

**THE NOXSO COMBINED SO<sub>2</sub>/NO<sub>x</sub> REMOVAL FLUE GAS CLEANUP  
SYSTEM COMMERCIAL DEMONSTRATION**

James B. Black  
John L. Haslbeck  
Mark C. Woods  
NOXSO Corporation  
P.O. Box 469  
Library, Pennsylvania 15129

Gerard G. Elia  
Department of Energy  
Pittsburgh Energy Technology Center  
P.O. Box 10940  
Pittsburgh, PA 15236-0940

Robert A. Malinak  
Michael D. Morrell  
Leonard A. Papapietro  
Morrison Knudsen Corporation  
MK-Ferguson Group  
1500 West 3rd Street  
Cleveland, Ohio 44113-1406

**ABSTRACT**

The NOXSO process is a dry, post-combustion flue gas treatment technology which uses a regenerable sorbent to simultaneously adsorb sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) from the flue gas of a coal-fired utility boiler. The process does not produce any waste products. The SO<sub>2</sub> is converted to a saleable sulfur by-product and the NO<sub>x</sub> is reduced to nitrogen and oxygen. The process is suited for either retrofit or new facility applications.

Testing was recently completed at the NOXSO pilot plant at Ohio Edison's Toronto Power Plant. Results showed that the process can economically remove more than 90% of the acid rain precursor gases. Removal efficiencies as high as 99+ % for SO<sub>2</sub> and 95% for NO<sub>x</sub> were demonstrated during more than 6500 hours of testing.

The NOXSO Clean Coal Technology Project will demonstrate the NOXSO process on a commercial-scale. The \$66 million project is co-funded by the U.S. Department of Energy (DOE) under round III of the Clean Coal Technology program. The DOE manages the project through the Pittsburgh Energy Technology Center (PETC). The NOXSO process, pilot plant results, commercial-scale plant layout, and commercial-scale economics are described in this paper.

## INTRODUCTION

The NOXSO process is a dry, post-combustion flue gas treatment technology which uses a regenerable sorbent to simultaneously adsorb sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>) from the flue gas of a coal-fired utility boiler. In the process, the SO<sub>2</sub> is converted to a sulfur by-product (elemental sulfur, sulfuric acid, or liquid SO<sub>2</sub>) and the NO<sub>x</sub> is reduced to nitrogen and oxygen. Based on pilot plant results, the process can economically remove 90% of the acid rain precursor gases from the flue gas stream in a retrofit or new facility.

Process development began in 1979 starting with laboratory-scale tests and progressing to pre-pilot scale tests (3/4-MW) and a life cycle test. Each of these test programs [1,2,3] has provided data necessary for the process design. Tests of the NO<sub>x</sub> recycle concept which, is inherent to the NOXSO process, have been conducted on small boilers at PETC and the Babcock & Wilcox (B&W) Research Center in Alliance, Ohio [4]. A 5 MW Proof-of-Concept (POC) pilot plant test at Ohio Edison's Toronto Plant in Toronto, Ohio was recently completed [5]. The Clean Coal Project is currently in the project definition phase incorporating recently obtained pilot plant data into a commercial-scale design.

The objective of the NOXSO Clean Coal Technology Project is to demonstrate the NOXSO process on a commercial-scale. At the completion of this project, economic and operating data will be available to assist utilities in making decisions regarding the choice of flue gas cleanup technology.

The project will be managed through the Pittsburgh Energy Technology Center (PETC) of the Department of Energy (DOE) through a Cooperative Agreement. The Cooperative Agreement is in the process of being assigned to NOXSO by Morrison Knudsen Corporation - MK-Ferguson Group (MK-Ferguson). With the reorganization of the project group, NOXSO will provide overall project management. MK-Ferguson will provide engineering and construction services and W.R. Grace & Co.-Conn. will be the sorbent supplier. NOXSO will conduct the operation phase of the project.

Funding for the \$66 million project will be provided by the DOE, the NOXSO development team, the Ohio Coal Development Office (OCDO), the Electric Power Research Institute (EPRI), and the Gas Research Institute (GRI).

## **NOXSO PROCESS DESCRIPTION**

Flue gas is drawn from the power plant duct work either upstream or downstream of the particulate collection device by a flue gas booster fan. Figure 1 shows a process flow diagram with flue gas drawn from the particulate collection device discharge. Figure 1 shows single pieces of equipment, however multiples will be used as required to provide the necessary capacity. Tail gas from the sulfur by-product plant is mixed with the flue gas at the booster fan suction. The flue gas then passes through a two-stage, fluidized bed adsorber where  $\text{SO}_2$  and  $\text{NO}_x$  are simultaneously removed using a high surface area  $\gamma$ -alumina sorbent impregnated with an alkali material. Water sprays into the fluid beds maintain a 250°F temperature by evaporative cooling. The cleaned flue gas passes through a particulate separator and is returned to the power plant chimney. Sorbent fines removed by the separator are directed to the dense phase transport system.

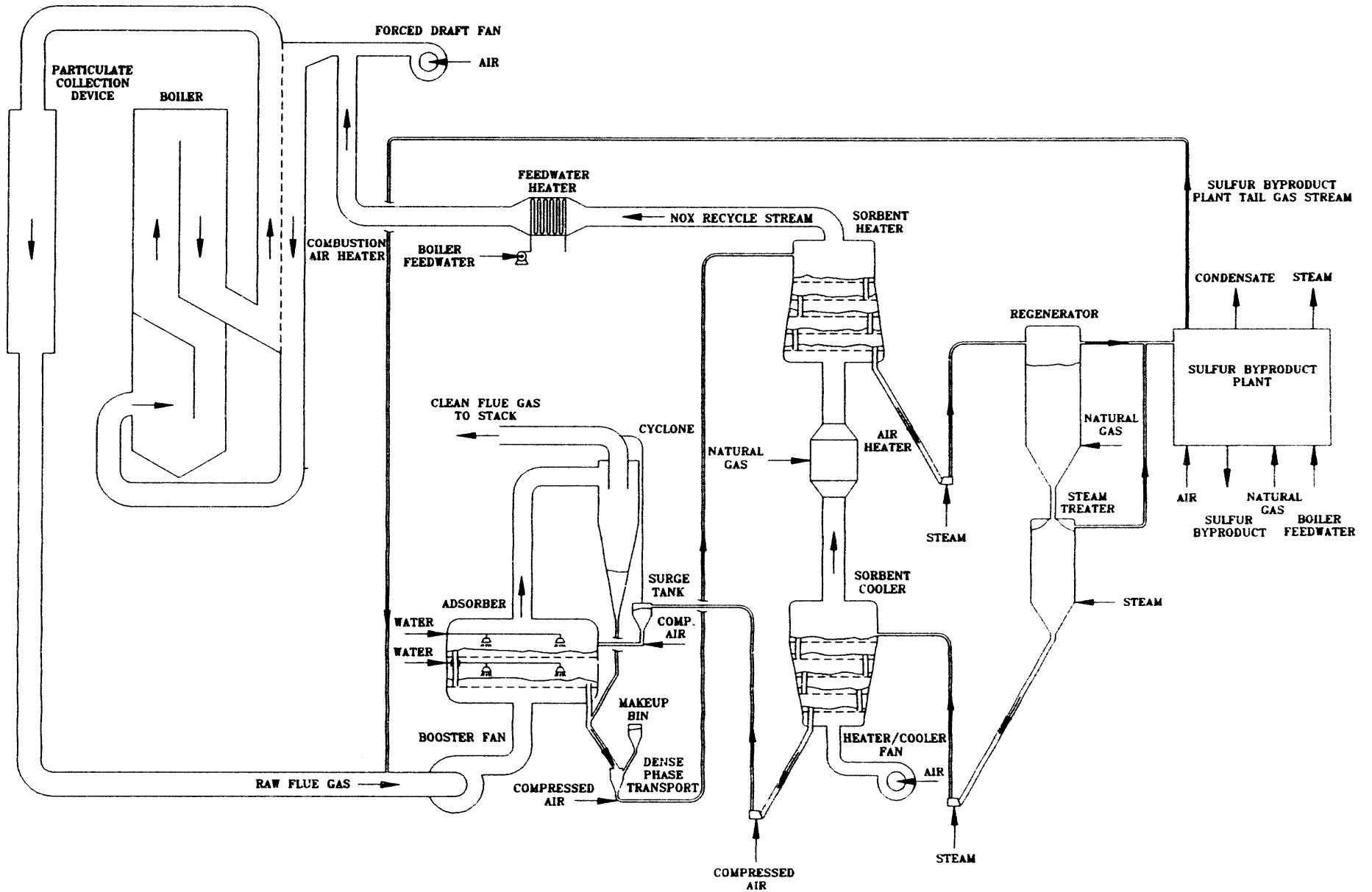


Figure 1. Process Flow Diagram

Sorbent from the adsorber is transported to the sorbent heater by a dense phase pneumatic conveying system. Make-up sorbent to maintain the sorbent inventory is added downstream of the adsorber. The sorbent heater is a variable area five-stage fluidized bed where a hot air stream is used to raise the sorbent temperature to 1150°F. During the heating process, NO<sub>x</sub> and loosely bound SO<sub>2</sub> are desorbed and transported away in the heating gas (NO<sub>x</sub> recycle) stream. This hot air stream at 500°F can be used to heat a slip stream of the power plant's main condensate before being injected into the combustion air system upstream of the combustion air preheater. The NO<sub>x</sub> recycle stream provides approximately 30% of the required combustion air. Upon entering the boiler, a portion of the recycled NO<sub>x</sub> is converted to nitrogen (N<sub>2</sub>) reaction with free radicals in the reducing atmosphere of the combustion chamber.

Once the sorbent reaches a regeneration temperature of 1150°F, it is transported by means of a J-valve to the moving bed regenerator. In the regenerator, sorbent is contacted with natural gas in a countercurrent manner. The natural gas reduces sulfur compounds on the sorbent (mainly sodium sulfate) to primarily SO<sub>2</sub> and hydrogen sulfide (H<sub>2</sub>S) with some carbonyl sulfide (COS) also formed. Some of the sodium sulfate (Na<sub>2</sub>SO<sub>4</sub>) is reduced to sodium sulfide (Na<sub>2</sub>S) which is subsequently hydrolyzed in a moving bed steam treatment reactor which follows the regenerator. A concentrated stream of H<sub>2</sub>S is obtained from the reaction of steam with Na<sub>2</sub>S. The offgases from the regenerator and steam treater are combined and sent to a sulfur by-product plant which produces elemental sulfur, sulfuric acid, or liquid SO<sub>2</sub>. The tail gas stream from the sulfur by-product plant is recycled to the suction of the flue gas booster fan.

