pulse Energization, Tall Plates, and an Additional Field

The design parameters given in Table 2 were submitted to vendors for retrofit ESP pricing for the following retrofit options.

- Option 1: Rebuild the existing precipitator (9-inch plate spacing) with new 12-inch plate spacing
- Option 2: Rebuild the existing precipitator (9-inch plate spacing) with new 16-inch plate spacing
- Option 3: Option 1 + pulse energization.
- Option 4: Option 2 + pulse energization.
- Option 5: Rebuild the existing precipitator (9-inch plate spacing, 30-feet high) with taller plate - about 35 feet, i.e., Option 1 + taller plates (35 feet).
- Option 6: Option 2 + taller plates (35 feet).
- Option 7: Rebuild the existing precipitator with an additional field, i.e., Option 1 + additional field (9-foot field).
- Option 8: Option 2 + additional field (9-foot field).

The scope of the work included the following:

- internal flow devices such as baffles, vanes, division plates, and/or perforated plates/discharge and collector electrodes, modification of inlet and outlet plenums with gas distribution devices, ESP roof and hopper enclosures, insulation, galleries, penthouse, etc., if required;
- structural steel supports for ESP equipment, penthouse enclosure, etc., if required;
- rappers and controls, T-R sets and controls, all electrical work within battery limits as appropriate for the retrofit option; and
- erection, including all services, materials, equipment, and facilities required to expedite, ship, route, receive, unload, store, transport, assemble, protect from weather, clean, and erect in the existing ESP casing.

The balance-of-plant cost, wherever it was necessary, was estimated by Sargent & Lundy based on recent bids and other in-house data.

Retrofit with SO_3 Conditioning

Conventional. The design parameters given in Table 2 were submitted to vendors to retrofit the SO_3 conditioning system for the base case (250 MW), and two sensitivity cases (125 MW and 500 MW). The bids were sought to supply approximately 25 ppm SO_3 conditioning system on turnkey basis. The scope of the work included the following:

- a complete SO_3 conditioning system including sulfur storage tank, SO_2 generator, blower, converter(s), injection nozzle assembly, and insulation;
- structural steel, all electrical work, control system, and erection, including all the requirements specified for the ESP option.

In Situ SO_3 Conditioning (EPRICON). EPRI has previously developed the capital cost estimate for the base case, 250 MW, unit.[1] The scope of the work included the following:

- catalyst vessel(s), insulation, ductwork, ductwork insulation, expansion joints, dampers, sootblowers, air compressors, air receiving tank;
- structured steel; all electrical work and controls, and erection (similar scope to that described in previous section).

The estimate provided by EPRI was scrutinized by Sargent & Lundy, and based on this estimate, the cost for two sensitivity cases were developed.

Retrofit with Temperature Control Electrode Precharging

EPRI with Southern Company Services has developed the capital cost estimate for Georgia Power Company in 1988.[2] The scope of the work included the following:

- heat exchanger, piping system, water pumps, water intake piping, valves, tank, temperature controller, sensors, cables, plate rapper assemblies, T-R sets, and T-R set voltage controller;
- structured steel, all electrical work and controls, and erection (similar scope to that described in the previous section).

The estimate were scrutinized by Sargent & Lundy and updated for dollar 1991 costs.

Retrofit with Pulse-Jet Baghouse in Existing ESP Casing

The design parameters given in Table 2 were submitted to vendors for retrofitting an existing ESP with a pulse-jet baghouse. The scope of the work included the following:

- a complete baghouse system from inlet flange to outlet flange, casing modifications, baffles, vanes, division plates and/or perforated plates, modifications of inlet and outlet plenums with gas distribution devices, Ryton fabric filter bags, bag cages, etc.;
- pulse air supply and distribution system, including blower, cooler, and compressors;
- instrumentation and control system;
- all electrical work; and
- erection (similar scope to that described in the previous section).

The balance-of-plant cost was estimated by Sargent & Lundy based on recent bids and other in-house data. The balance-of-plant cost included the cost of a booster fan. The bids from the ESP vendors were scrutinized to make the scope adjustment and were used to estimate the cost of this retrofit option.