From the steam treatment vessel, the sorbent is transported by means of a J-valve to the sorbent cooler. The cooler is a five-stage variable area fluidized bed which uses ambient air to cool the sorbent. The hot air exiting the cooler is further heated by a natural gas fired in-duct heater before being used to heat the sorbent in the fluidized bed sorbent heater. The sorbent temperature is reduced in the sorbent cooler to the adsorber temperature of 250°F. Sorbent from the sorbent cooler is transported by means of a J-valve to a surge tank located above the adsorber. The surge tank is used as a source and sink for

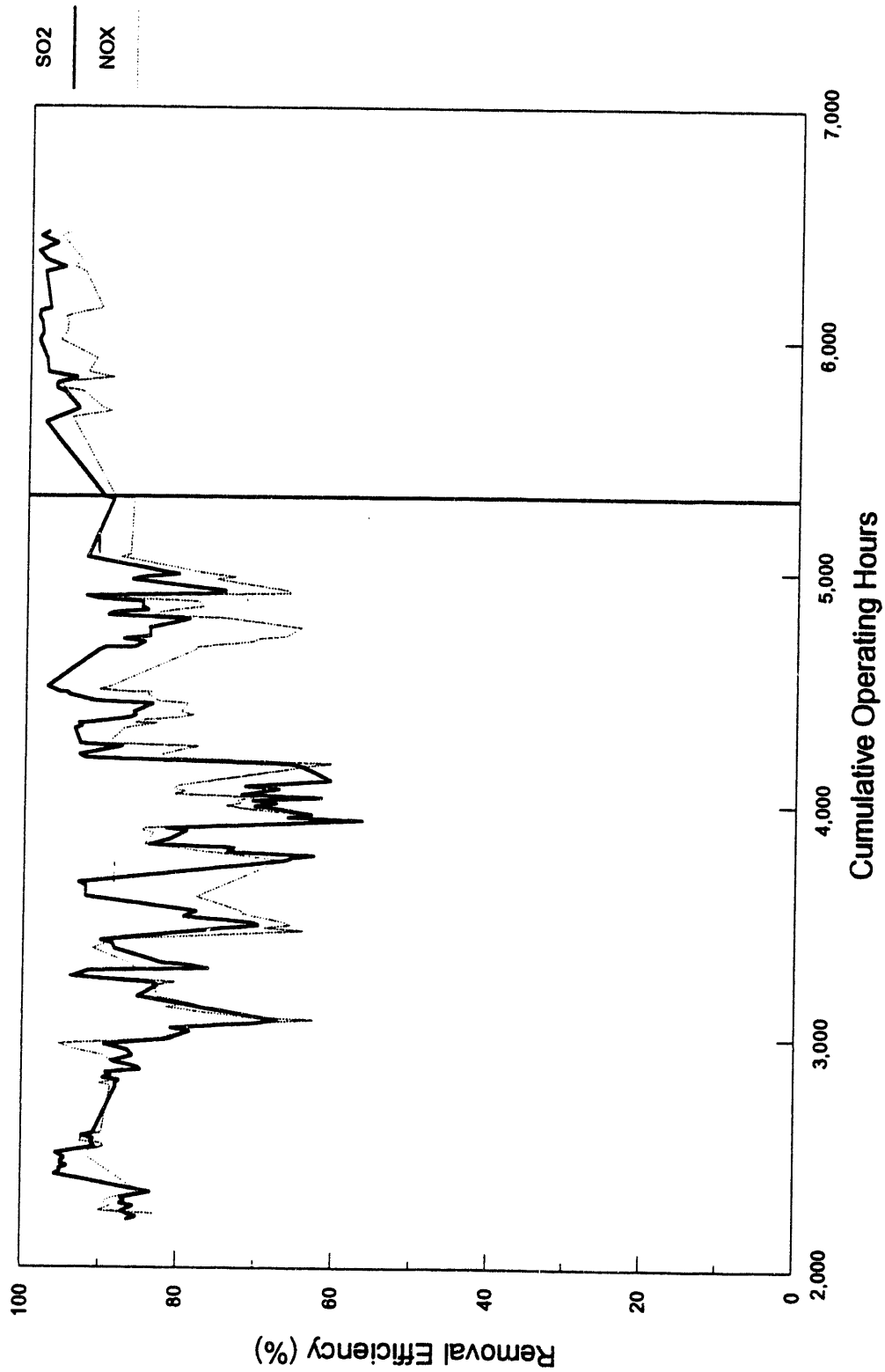
sorbent to maintain constant bed levels in the other process vessels. From the surge tank, sorbent flow to the adsorber is regulated using an L-valve, thus completing one full cycle.

## PILOT PLANT SO<sub>2</sub>/NO<sub>x</sub> ADSORPTION RESULTS

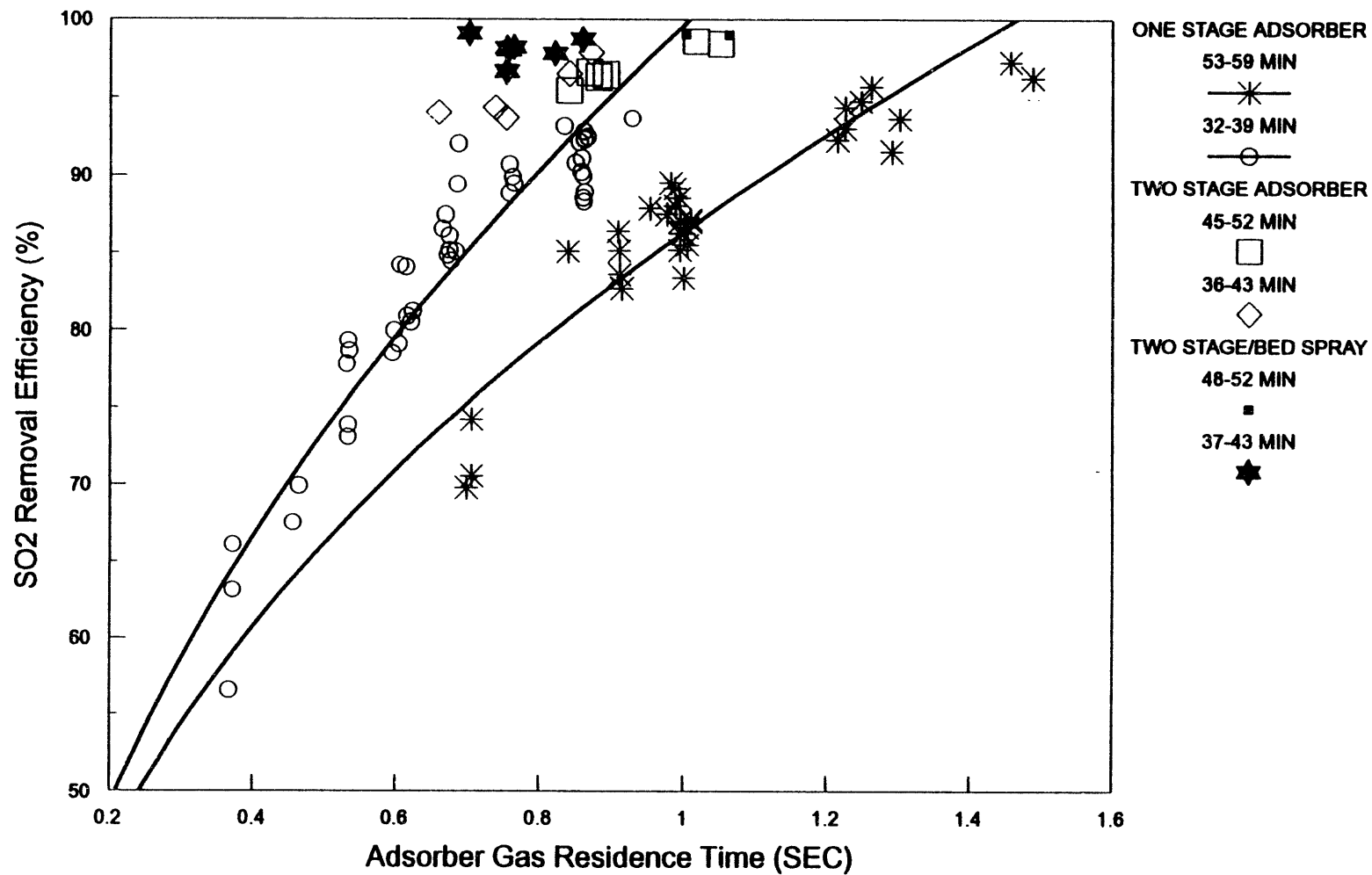
NOXSO operated a 5 MW pilot plant at Ohio Edison's Toronto Plant from September 1991 until August 1993. A major objective was to determine the effect of operating variables on the SO<sub>2</sub> and NO<sub>x</sub> removal efficiency. Operating variables studied included sorbent circulation rate, gas residence time, solids residence time, number of adsorber grids, adsorber temperature, and pollutant concentration.

Figure 2 is a plot of SO<sub>2</sub>/NO<sub>x</sub> removal efficiencies versus cumulative plant operating hours. The data are averages computed over a minimum of four hours and a maximum of twelve hours. The data are selected from periods in which the plant sulfur and nitrogen oxides mass balance closures were 100 ±15%. The removal efficiencies in Figure 2 vary with time due to the fact that NOXSO process operating conditions were intentionally varied to quantify their effect on process performance. The process operating conditions varied and included flue gas flow rate, sorbent circulation rate, adsorber sorbent inventory, adsorber bed temperature, and adsorber inlet SO<sub>2</sub> and NO<sub>x</sub> concentrations. Also tested were two different adsorber configurations: 1) a single-stage fluidized bed with flue gas cooling via water spray into the ductwork approximately 90 feet upstream of the adsorber, and 2) two fluidized beds in series with cooling via direct water spray into the beds. The vertical line in Figure 2 marks the time at which the second adsorber grid and in-bed water sprays were installed. Note that both SO<sub>2</sub> and NO<sub>x</sub> removal efficiencies improved with the installation of the second grid.

Figure 3 is a plot of SO<sub>2</sub> removal efficiency versus adsorber gas residence time. When the data are segregated into groups with essentially the same sorbent residence time, an equation of the form,  $y = ax^{1/N}$ ,  $N > 1$ , satisfactorily represents the data. This is true for the entire database of 117 data points, although for clarity only a portion of the database is



**Figure 2. NOXSO Pilot Plant  
SO2/NOx Removal Efficiencies**



**Figure 3. SO2 Removal VS Gas/Sorbent Residence Time  
77 Data Points Used In Non-Linear Regression**



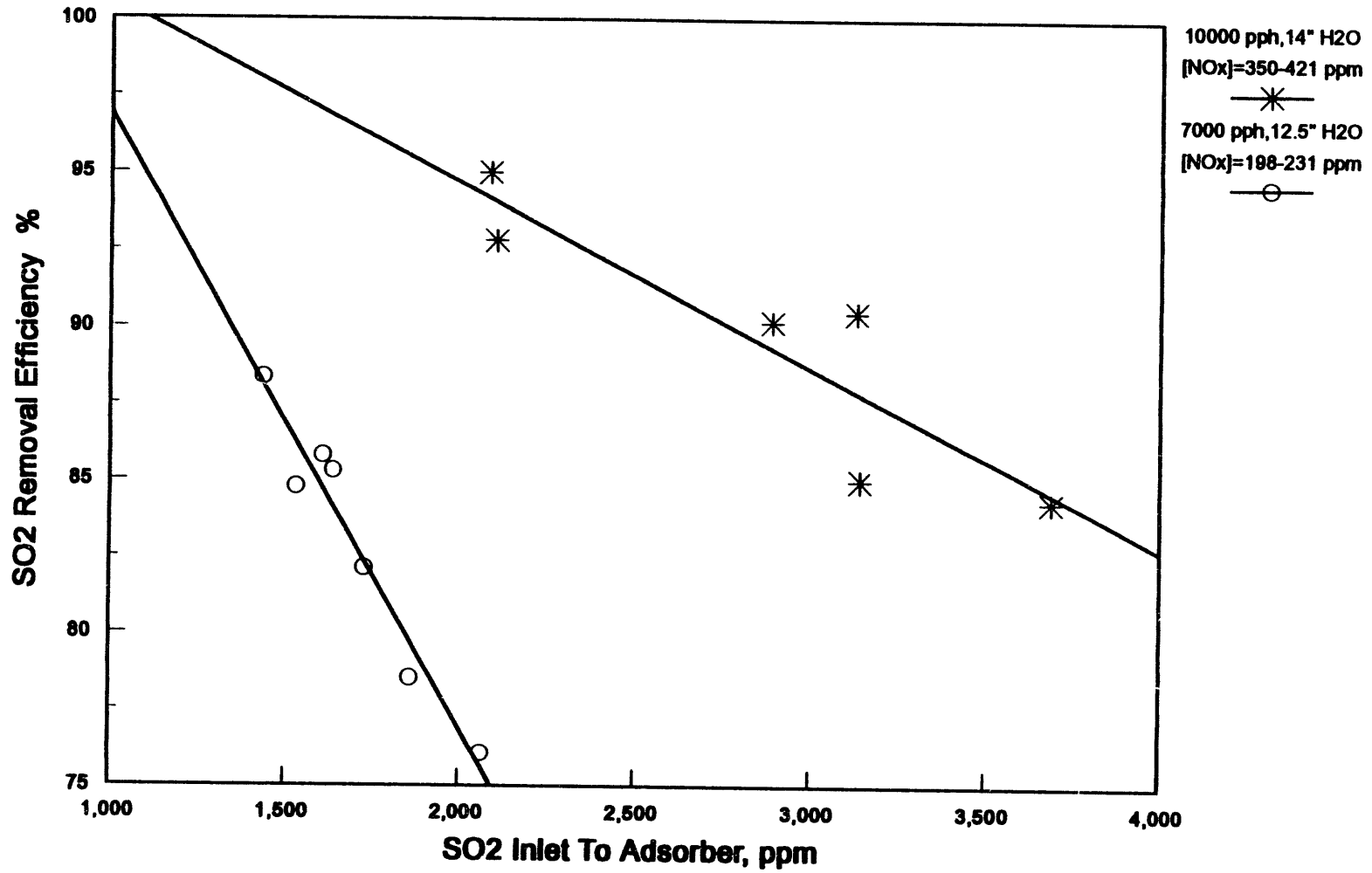
shown in Figure 3. The correlation coefficients ( $r^2$ ) for the two curves shown in the figure are 0.85 (53-59 min) and 0.89 (32-39 min).

The strictly empirical correlation is best for intermediate values of SO<sub>2</sub> removal and short sorbent residence times when the relationship between SO<sub>2</sub> removal and gas residence time is nearly linear. The correlation is worst for high values of SO<sub>2</sub> removal and gas residence time, since the correlation gives no limiting value of removal efficiency, although the actual limit is 100%.

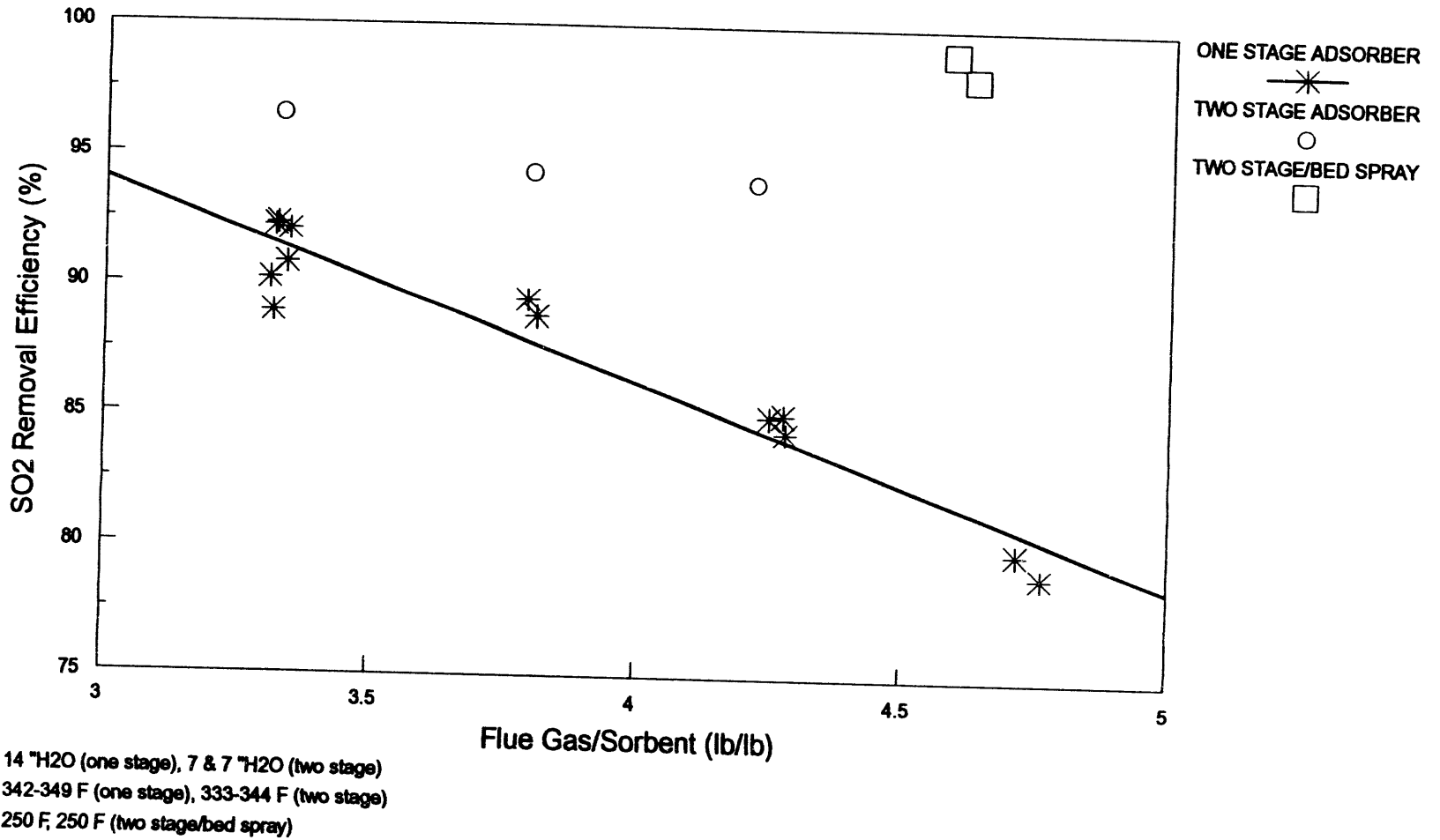
In addition to gas and sorbent residence time, SO<sub>2</sub> removal efficiency varies with the concentration of SO<sub>2</sub> in the flue gas inlet to the adsorber. Figure 4 shows that SO<sub>2</sub> removal efficiency is inversely proportional to the inlet SO<sub>2</sub> concentration. The proportionality constant (the slope of the lines in Figure 4) varies depending upon the ratio of flue gas flow to sorbent circulation rate.

Figure 3 also shows that the two-stage adsorber consistently out-performed the single-stage adsorber. This is seen more clearly in Figure 5 which shows the results of an identical series of tests on the one and the two-stage adsorber. For the one-stage adsorber, SO<sub>2</sub> removal efficiency is shown to be inversely proportional to the flue gas to sorbent mass ratio, all other operating variables are constant as noted at the bottom of the figure. When the tests were repeated with the two-stage adsorber, SO<sub>2</sub> removal efficiencies were higher by 5 to 10 absolute percentage points. This improvement is due to 1) better gas distribution with the addition of the second grid plate and 2) counter-current flow of gas and sorbent so that in the bottom bed of the adsorber partially sulfated sorbent is in contact with the highest concentration of pollutants providing the driving force to put more sulfur on the sorbent. All the data in Figure 5 were obtained at equal adsorber sorbent inventories, therefore the pressure drop across the two-stage adsorber is only greater than the one stage by the pressure drop across the second grid plate. (2-3" H<sub>2</sub>O).