COHPAC. Bids were obtained from various vendors to reduce the emission from 0.2 lb/MBtu to 0.01 lb/MBtu with the installation of a compact pulse-jet baghouse with gross air-to-cloth ratio of 11.5 ft/min. The scope of work included the following:

- a complete baghouse system from inlet flange to outlet flange including casing, hoppers, structural frame, inlet and outlet plenums with gas distribution devices, Ryton fabric filter bags, bag cages, galleries and walkway, access doors, quick removal compartment lids, insulation, dampers with pneumatic operators, bypass ducts, baghouse penthouse roof enclosure, vacuum cleaning system, painting, etc.;
- structural steel, control system, electric work, and erection (scope similar to that described in the previous section).

The balance-of-plant cost, which includes 100 feet of ductwork and a booster fan, was estimated by Sargent & Lundy based on recent bids and other in-house data.

New Pulse-Jet Baghouse. The scope of the work was similar to that for COHPAC. The balance-of-plant cost, which included 200 feet of ductwork and a booster fan, was estimated by Sargent & Lundy.

Economic Design Premises

The economic criteria used in this study conform to EPRI's guidelines in order to provide consistent comparisons with other EPRI studies on baghouses (for example, EPRI TR-100748, September 1992). The cost development and breakdown follow "EPRI Economic Premises" (Technical Assessment Guide, 1989) and are based on December 1990 dollars with a January 1, 1991, plant start-up.

Capital Cost Estimation

The process capital cost for each of the control systems is divided into four different cost areas including subsystems as follows:

Area	Subsystem
10	Particulate collector flange to flange
20	Ductwork to and from Area 10
30	Ductwork demolition
40	Booster I.D. Fan

The equipment included in each cost area was broken down further into accounts and each account was further divided into four major account categories, i.e., mechanical, electrical, structural, and sales taxes. Each of these major accounts consisted of equipment cost, material cost, and labor cost. The actual costs of the equipment in each area were estimated differently depending on the amount of information available.

Operating and Maintenance Cost

The operating costs for the particulate collection systems were separated into fixed and variable components. The incremental fixed and operating costs were developed for all retrofit options. The fixed operating costs include O&M labor, materials, filter bags, cages, and administrative-plus support-labor. These factors are based on estimates provided in EPRI's economic premises. A bag life of three years was assumed for the pulse-jet baghouse options. The maintenance cost was estimated from the process capital cost of subsystems and utility industry's experience. The operating labor costs were estimated from the past operational experience. The cost of bags and cages was linearized over the life of bags and cages.

The variable operating costs are those that depend on the unit's capacity factor and include consumables such as chemicals, power, and waste disposal. The power cost was estimated as 5.54 cents/kWh.

Collector Systems Levelized Cost

The levelized cost of the ESP and pulse-jet baghouse options is based on a 30-year plant life. The economic parameters for this analysis are presented in Table 3. The capital cost was levelized using the factor given in Table 3 (levelization factor equal to 0.165). The fixed operating cost was calculated in mills per kilowatt-year and then levelized using a factor of 0.296 (calculated based on economic parameters) to convert into mills per kilowatt-hour. The factors for the ash disposal and electricity were 0.296 and 0.307, respectively. The total levelized bus-bar cost is determined by summing the levelized total capital requirement, the levelized fixed operating cost, and the levelized variable operating cost.

Cost Models

The capital cost models for all retrofit options were developed as an analytical tool to predict capital cost and incremental O&M cost.[3] These models provide a means of estimating total capital requirements for a particulate collection system and a method of analyzing the effects of various design variables on system cost.

Economic Comparison of Retrofit Options

This study started with an existing precipitator that needed upgrading. The base case ESP has a specific collection area (SCA) of 277 $ft^2/1000$ acfm with a weighted-wire design that had plates spaced 9 inches apart (center-to-center). In a second case, an ESP with 150 SCA was also considered.

Base Case Design

The capital and levelized costs for various options are presented in Figures 1 and 2, respectively, for the base case design. The incremental capital cost for adding new plate area in the form of taller plates or an additional field is proportional to the plate area. For example, to increase the height from 30 feet to 35 feet, i.e., to add 17% to the plate area, results in an incremental cost of 17% over the cost for wide plate spacing. Similarly, if two fields need to be added, then the increase in levelized cost would be twice the difference between the levelized cost of an additional field with wide plate spacing and only wide plate spacing for the existing ESP. As can be seen from Figures 2 and 3, the incremental capital and levelized cost for all pulse-jet baghouse options are much higher than the ESP retrofit option. However, such a conclusion may be misleading without knowing the effect of coal type and the outlet emission level.