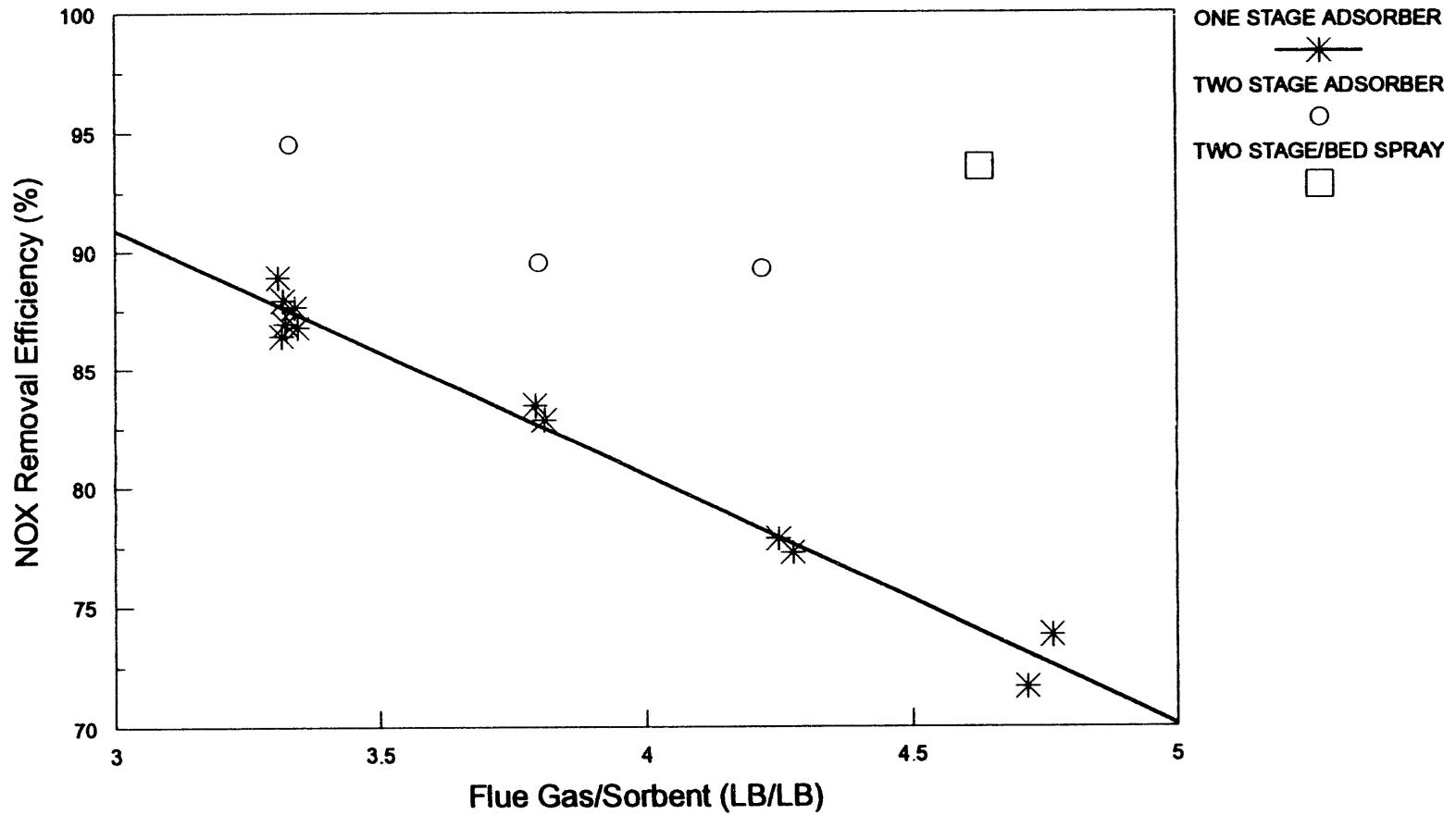
Figure 6 shows NO<sub>x</sub> removal efficiency as a function of flue gas to sorbent mass ratio. As is the case with SO<sub>2</sub>, NO<sub>x</sub> removal efficiency decreases in proportion to the increase in mass



**Figure 4. SO2 Removal as a Function of Inlet SO2  
All Tests at 7000 scfm**



**Figure 5. NOXSO Pilot Test  
SO2 Removal Efficiency  
and Two-Stage Adsorbers**



14"H<sub>2</sub>O (one stage), 7 & 7 "H<sub>2</sub>O (two stage)  
342-349 F (one stage), 333-344 F (two stage)  
250 F, 250 F (two stage/bed spray)

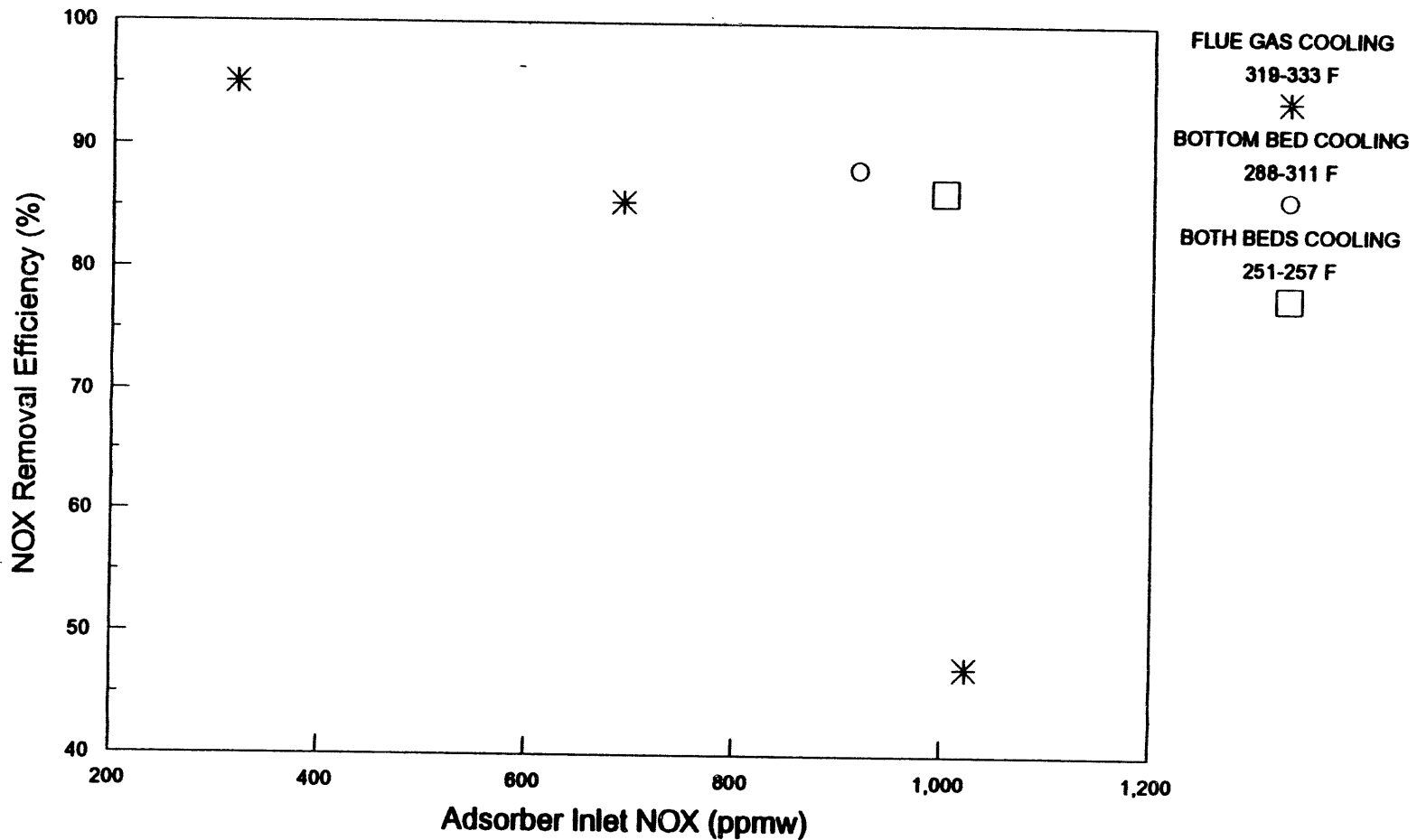
**Figure 6. NOXSO Pilot Test  
NOx Removal Efficiency  
and Two-Stage Adsorbers**

ratio, all other operating variables constant. The line drawn in the figure through the one-stage data has a correlation coefficient ( $r^2$ ) of 0.98. The two-stage data show the same trend but removal efficiencies are 6 to 12 absolute percentage points higher than the one stage. The best line through the two-stage data extrapolates to 86%  $\text{NO}_x$  removal efficiency at a flue gas to sorbent mass ratio of 4.6. The two-stage/in-bed spray data point shown in Figure 6 is 93.5%  $\text{NO}_x$  removal at a mass ratio of 4.6. This shows the effect of adsorber bed temperature on  $\text{NO}_x$  removal. Data obtained over an adsorber bed temperature range of 250-356°F show a definite trend of increasing removal efficiency with decreasing bed temperature. Further improvement is probable at bed temperatures lower than 250°F. This trend was best illustrated in tests where the flue gas was spiked with  $\text{SO}_2$  and  $\text{NO}_x$  from pressurized gas cylinders. Figure 7 shows  $\text{NO}_x$  removal efficiency as a function of inlet adsorber  $\text{NO}_x$  concentration from 300-1065 ppm. This is the range of  $\text{NO}_x$  concentration that exists in flue gas from coal-fired utility boilers. All tests were run at flue gas to sorbent mass ratios of 4.2 to 5 and total bed pressure drop of 19"  $\text{H}_2\text{O}$  in the two-stage adsorber. The data in Figure 7 clearly show that adsorber  $\text{NO}_x$  removal efficiencies of 86-88% are achievable at 917 to 1000 ppm inlet  $\text{NO}_x$  using the two-stage adsorber with in-bed water spray.

Figure 8 shows that  $\text{SO}_2$  removal efficiency increases as the concentration of  $\text{NO}_x$  in the incoming flue gas goes up. This is because the  $\text{SO}_2$  and  $\text{NO}_x$  adsorption mechanisms do not proceed independent of one another. In one-step in the mechanism, NO catalyses the reaction of  $\text{O}_2$  and  $\text{SO}_2$  on the sorbent's surface to form  $\text{Na}_2\text{SO}_4$ , a stable compound.

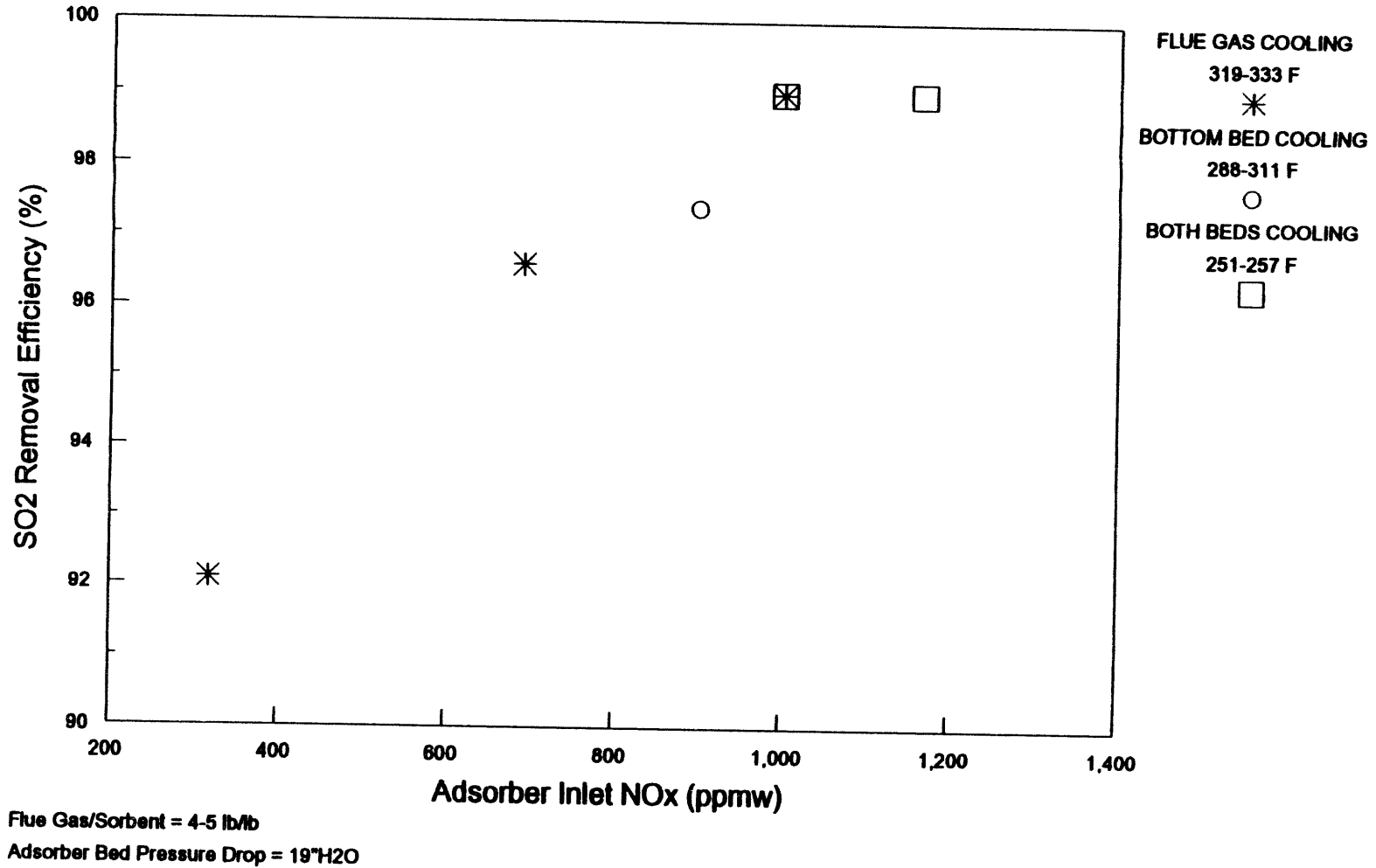
## **SORBENT ATTRITION**

Sorbent attrition is caused by physical and thermal stresses that come to bear on the sorbent as it is transported through the processing loop and as it resides in the fluid beds. These stresses can fracture sorbent beads and/or erode the surface of the beads. If the sorbent bead becomes small enough, it can be entrained by the gas and exit the fluid bed. Sorbent makeup is then required to maintain a constant sorbent inventory.



Flue Gas/Sorbent = 4-5 LB/LB  
Adsorber Bed Pressure Drop = 19"H2O

**Figure 7. NOXSO Pilot Test  
Flue Gas Spiking with SO<sub>2</sub>/NO<sub>x</sub>  
{SO<sub>2</sub>}=2300-2600 ppm Two-Stage Adsorber**



**Figure 8. NOXSO Pilot Test  
Flue Gas Spiking with SO<sub>2</sub>/NO<sub>x</sub>  
[SO<sub>2</sub>]=2300-2600 ppm Two-Stage Adsorber**

The rate of sorbent attrition equals the rate of sorbent makeup provided the starting and ending sorbent inventories are equal. The sorbent makeup rate at the NOXSO pilot plant for a 7-month period of operation is summarized in Table 1. The sorbent makeup rate is 3 PPH or  $3/27,000 = 0.011\%$  of total sorbent inventory per hour. This equates to replacing the entire sorbent inventory approximately once a year. This makeup rate is slightly lower than the makeup rate (0.016%/hr) used in previously published estimates of NOXSO process operating costs.

<b>Operation</b>	
Start date	7/17/92
End date	2/11/93
Flue gas, hrs	3,232
<b>Sorbent Inventory</b>	
Total makeup, lbs	20,307
Sorbent lost, lbs	-6,415
Deduct sorbent inventory, lbs	-4,245
Net Sorbent Makeup, lbs	9,647
Sorbent Makeup Rate, lb/hr	3.00

**Table 1. Sorbent Makeup Rate**

## **GENERAL ARRANGEMENT**

Figure 9 shows a general arrangement for a nominal 100 MW NOXSO plant. The major components will be identified by tracing the flow paths of the flue gas, the heater/cooler gas, and the sorbent through the system. This arrangement shows two adsorber trains. Flue gas enters the NOXSO system thru the flue gas inlet duct, splits and flows through the flue gas booster fans, adsorbers, and particulate separators before recombining and exiting the NOXSO tower thru the flue gas outlet duct.



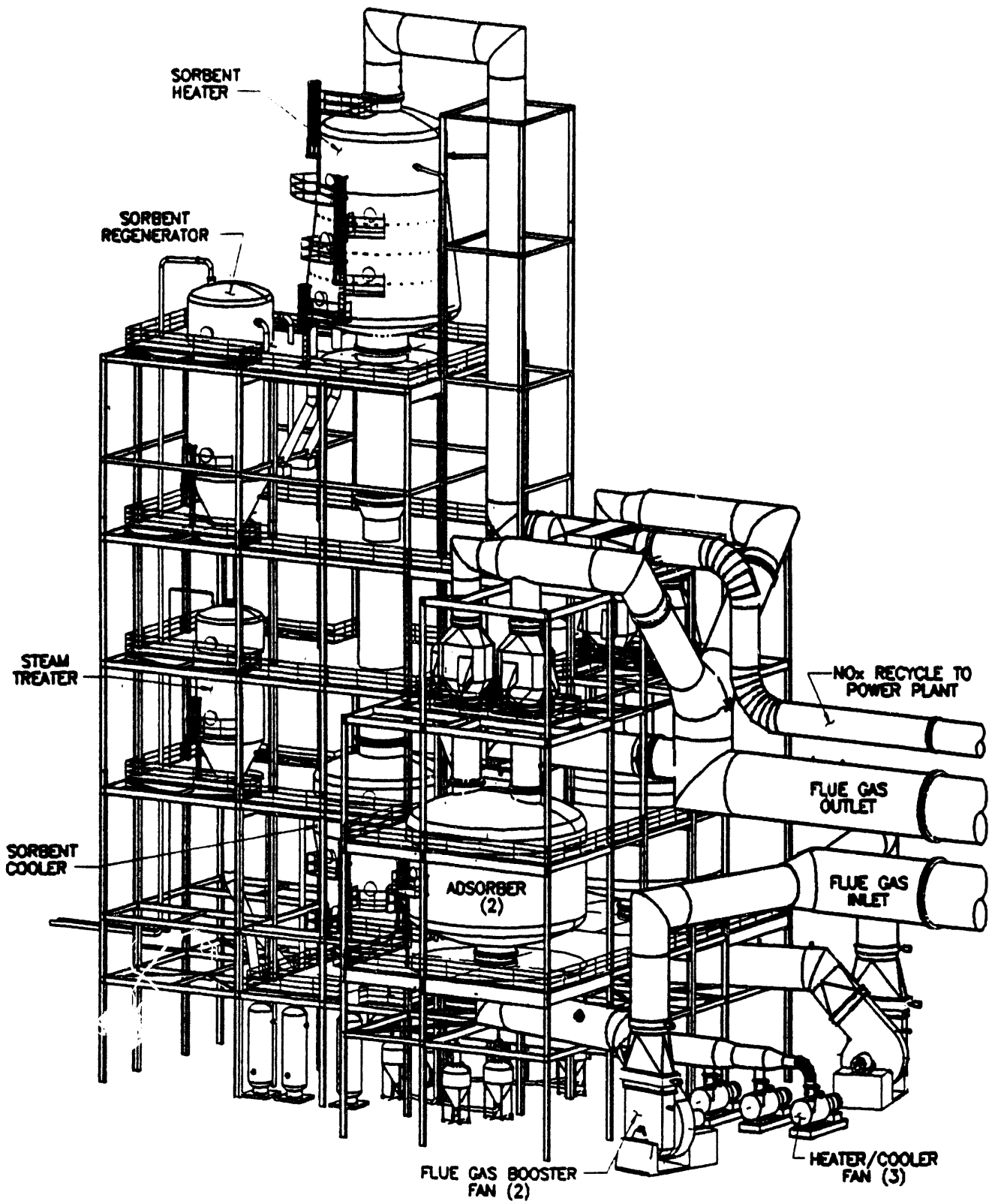


Figure 9. NOXSO Process Tower

Ambient air for cooling the sorbent enters through two of three 50% capacity heater/cooler fans. The air is preheated by the sorbent in the tapered sorbent cooler before flowing through the air heater (located below the sorbent heater) where it is heated by burning natural gas. The high temperature air enters the bottom of the tapered sorbent heater and exits from the top. This exit gas is the NO<sub>x</sub> recycle stream which goes to the combustion air system of the power plant.

Sorbent is transported from the adsorbers to the sorbent heater. After being heated in the sorbent heater, the sorbent is transported to the moving bed sorbent regenerator and then to the steam treater. From the steam treater, the sorbent flows to the sorbent cooler where it is cooled before being transported back to the adsorber, completing the cycle.

## PROJECT SCHEDULE

The Cooperative Agreement was awarded in March of 1991. The project has been in a project definition phase while the pilot plant has been operating. Current emphasis is on incorporating pilot plant results into a preliminary design for a commercial-scale plant and identifying a host site for the project. The project schedule by each phase is indicated in Table 2.

Preliminary Design	March 1991 - April 1994
Detail Design	May 1994 - October 1994
Construction	November 1994 - December 1995
Operation	January 1996 - December 1997

Table 2. Project Schedule

## ECONOMICS

Data from the pilot plant have been incorporated into the design of a commercial-scale NOXSO plant. Using this commercial plant design, an economic analysis was performed.

The basis for the analysis and cost information are included in Table 3. The analysis was conducted for a 500 MW power plant burning 3% sulfur coal and emitting 0.6 lb NO<sub>x</sub>/MMBtu.

Since the NOXSO process is a combined SO<sub>2</sub>/NO<sub>x</sub> removal process, it is not possible to separate the cost of removing SO<sub>2</sub> from the cost of removing NO<sub>x</sub>. Consequently, an assumption is made that the cost of removing NO<sub>x</sub> is 3.0 times higher than the cost of removing SO<sub>2</sub>. The value of 3.0 represents a reasonable average for the relationship between the cost of NO<sub>x</sub> and SO<sub>2</sub> removal based on published economic studies of separate high efficiency technologies. This value does not affect the overall economics, however it does affect the relative cost of SO<sub>2</sub> and NO<sub>x</sub> removal.

Emissions data are also listed in Table 3. The "Phase I SO<sub>2</sub> Limit" is calculated based on allowable emissions of 2.5 lb SO<sub>2</sub>/MMBtu. It is appropriate to consider over compliance since the high removal efficiency of the NOXSO process will allow a utility to generate SO<sub>2</sub> allowances which can be sold to partially offset the operating cost. A value of \$300 has been assumed for SO<sub>2</sub> allowances. Beginning in the year 2000, the number of allowances generated will decrease, however it is also likely that the value of allowances will be significantly higher offsetting to some degree the reduction in the number of allowances generated.

The annual operating and maintenance cost is \$24.7 million with the cost of sorbent at \$10.1 million representing 41% of the total. The capital cost of \$257/kw is based on a recent EPRI study [6].