Impact of Coal Type

The type of coal used in the boiler determines the amount of flue gas and fly ash generated and the chemical and physical characteristics of the fly ash. These properties affect the size and operating requirements for the particulate collection device. As part of this study, six coals representing the range of coal compositions commonly found in U.S. utility applications were selected to determine how the performance of the particulate collection device is affected by different coal types. A computer simulation was performed for each option and each coal to determine the ESP's performance and emission. ESPM (Electrostatic Precipitator Model), a computation tool developed by EPRI and Southern Research Institute (SRI), was used to predict the performance. The study's intent was to characterize the performance of the existing precipitator and upgrade options with the range of outlet emissions of 0.1 to 0.01 lb/MBtu.

Table 4 shows the performance of various coals with different retrofit options. It can be seen that typical low resistivity coals (e.g., Illinois #6) will meet the 0.1 lb/MBtu emission level with existing ESP and the 0.03 lb/MBtu emission level with an addition of a 9-foot field. However, to meet the 0.01 lb/MBtu emission level, more SCA in the form of additional fields is required. For typical high resistivity coals (e.g., high resistivity Powder River Basin coals), the existing ESP will not be able to meet even the 0.1 lb/MBtu emission level. As shown in Table 5, SO_3 conditioning will be required to achieve the 0.1 lb/MBtu emission level, addition of two fields and SO_3 conditioning will be required to achieve the 0.03 lb/MBtu emission level, and three fields with SO_3 conditioning will be required to meet the 0.01 lb/MBtu emission level. It should be noted that the TCEP option will have a similar performance, which could be achieved by SO_3 conditioning. However, due to the commercial status and immediate availability of the technology, SO_3 conditioning was chosen for cost comparison.

Figures 3 and 4 show the capital and levelized cost comparison for various retrofit options suitable for two typical low and high resistivity coals. It should be noted that the baghouse options include a 10% process contingency to cover their applicability at the 0.01 lb/MBtu emission level. Figure 3 indicates that, if capital cost was the only consideration, a pulse-jet baghouse (PJBH) in the ESP casing and COHPAC would be an alternative for high resistivity coal required to meet the 0.03-to-0.01 lb/MBtu emission level. For low resistivity coals with emission levels between 0.1 and 0.01 lb/MBtu and for high resistivity coals with emission levels between 0.1 and 0.03 lb/MBtu, ESP options will be lower in capital cost than PJBH options (Ryton bags are used for fabric filter options). However, the levelized cost indicates that only the COHPAC option would be an alternative for high resistivity coals required to meet the 0.01 lb/MBtu emission level (see Figure 4). This is primarily because of the high operating cost of baghouses due to bag replacement and auxiliary power. Since the COHPAC is much smaller than conventional PJBHs, the lower operating cost makes it comparable with the ESP upgrade option.

Large numbers of old utility units have much smaller ESPs, that is, ESPs with 150 SCA or less. Table 6 shows the effect of emission levels on the applicability of various retrofit options for various coals for these smaller ESPs.

Figures 5 and 6 show the capital and levelized cost comparison for various retrofit options suitable for two typical low and high resistivity coals. Figure 6 indicates that, if capital cost was the only consideration, PJBH options would be an alternative for high resistivity coals required to meet the 0.03-0.1 lb/MBtu emission level and for low resistivity coals required to meet the 0.01 lb/MBtu emission level. However, the levelized cost indicates that only the COHPAC option will have a lower cost than

ESP upgrades for the high resistivity coals required to meet the 0.01 lb/MBtu emission level (see Figure 6).

It should be noted that this analysis does not take into account the cost of the outage required to incorporate the retrofit changes. If the cost of outage is taken into account, then COHPAC and the new baghouse options would be more cost effective than the ESP upgrade options to meet the 0.01 lb/MBtu emission level.

Conclusions

The major conclusions drawn from this study include the following:

- Large number of ESP upgrade options are available for existing ESPs and the choice of option depends on the coal type and emission level.
- For low resistivity coals, upgrading the existing ESP may be the lowest cost retrofit option to meet an emission level between 0.1 and 0.01 lb/MBtu.
- For high resistivity coals, if the existing ESP has a plate area of 277 SCA and if the required emission level is between 0.1 and 0.03 lb/MBtu, then the ESP upgrade is the lowest cost option. If the required emission level is 0.01 lb/MBtu, then COHPAC may be the lowest cost option.
- For high resistivity coals, if the existing ESP has a plate area of 150 SCA and the required emission level is between 0.03 and 0.01 lb/MBtu, COHPAC and PJBHs in ESP casing may be the lowest cost option.
- If the outage requirement is taken into account, then COHPAC and replacement of existing ESP (150 SCA) with new PJBHs becomes an attractive retrofit option for high resistivity coals to meet an emission level between 0.03 and 0.01 lb/MBtu.