Revenues for the process will be generated by the sale of the sulfur by-product and the SO<sub>2</sub> allowances. The sulfur by-product can be elemental sulfur, sulfuric acid, or liquid SO<sub>2</sub>. The choice of sulfur by-product will be influenced significantly by the local demand for the specific product. Since the market for sulfur is larger than the other two, sulfur is used in this analysis. If a local market exists for sulfuric acid or liquid SO<sub>2</sub>, either would be a more economical choice since the revenue from sulfuric acid would be approximately three times

**Table 3. NOXSO PROCESS ECONOMIC ANALYSIS (1)**

**POWER PLANT PARAMETERS**

GROSS CAPACITY	500 MW
CAPACITY FACTOR	70.0 %
HEAT RATE	10,000 Btu/kWh
COAL HEATING VALUE	12,000 Btu/lb
COAL SULFUR	3.0 %
NO <sub>x</sub> EMISSIONS	0.6 lb/MMBtu

**ECONOMIC PARAMETERS**

ELECTRICITY	\$0.03 /kWh
NATURAL GAS	\$2.50 /Mscf
SORBENT	\$3.40 /lb
NET SULFUR VALUE	\$50 /ton
SO <sub>2</sub> ALLOWANCE VALUE	\$300
FIXED CHARGE RATE (2)	10.6 %
REMOVAL COST NO <sub>x</sub> /REMOVAL COST SO <sub>2</sub>	3.0

**NOXSO PROCESS REMOVAL EFFICIENCIES**

SO <sub>2</sub>	95 %
NO <sub>x</sub>	80 %

**EMISSIONS DATA**

UNCONTROLLED SO <sub>2</sub>	76,650 tons/year
CONTROLLED SO <sub>2</sub>	3,833 tons/year
PHASE I SO <sub>2</sub> LIMIT	38,325 tons/year
SO <sub>2</sub> ALLOWANCES GENERATED	34,493 tons/year
UNCONTROLLED NO <sub>x</sub>	9,198 tons/year
CONTROLLED NO <sub>x</sub>	1,840 tons/year
POLLUTANT REMOVAL EFFICIENCY	93.4 %

**OPERATING AND MAINTENANCE COSTS**

FIXED (3)	\$5,714,000
VARIABLE (4)	\$129,000
NATURAL GAS	\$5,131,000
SORBENT	\$10,112,000
ELECTRICITY	\$3,642,000
TOTAL	\$24,728,000

**CAPITAL COST**

\$128,500,000
\$257 /kW

**REVENUES**

SO <sub>2</sub> ALLOWANCES	\$10,347,750
SULFUR VALUE	\$1,820,438
TOTAL	\$12,168,188

**NET LEVELIZED COST**

\$26,180,813 /year
8.5 mills/kWh
\$276 /ton-SO <sub>2</sub>
\$828 /ton-NO <sub>x</sub>

(1) 1993 dollars.

(2) Based on 30 year book life, 20 year tax life, 38% composite federal and state tax, and 2.0% for property taxes and insurance.

(3) Includes operating labor, fringes, and supervision; maintenance labor and equipment; and general and administrative expenses.

(4) Includes process water and Claus plant catalyst.

more than sulfur and liquid SO<sub>2</sub> would be six to eight times more. Making sulfuric acid or liquid SO<sub>2</sub> would also result in minor increases in capital and operating costs.

The net levelized cost for the process is presented from three points of view. The cost of buying, operating, and maintaining the plant will be \$26.2 million dollars per year. This translates to 8.5 mills/kwh of electricity produced. On a pollutant removal basis, it cost \$276 to remove each ton of SO<sub>2</sub> and \$828 to remove each ton of NO<sub>x</sub>.

## ACKNOWLEDGEMENT

The authors wish to thank the following for their contributions to the project: U.S. Department of Energy's Pittsburgh Energy Technology Center, Ohio Coal Development Office, Ohio Edison Company, W.R. Grace Co-Conn., Morrison-Knudsen Corporation MK-Ferguson Group, the Electric Power Research Institute, and the Gas Research Institute.

## REFERENCES

1. Haslbeck, J.L., C.J. Wang, L.G. Neal, H.P. Tseng, and J.D. Tucker, "Evaluation of the NOXSO Combined NO<sub>x</sub>/SO<sub>2</sub> Flue Gas Treatment Process," U.S. Department of Energy Contract NO. DE-AC22-FE60148, (November 1984).
2. Haslbeck, J.L., W.T. Ma, and L.G. Neal, "A Pilot-Scale Test of the NOXSO Flue Gas Treatment Process," U.S. Department of Energy Contract No. DE-FC22-85PC81503, (June 1988).
3. Ma, W.T., J.L. Haslbeck, and L.G. Neal, "Life Cycle Test of the NOXSO Process," U.S. Department of Energy Contract NO. DE-FC22-85PC81503, (May 1990).
4. Zhou, Q., J.L. Haslbeck, L.G. Neal, "An Experimental Study of NO<sub>x</sub> Recycle in the NOXSO Flue Gas Cleanup Process," U.S. Department of Energy Contract No. DE-AC22-91C91337, (March 1993).
5. Haslbeck, J.L., M.C. Woods, W.T. Ma, S.M. Harkins, J.B. Black, "NOXSO SO<sub>2</sub>/NO<sub>x</sub> Flue Gas Treatment Process: Proof-of-Concept Test," presented at the SO<sub>2</sub> Symposium, Boston, MA (August 1993).
6. J.E. Cichanowicz, C.E. Dene and W. DePriest, et al., "Engineering Evaluation of Combined NO<sub>x</sub>/SO<sub>2</sub> Controls for Utility Application," Electric Power Research Institute, Palo Alto, CA, (December 1991).



## **THE MILLIKEN STATION CLEAN COAL DEMONSTRATION PROJECT: THERE'S MORE TO IT THAN CONCRETE AND STEEL**

**C.M. Ellis  
New York State Electric & Gas Corporation (NYSEG)  
P.O. Box 3607  
4500 Vestal Parkway East  
Binghamton, NY 13902-3607**

**W.J. Savichky  
New York State Electric & Gas Corporation (NYSEG)  
P.O. Box 5227  
Corporate Drive  
Kirkwood Industrial Park  
Binghamton, NY 13902-5227**

**G.G. Elia  
Project Manager  
Department of Energy  
Pittsburgh Energy Technology Center  
P.O. Box 10940  
Pittsburgh, PA 15236**

### **INTRODUCTION**

Three years after its conception, the Milliken Station Clean Coal Demonstration Project in the Town of Lansing, north of Ithaca, New York, is reality.

A network of gray steel I-beams, the superstructure of the flue gas desulfurization building, dissects the view of Cayuga Lake from the hillside above the plant. That steel and the flurry of construction activity at Milliken Station somehow make March 1995 -- the target for the wet limestone scrubber to begin removing up to 98 percent of Milliken's sulfur dioxide emissions -- seem much closer than it did even a few months ago.

The goals of the project are to:

- Reduce SO<sub>2</sub> emissions by up to 98 percent using Saarberg-Hölter Umwelttechnik's (Saarbrücken, Germany) formic-acid enhanced scrubbing process in a split-module absorber. The absorber will be lined with ceramic tile manufactured by Stebbins Engineering & Manufacturing Company (Watertown, New York).
- Reduce nitrogen oxides (NO<sub>x</sub>) emissions by installing low-NO<sub>x</sub> burners in Milliken's two tangentially-fired boilers and by demonstrating Nalco Fuel Tech's (Naperville, Illinois) urea injection NO<sub>x</sub>OUT<sup>®</sup> process on one boiler.
- Minimize solid waste production by making high quality, commercial grade gypsum, marketable mixed chloride salts.
- Maintaining fly ash quality to ensure continued sales.
- Demonstrate zero wastewater discharge.
- Minimize the scrubber's impact on Milliken's thermal efficiency primarily by installing a high efficiency air heater system manufactured by ABB Air Preheater (Wellsville, New York). (Milliken Station is consistently among the top 20 fossil fuel-fired generating station's in the U.S. in heat rate).
- Achieve 95 percent scrubber availability.

## **PROJECT STATUS**

Several major milestones have been reached since the last Clean Coal Technology Conference in September 1992:

- Secured all permits to construct and operate the scrubber on or before September 1, 1992.
- Executed a cooperative agreement and repayment plan with the U.S. Department of Energy on October 22, 1992.
- Started construction of the scrubber in April 1993; completed foundations for the scrubber and the flue gas desulfurization building on June 18; started erecting steel in June 1993.
- Completed Unit 1 outage, which included installation of low-NO<sub>x</sub> burners and new coal mills, on July 17, 1993.



- Received Finding of No Significant Impact from DOE on August 23, 1993.
- Constructed and began operating three ambient air quality monitoring stations and a central meteorological station in February 1993. Data will be collected through the end of the project's three-year demonstration period.

## **COMMUNICATIONS AND OUTREACH ACTIVITIES**

In many respects, the Milliken Clean Coal Demonstration Project began like any other construction project. Management put together a project team of engineers, contract administrators, environmental specialists and number crunchers to get the project done "on time and under budget." Fortunately, before NYSEG applied to the U.S. Department of Energy for funding from the Clean Coal Technology Program - Round IV, the Milliken project team realized that an important element was missing from the process, a communications function to open and maintain communications channels with external and internal stakeholders. \*

In another place and another time, employees were accepting of everything management prescribed and the public was docile and unwilling to question.

Today, employees insist on being involved and informed and the public is no longer at all hesitant to ask the tough questions and to stand up for what they believe is right.

The Milliken project team recognized the potential public concerns regarding the project, especially the visual impact of the new facilities, the year-round white plume

- \* A stakeholder is any person, group or organization that is affected by NYSEG's actions and/or depends on NYSEG for the realization of their goals.

from the new stack, and the impact of a significant increase in truck traffic on two-lane state highways. The project team was especially sensitive to these issues because Milliken Station is located on Cayuga Lake, the second largest of New York State's scenic Finger Lakes. The residents of this region are particularly tuned-in to environmental issues and sensitive to changes that would impact the landscape. The team also recognized that it was important for the public to understand the positive impacts the project would have -- especially the environmental and economic benefits.

The Milliken project team identified a sub-team to address project communications needs. The following have been active members of the project communications team:

- Project manager
- Milliken Station manager
- Ithaca Division manager
- Media specialist
- Project environmental and public information specialist
- Manager - environmental issues
- Representative from ENSR Consulting and Engineering

#### Identifying Communications Objectives

The project communications team's first task was to identify communications objectives. They are to:

- Open channels of communications with internal and external stakeholders early in the project planning process and maintain those open channels (As Ann Carney and Amy Jordan note in a recent article in Public Relations Journal: "It is human nature for people to gossip. What they don't know they will fabricate or what little they do know they will embellish...To avoid this, a company must communicate quickly, honestly and frequently with its various audiences. It is not a matter of how much the company communicates, as much as it is that the lines of communications are open." [1])
- Provide timely, accurate and understandable information to internal and external audiences
- Anticipate and diffuse any negative community reaction

- Serve as the most accurate and reliable source of information for the neighbors of Milliken Station, public officials, the media and the general public
- Provide opportunities for public participation throughout the planning, construction and operation phases of the project

The project communications team recognized that achieving these objectives was essential to the success of the project. As Fraser Seitel, a veteran communicator who spent 20 years at Chase Manhattan, states in his book, The Practice of Public Relations: "...a thoughtful public relations program can crystalize attitudes, reinforce beliefs, and occasionally change public opinion." [2]

Perhaps most visibly at the Seabrook and Shoreham nuclear generating stations, it has become apparent that the public, agitated and angry because it has been left out of the communications loop, can cause havoc. According to Seitel: "Intelligent organizations in our society must be responsive to the needs and desires of their communities. Positive community relations in the '90s must begin with a clear understanding of community concerns, an open door for community leaders, and an open and honest flow of information from the organization, and an ongoing sense of continuous involvement and interaction with community publics." [3]

The team then recognized that achieving these objectives need not involve mentally-exhausting planning sessions, complicated communications plans and convoluted messages. Rather, the team again sided with Seitel: "There is really no trick to effective communication. Other than some facility with techniques, hard work and common sense are the basic guiding principles. Naturally, communication must follow performance; organizations must back up what they say with action. Slick brochures, engaging speeches, intelligent articles, and a good press may capture the public's attention, but in the final analysis the only way to obtain continued public support is through proper performance." [4]

The team, working within the constraint that no one had been assigned full-time communications responsibilities for the project, also recognized that it would take several individuals with specific skills and responsibilities to pull together the communications effort. These individuals were forced into performing as a team, just as the corporation was beginning to instill in its employees the virtues of teamwork. The circumstances dictated that this would be a true test of what Jon Katzenbach and Douglas Smith extol in their book, The Wisdom of Teams: "We believe that teams -- real teams, not just groups that management calls "teams" -- should be the basic unit of performance for most organizations, regardless of size. In any situation requiring the real-time combination of multiple skills, experiences, and judgments, a team invariably gets better results than a collection of individuals operating within confined job roles and responsibilities." [5]

Finally, each member of the team recognized that in addition to their full-time project responsibilities they would each be acting in a dual communications role. As Seitel notes: "Public relations practitioners are basically interpreters. On one hand, they must interpret the philosophies, policies, programs, and practices of their management to the public; on the other hand, they must translate the attitudes of the public to their management." [6]

### Identifying Stakeholders

The following stakeholders were identified. This list was shortened to a list of key stakeholders to make the communications effort more manageable and maximize the opportunity to achieve the project communications objectives. The key stakeholders received most of the attention from the project communications team, but the remaining stakeholders were certainly not ignored. (The key stakeholders are noted with asterisks.)

- Neighbors of Milliken Station \*
- Other residents on the east and west sides of Cayuga Lake \*
- Town of Lansing officials (host community) \*
- Tompkins County Environmental Management Council \*
- Local media \*

- Regional media
- National media
- State elected officials who represent the project area
- State agency officials
- Federal elected officials who represent the project area
- Federal agency officials
- Project co-funders (See addendum)
- Project participants (See addendum)
- Project consultants (See addendum)
- NYSEG employees
- NYSEG customers
- NYSEG shareholders

### Stakeholder Analysis

Once the key stakeholders had been identified, the project communications team completed a stakeholder analysis during which it identified:

- Any individuals, groups or organizations which represented those key stakeholders or groups (for example, the neighbors of Milliken Station are represented by the Town of Lansing officials, the Tompkins County Environmental Management Council, other elected and agency officials, and even the media)
- Any individuals, groups or organizations which the key stakeholders represent (for example, the neighbors of Milliken Station also represent the interests of residents who live on both sides of Cayuga Lake)
- Issues or concerns of the key stakeholders (for example, the neighbors of Milliken Station might be concerned with increased traffic and noise both during construction and after the scrubber begins operating)
- Strategies to resolve the key stakeholder's issue or concern (for example, certain construction activities were limited to specific hours, noise abatement was investigated, and ways to control traffic once the scrubber begins operating were studied)
- Actions required (for example, contract terms were written to limit construction activities, a noise abatement consultant was hired, and a new entrance road to Milliken was constructed to improve traffic flow)

The stakeholder analysis provided the project communications team with a clear picture of interrelationships between key stakeholders and a reasonable idea of what needed to be planned into the project to address the concerns of key stakeholders. In addition, the analysis provided the project communications team with direction to develop the following communications tools:

- Project presentation with slides
- Newsletter for neighbors
- Project fact sheet

Key members of the project communications team were also trained in how to deal with the public and the media.

To open channels of communications with key stakeholders, the project communications team scheduled and carried out the following activities:

- Public information meetings in the cities of Ithaca and Auburn and the towns of Lansing, King Ferry and Trumansburg (These meetings, which were initiated by NYSEG prior to permitting activities, included a brief presentation on the project, highlighted the project benefits and trade-offs, and provided all interested parties with an opportunity to ask questions. In addition, the meetings provided an opportunity for the project communications team to confirm the results of their stakeholder analysis and gather suggestions from stakeholders for investigation.)
- Meetings with elected officials in the towns of Lansing and Genoa (These meetings provided elected officials with basic project information and personal contacts to foster rumor control.)
- Meeting with the Tompkins County Environmental Management Council (This meeting allowed the project communications team to understand the Council's concerns so they could be addressed during project design.)
- Media tour of Milliken Station (The tour provided the local media with basic project information and a walk-through. None of the five reporters in attendance had ever been in a generating station.)

- Meetings with a variety of service clubs and other organizations (The project communications team made it known that it would meet with anyone, at any place and any time to discuss the project. This offer generated many requests, all of which were honored.)
- Production of a public information videotape.
- Hand delivery of information to the neighbors of Milliken Station regarding unusual construction activities, such as blasting, and changing traffic patterns.

In each of these instances, all interested parties were given the opportunity to be added to a mailing list to receive News for Neighbors, a periodic newsletter on the project, and other project information.

## **RESULTS**

As Seitel notes in The Practice of Public Relations: "Public opinion is a lot easier to measure than it is to influence." [7] We, however, do believe very strongly that we have influenced public opinion regarding the Milliken Clean Coal Demonstration Project by opening communications channels very early in the project, providing a comprehensive overview of the project, answering questions openly and honestly, respecting people's opinions and considering their suggestions. As we near the half-way point in construction of the scrubber, public support of the project has never been stronger and the organizations participating in the project have never been more supportive.

The most recent evidence of this broad support came on August 23 when representatives of NYSEG, all project co-funders, participants and consultants, the New York State Department of Environmental Conservation, the New York State Public Service Commission, the Adirondack Council, and local, state and federal elected officials gathered at Milliken Station to recognize progress to-date and pledge support for the future.

**We are now broadening the communications objectives to accommodate:**

- **Verification to stakeholders that we have kept our promises**
- **Communications needs of project participants**
- **Discussion of the environmental monitoring plan**
- **Discussion of demonstration results**

**Communications efforts continue as we strive to cement support for the Milliken project during construction and the three-year test period.**



## REFERENCES

1. Carney, Ann and Jorden, Amy, "Prepare for Business-Related Crises," Public Relations Journal (August 1993), p. 34.
2. Seitel, Fraser P., The Practice of Public Relations, (MacMillen Publishing Company, New York, 1992), p. 88.
3. Ibid, p. 452.
4. Ibid, p. 183.
5. Katzenbach, Jon R. and Smith, Douglas K., The Wisdom of Teams: Creating the High Performance Organization, (Harvard Business School Press, Boston, 1993), p. 15.
6. Seitel, Fraser P., The Practice of Public Relations, (MacMillen Publishing Company, New York, 1992), p. 10.
7. Ibid, p. 88.

## **ADDENDUM**

### **PROJECT CO-FUNDERS**

New York State Electric & Gas Corporation Binghamton, New York	\$97 million
U.S. Department of Energy Clean Coal Technology Program - Round IV	\$45 million
Electric Power Research Institute Palo Alto, California	\$7 million
Empire State Electric Energy Research Corporation New York, New York	\$7 million
CONSOL, Inc. Library, Pennsylvania	\$2 million
New York State Energy Research and Development Authority Albany, New York	\$1 million

### **PROJECT PARTICIPANTS**

Saarberg-Hölter Umwelttechnik Saarbrücken, Germany	Scrubber technology
Stebbins Engineering & Manufacturing Company Watertown, New York	Tile lining for scrubber
Nalco Fuel Tech Naperville, Illinois	NO <sub>x</sub> control technology
ABB Air Preheater Wellsville, New York	Air heater system

### **PROJECT CONSULTANTS**

Gilbert/Commonwealth Reading, Pennsylvania	Engineering, construction management
ENSR Consulting and Engineering Acton, Massachusetts	Environmental consultant, air quality
Galson Corporation Raleigh, North Carolina	Air impact modeling
Acentech Cambridge, Massachusetts	Noise abatement consultant

## **Luncheon**

---

Speaker introduced by:

**C. Lowell Miller,**

Associate Deputy Assistant Secretary for  
Clean Coal Technology,  
U.S. Department of Energy

---



**WHAT CLEAN COAL BRINGS TO THE  
INTERNATIONAL MARKET**

**David C. Crikelair  
Vice President  
Texaco, Inc.**

**(The comments of Mr. Crikelair were not  
available at the time of publication.)**



# **Plenary Session 2**

## **Emerging Issues/Environmental**

---

Moderator:

**C. Lowell Miller,**

Associate Deputy Assistant Secretary for  
Clean Coal Technology,  
U.S. Department of Energy

---





**COMPLIANCE STRATEGIES -  
IMPACT ON CLEAN COAL DEPLOYMENT**

**Stephen D. Jenkins  
Manager, Advanced Technology  
TECO Power Services Corporation**

**(The comments of Mr. Jenkins were not  
available at the time of publication.)**



**EPRI**



**DEFINING UTILITY TRACE SUBSTANCE  
EMISSIONS AND RISKS**

**Ian M. Torrens**

**Electric Power Research Institute**

**P.O. Box 10412**

**Palo Alto, CA 94303**

**Second Annual Clean Coal Technology Conference**

**Atlanta, Ga.**

**September 7-9, 1993**

# DEFINING UTILITY TRACE SUBSTANCE EMISSIONS AND RISKS

Ian M. Torrens

## I. INTRODUCTION

The purpose of this paper is to provide an update on the activities of EPRI and other organizations, including DOE, aimed at improving the quality of available information on utility trace element emissions, control technologies and risks. Thanks to these efforts, the state of knowledge is advancing rapidly. The rapid pace of progress was most evident at the recent Second International Conference on Managing Hazardous Air Pollutants, held in Washington DC this July. However, as in many fields of investigation, new information can sometimes raise more questions than it answers!