Acknowledgements

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References

1. "In Situ SO_3 Conditioning (EPRICON)," Internal correspondence between EPRI and Sargent & Lundy, January 1992.

2. "Cost Estimates for Full-Scale Demonstration of the Temperature-Controlled Electrode Precharger at Georgia Power Company," Internal correspondence between EPRI and Sargent & Lundy, July 1992.
3. "Economic Evaluation of Particulate Control Technologies — Retrofit Units," Draft Report RP-3083-4, EPRI. Prepared by Sargent & Lundy, Chicago, Illinois, September 1992.

Table 1

General Design Premises - Base Case

Application	Utility boiler
Location	Kenosha, WI
Elevation	Approx. 600 feet
Particulate	Fly ash
Boiler size	250 MW
Boiler type	Pulverized coal
Volume (acfm)	950,000
Temperature (°F)	282
Status of development	Commercial
Plant life	30 years

Table 2

ESP - Specific Design Parameters

Parameter Description	Sensitivity Case 1 (125 MW)	Base Case (250 MW)	Sensitivity Case 2 (500 MW)
Unit Rating (MW)	125	250	500
Flue Gas Flow Rate (1000 acfm)	475	950	1,900
Flue Gas Flow Rate (1000 acfm)	322	643	1,286
Gas Temperature (°F)	282	282	282
MCR Gas Pressure (in. H_2O)	-20	-20	-20
Fly Ash Loading (lb/hr)	9,556	19,111	38,222
Grain Loading (gr/scf)	3.47	3.47	3.47
Weighted Wire Precipitator	YES	YES	YES
Plate Spacing (in.)	9	9	9
Mechanical Field Length (ft)			
1st	6	6	6
2nd	9	9	9
3rd	9	9	9
4th	6	6	6
Plate Height (ft)	30	30	30
Number of Passages per Casing	73	73	146
Number of Casing	1	2	2
SCA ft^2/1000 acfm	277	277	277
Gas Velocity (fps)	4.8	4.8	4.8

Table 3

Economic Parameters

Commercial Operating Date	January 1991
Present Value Data	January 1991
Construction Period	
250 and 500 MW	3.0 Years
125 MW	2.0 Years
Total Life	30 Years
Discount Rate After Tax	9.8%/year
General Rate of Inflation	5.0%/year
Real Escalation Rate	
Power	0.3%/year
Other	0%/year
Capital Levelization Factor	0.165
Design Capacity Factor	65%

Table 4

Emissions for Retrofit Options for Various Coals
Base Case ESP - 277 SCA (950,000 acfm)

		OPTIONS					
COAL TYPES	Resistivity (ohm-cm)	Existing ESP (lb/MBtu)	35' Tall Plates (lb/MBtu)	9' Field Addition (lb/MBtu)	Pulse Energization (lb/MBtu)	TCEP (lb/MBtu)	SO3 Conditioning (lb/MBtu)
Appalachian Medium Sulfur	1.00 E+10	0.027	0.021	0.01	N/A	N/A	N/A
Appalachian Low Sulfur	7.5E+11	0.27	0.194	0.113	0.164	0.046	0.044
Wasatch Plateau	2.30E+10	0.064	0.051	0.03	N/A	N/A	N/A
East Central Illinois No.6	1.00E+10	0.052	0.031	0.022	N/A	N/A	N/A
No. Dakota Lignite	1.00E+10	0.094	0.062	0.036	N/A	N/A	N/A
Wyoming	2.00E+10	0.073	0.057	0.03	N/A	N/A	N/A
Powder River Basin	3.00E+11	0.15	0.12	0.081	0.094	0.047	0.091

N/A = Not Applicable

Table 5

Retrofit Options for Various Coals - Effect of Emission Level
Base Case ESP - 277 SCA (950,000 acfm)

		EMISSION LEVEL		
COAL TYPES	Resistivity (ohm-cm)	0.1 lb/MBtu	0.03 lb/MBtu	0.01 lb/MBtu
Appalachian Medium Sulfur	1.00E+ 10	Existing (4.84, 0.56)	Existing (4.84, 0.56)	9' Field Addition (6.36, 0.8)
Appalachian Low Sulfur	7.5E+11	SO3 Conditioning (6.52, 0.94)	9' Field Addition + SO3 Conditioning (8.04, 1.18)	Two Fields Add. SO3 Conditioning (9.56, 1.42)
Wasatch Plateau	2.30E+10	Existing (4.84, 0.56)	9' Field Addition (6.36, 0.8)	Three Fields Add. (9.4, 1.28)
East Central Illinois No.6	1.00E+10	Existing (4.84, 0.56)	9' Field Addition (6.36, 0.8)	Two Fields Add. (7.88, 1.04)
No. Dakota Lignite	1.00E+10	Existing (4.84, 0.56)	9' Field Addition + 35' Plate Spacing (7.37, 0.94)	Three Fields Add. (9.4, 1.28)
Wyoming Powder River Basin	2.00E+10	Existing (4.84, 0.56)	9' Field Addition (6.36, 0.8)	Three Fields Add. (9.4, 1.28)
	3.00E+11	SO3 Conditioning (6.52, 0.94)	Two Fields Add. SO3 Conditioning (9.56, 1.42)	Three Fields Add. SO3 Conditioning (11.08, 1.66)

Pulse Jet Baghouse in ESP Casing (9.67, 1.88) - meets 0.03 to 0.01 lb/MBtu emission level

New Pulse Jet Baghouse with 200 ' of Ductwork and Booster Fan (13.07, 2.22) - meets 0.03 to 0.01 lb/MBtu emission level

COHPAC (9.00, 1.63) - meets 0.03 to 0.01 lb/MBtu emission level

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Note: The first number in bracket represents capital cost in million dolllars and
the second number represents levelized cost in mill/kWh
SO3 Conditioning is comparable to TCEP

Table 6

Retrofit Options for Various Coals - Effect of Emission Level
Base Case ESP - 150 SCA (950,000 acfm)

		EMISSION LEVEL		
COAL TYPES	Resistivity (ohm-cm)	0.1 lb/MBtu	0.03 lb/MBtu	0.01 lb/MBtu
Appalachian Medium Sulfur	1E+10	Two Fields Add. (7.88, 1.04)	Two Fields Add. (7.88, 1.04)	Three Fields Add. (9.4, 1.28)
Appalachian Low Sulfur	7.5E+11	Two Fields Add. SO3 Conditioning (9.56, 1.42)	Three Fields Add. SO3 Conditioning (11.08, 1.66)	Four Fields Add. SO3 Conditioning (12.6, 1.90)
Wasatch Plateau	2.30E+10	Two Fields Add. (7.88, 1.04)	Three Fields Add. (9.4, 1.28)	Five Fields Add. (12.44, 1.76)
East Central Illinois No.6	1.00E+10	Two Fields Add. (7.88, 1.04)	Three Fields Add. (9.4, 1.28)	Four Fields Add. (10.92, 1.52)
No. Dakota Lignite	1.00E+10	Two Fields Add. (7.88, 1.04)	Three Fields Add. (9.4, 1.28)	Five Fields Add. (12.44, 1.76)
Wyoming Powder River Basin	2.00E+10	Two Fields Add. (7.88, 1.04)	Three Fields Add. (9.4, 1.28)	Five Fields Add. (12.44, 1.76)
	3.00E+11	Two Fields Add. SO3 Conditioning (9.56, 1.42)	Four Fields Add. SO3 Conditioning (12.6, 1.90)	Five Fields Add. SO3 Conditioning (14.12, 2.14)

New Pulse Jet Baghouse with 200' of Ductwork and Booster Fan (13.07, 2.22) - meets 0.03 to 0.01 lb/MBtu emission level

COHPAC (9.00, 1.63) - meets 0.03 to 0.01 lb/MBtu emission level

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Note: The first number in bracket represents capital cost in million dolllars and
the second number represents levelized cost in mill/kWh
SO3 Conditioning is comparable to TCEP

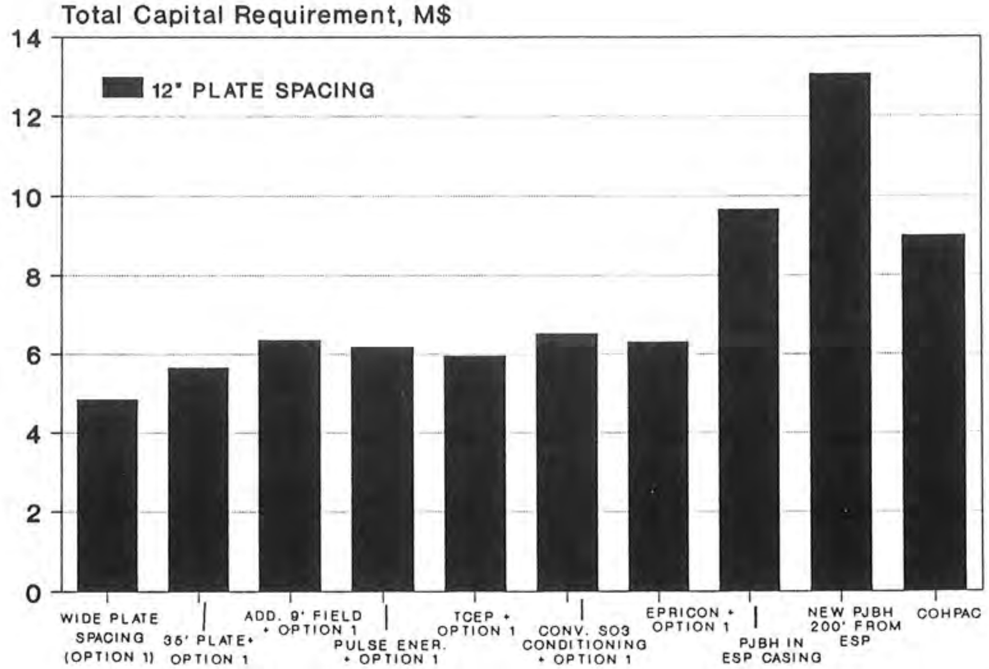

Figure 1: Capital Cost Comparison of Various Retrofit Options for Base Case (250 MW, 0.95 Macfm)

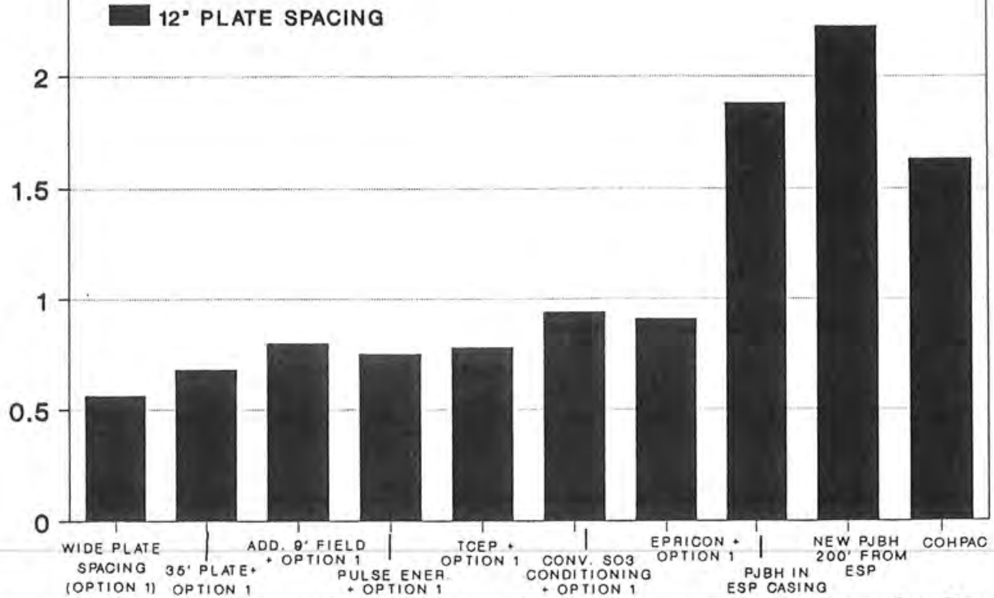

Figure 2: Levelized Cost Comparison of Various Retrofit Options for Base Case (250 MW, 0.95 Macfm)

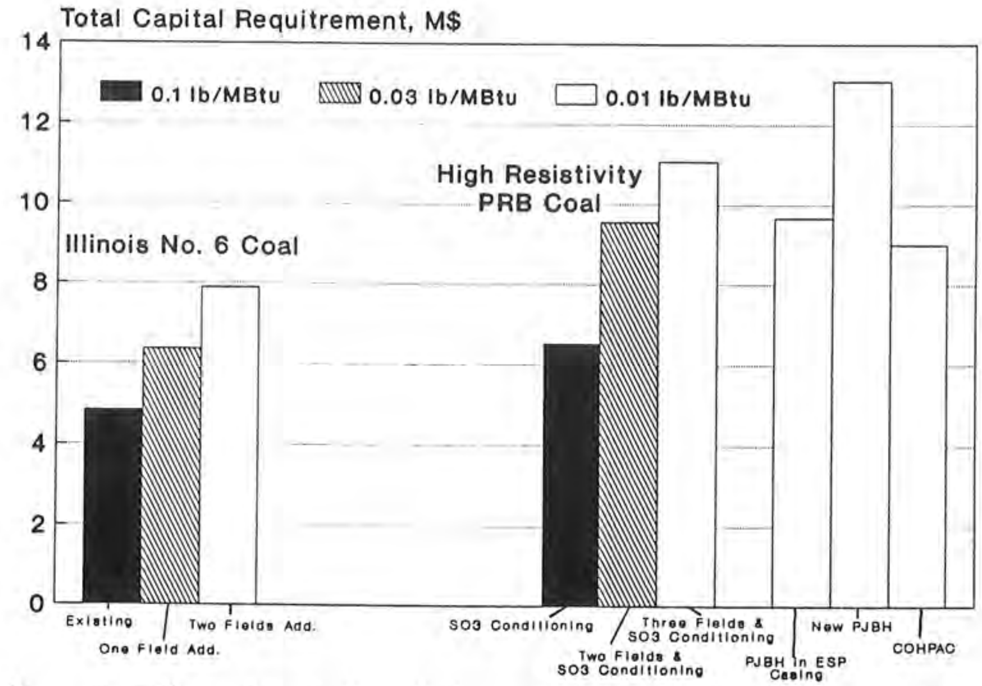

Figure 3: Effect of Emission Limit on Capital Cost for Two Typical Coals (Base ESP - 277 SCA, 0.95 Macfm)

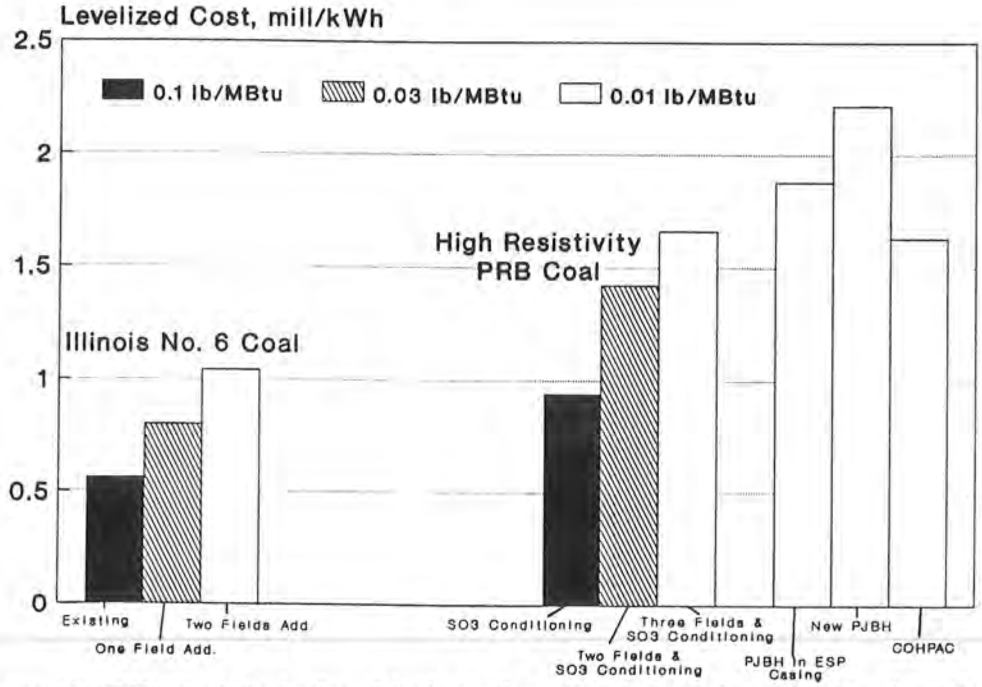

Figure 4: Effect of Emission Limit on Levelized Cost for Two Typical Coals (Base ESP - 277 SCA, 0.95 Macfm)

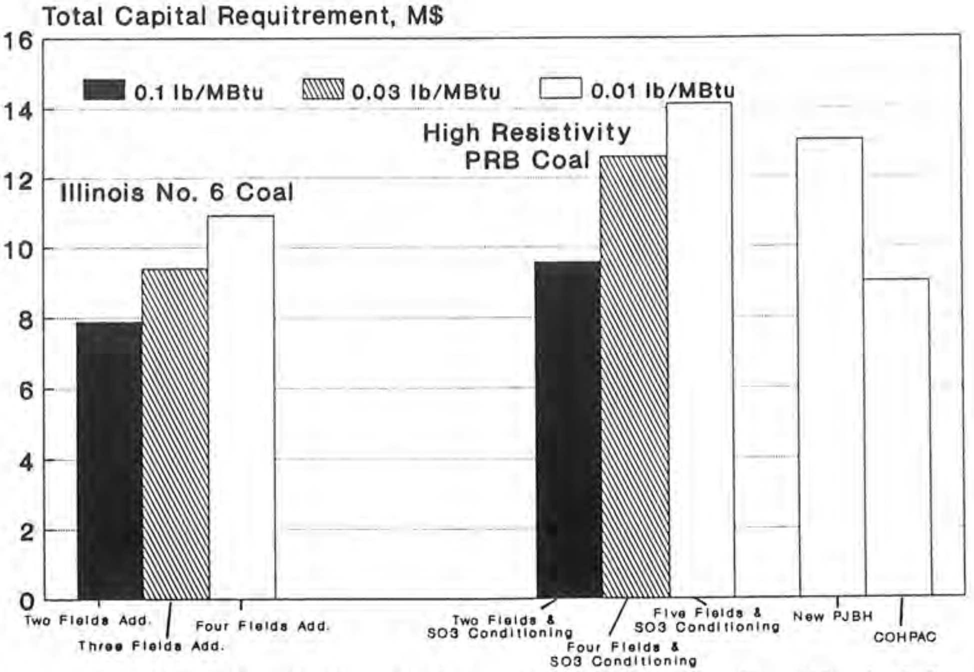

Figure 5: Effect of Emission Limit on Capital Cost for Two Typical Coals (Base ESP - 150 SCA, 0.95 Macfm)

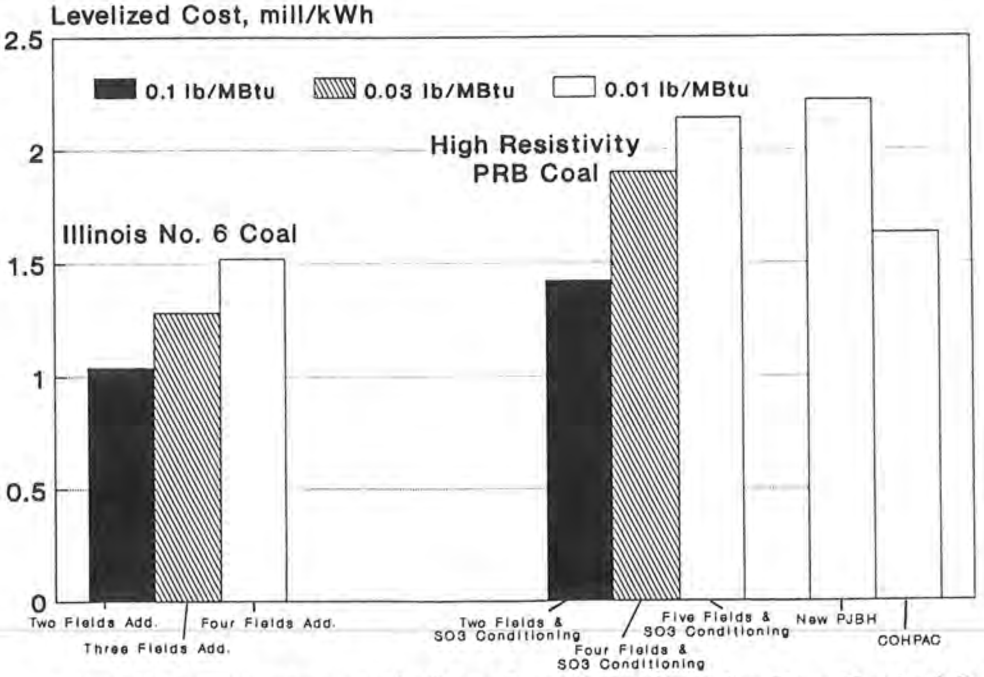

Figure 6: Effect of Emission Limit on Levelized Cost for Two Typical Coals (Base ESP - 150 SCA, 0.95 Macfm)