The 1990 Clean Air Act Amendments aim to reduce emissions of 189 substances that they designate as hazardous air pollutants - commonly called air toxics. The more neutral term "trace substances" is used in this paper, since most are emitted in extremely low concentrations from utility stacks. The degree of toxicity or hazard at these concentrations is subject to considerable uncertainty, and clarifying this is one of the objectives of the work in progress. A 1989 EPA-sponsored report concluded that emissions of potential cancer-causing substance from electric utility boilers pose insignificant risks - less than 1 excess cancer per year in a population of over 200 million [1]. Nonetheless, how to manage these substances may be a new challenge for the electric power industry.

The most clear and urgent need emanating from the CAAA has been to obtain reliable information on which of the substances on the CAAA list are emitted from different types of power plants - in what amounts, what risks they pose, how much is removed by today's pollution control equipment, and how these substances will affect health risk for the industry after the year 2010? We also need to know how and at what cost they may be controlled if some significant risk is found leading to their regulation .

EPRI is addressing the issue on several fronts:

- developing a data base and tools that will enable utilities to estimate emissions levels from their power facilities, given the types of fuels burned and plant characteristics;
- developing a better understanding of how emissions are transported and transformed before they encounter humans and ecological systems;
- and assessing the risk to public health and the environment posed by utility releases of these substances.

## **II. THE EPRI PISCES PROJECT**

To help the electric utility industry better understand emissions of potentially toxic chemicals from fossil fuel power plants, EPRI initiated the PISCES (Power Plant Integrated Systems: Chemical Emissions Study) project in mid-1988. The project involves the collection and review of data regarding the source, distribution, and fate of chemicals in both conventional and advanced fossil-fuel fired power systems.

The PISCES project has built a database from published information, and constructed a predictive computer model for power plant emissions. PISCES is multi-media in perspective; that is, it evaluates the presence and fate of chemicals in water and solid waste discharges, as well as in air emissions. This approach is being taken so that the effects of controls on air emissions, for example, can be assessed with full knowledge of the impacts on other plant process streams -- a way of integrating the array of pollution mitigating strategies.

The project consists of several major products and activities (Figure 1) including:

- a database of information gathered from the literature and other sources;
- an interactive power plant computer model to track the pathways of chemical substances and predict trace substance emissions;
- a field measurement program to measure emissions of two dozen chemicals in utility flue gas at plants and pilot test facilities employing a variety of emission control technologies. The results are being incorporated into the database and computer model;
- a series of emission control technology engineering reference guidelines to be developed following the completion of the database with new field measurements;
- measurement methods validation and a set of guidelines for measuring trace chemicals in utility process and discharge streams;

### **1. PISCES Data Base and Model**

A great deal of information, both domestic and international, was available at the time PISCES was initiated, but there had been little uniformity in either measurement or estimation methodologies [2,3]. Early phases of the PISCES project focused on available literature information collection for conventional coal-, oil-, and gas-fired power plants. Over 500 chemicals have been identified in power plant process streams. Approximately 80 of these 500 were selected for additional data search on regulatory limits and health effects. The PISCES database currently contains more than 150 megabytes of literature information, including 80,000 records of reported quantity data. Detailed descriptions of the database have been reported elsewhere [4].

Given sufficient data in the PISCES database, first order predictions of air quality control technology performance for air toxics removals could reasonably be attained. However, the major issue is the lack of fundamental data about these technologies for chemical species of concern. Although the number of available data points for plant emissions of various chemical species is quite large, the number of paired data sets – inlet and outlet – on any given control device is sparse. This led to initiating EPRI's Field Chemical Emission Measurement (FCEM) program in association with EPRI member companies and the U.S. DOE.

## 1. PISCES Field Chemical Emissions Measurement

The PISCES FCEM program began in May 1990. Emissions and discharges are being measured for several control technologies, including cold-side ESPs, fabric filters (conventional and pulse-jet), low-NO<sub>x</sub> burners, postcombustion NO<sub>x</sub> systems, spray dry FGD, and wet lime/limestone FGD. Plant mass balances are being performed for some 24 chemicals also define sources, pathways, and the way they partition in the plant system.

Table 1 shows the substances being measured. Liquid and solid waste streams are sampled in addition to the flue gas. A variety of fuel types, combustion systems and types of environmental control for particulates, SO<sub>2</sub> and NO<sub>x</sub> are included in the program. Early measurements pointed up the need for better sampling and analysis techniques for some of the trace chemicals, and as these have improved, so has the quality of the data (see Section II.7). Until the current series of tests has been completed and the entire body of information analyzed later this year and early next, the data should be considered preliminary.

Sampled early in the program was a midwestern U.S. power plant equipped with an ESP and wet limestone scrubber burning a western subbituminous coal. The FGD system at the time was operating with 24% flue gas bypass. The data indicate that, with the exception of mercury and chloride, over 90% of each chemical was removed with most showing over 95% removal (Figure 2). Mercury removal has been difficult to accurately determine since it is present in such low concentrations in the clean flue gas (less than 0.2 micrograms/Nm<sup>3</sup>).

Comparing the PISCES FCEM test results to information in the literature database, one can reaffirm our common understanding of the fate of certain classes of chemical species within the power plant. For example, comparing the concentration of chromium in coal with that found in the fly ash indicates that a large proportion of chromium is captured with the particulate matter (Figure 3). This would suggest that highly efficient particulate control devices, such as electrostatic precipitators (ESPs) and baghouses, would remove chromium and other similarly behaving elements from power plant flue gas streams quite efficiently. In fact, EPRI field studies have shown that chromium concentrations in the stack are quite low.

Electrostatic Precipitator (ESP) - controlled coal-fired power plants represent the largest segment of the industry tested under EPRI's PISCES and DOE's air toxics field sampling programs. Early test results have demonstrated the tremendous capacity of particulate collection devices to reduce many heavy metals from flue gas streams. A number of metals such as arsenic, nickel, chromium, lead, cadmium can be removed by an average of better than 90%. Figure 4 illustrates this point for arsenic and chromium. With very limited results (4 early sites), the removal performance from fabric filters are quite encouraging, indicating reductions over 99% for metals such as arsenic.

Much of the reductions are attributable to the metals condensation onto particulate material as combustion gas temperatures drop from 1260°C (2300°F) in the boilers to 121°C-149°C (250°F-300°F) inlet to the cold-side particulate capture devices. This suggests that conditions which promote lower temperatures and improved removals of combustion and post-combustion particulates and aerosols would also serve to control many of the heavy metals. [Future test data will be carefully examined to confirm these hypotheses.] The exceptions to this may be the more volatile elements such as mercury and selenium.

Material balance for variety of key elements has been excellent (Figure 5). Many are within or close to the 70% to 130% desirable interval. 100% closure represents a complete material balance. Of the key elements, selenium's balance appears consistently to be the most variable. The large uncertainties for selenium measurements in the flue gas may be attributable to interferences in the measurement methodologies, warranting further investigation.

### 3. Mercury

Mercury has been singled out for special study in the CAAA because of issues related to mercury from all sources, and human health (Figure 6). Mercury removal is difficult to determine accurately since the mercury is present in such low concentrations in the stack flue gas in the order of 0.0001 to 0.001 mg/Nm<sup>3</sup>. Uncontrolled emissions of a typical 500MW power plant would be about 500 pounds/year. Actual emissions in practice would be less since the plants environmental control systems actually do remove some mercury. Utility emissions of mercury are relatively small; that is, the annual contribution from U.S. fossil-fuel fired electric utility boilers represents roughly 2 percent of the 6 million kilograms global mercury budget and less than 4 percent of global anthropogenic emissions [5,6].

Most of the older mercury emissions data reported in the literature are suspect given the difficulties in mercury sampling and analysis. Since mercury amalgamates with many metals, it is ubiquitous in many laboratories and thus contaminates samples. It does appear that the more recently reported data using better sampling techniques and analytical methods are reducing some of this uncertainty. For instance, even results from early PISCES field sampling of mercury were unspectacular. Mercury recovery from the EPA multi-metals sampling train were a meager 30 to 40%. Material balances

were reporting less than 50% closure at the early test sites (Figure 5). However, with experience improvements to the sampling and analytical procedures, and frequent cross-comparisons with alternative mercury measurement methods, the accuracy and reproducibility of mercury determinations improved dramatically for flue gas, sluice water, flyash, and coal samples. Recent material balances for mercury around the power plant site are now within the 70-130% acceptance interval around the 100% closure mark.

Because of the measurement difficulty, EPRI has given specific attention to developing new methods of mercury measurement, and is cooperating with EPA in a jointly sponsored field validation test of a full-scale power plant stack gas for mercury concentrations.

The behavior of mercury in control devices such as FGD remains to be better understood. The current PISCES field data indicate about 20-90% removal for cold-side ESPs (5 data points) and 85-90% for fabric filters (3 data points). One theory to explain the higher removal percentage data points suggests that unburnt carbon carryover due to loss of ignition (LOI) may be adsorbing the element. This is a subject for follow-up research.

The dominant form of mercury in combustion gases is divalent  $Hg^{++}$ , at approximately 60% (Figure 7). Speciation properties after the boiler and in the stack emissions plume beyond the plant may depend to some extent on the HCl in the flue gas and therefore the chlorine concentration in the coal. Based on very limited mercury studies around a 4-MW pilot unit at the High Sulfur Test Center, consisting of a cold-side ESP plus wet limestone FGD combination treating bituminous coal gas, all species of mercury (methyl-, di-valent-, and elemental-) were found. Two observations are notable. First, the dominant form of mercury in the combustion flue gas was the di-valent (at approximately 60% of the total mercury); and second, the combination pilot ESP and wet FGD captured all of the di-valent mercury and all of the methyl-mercury, leaving a third of the elemental mercury behind in the emitted flue gas (Figure 7).

Several papers have reported that mercury can be removed from municipal waste incinerator flue gas through use of chemical additives. Joy Technologies[7] reported that use of an additive in a spray dryer system improved mercury removal as did operation at lower exit gas temperatures. Joy's data show that a spray dry/baghouse combination operating on a municipal waste incinerator removed 69% of the total mercury without the additive and from 91% to 95% with the additive. The spray dry/ESP combination removed from 27% to 66% of total mercury without the additive and from 78% to 86% with the additive. The higher removals were observed at the lower exit gas temperatures. Although the additive was not specified, it is assumed to be activated carbon. Use of activated carbon has been reported by others with similar results [8-11].



More recent EPRI exploratory tests were conducted with activated carbon injection just upstream of a 1-MW pilot pulse jet fabric filter system at a low sulfur subbituminous coal-fired power plant [12]. Inlet mercury concentrations ranged from 2 to 8  $\mu\text{g}/\text{Nm}^3$ . When activated carbon was injected at a ratio of 4000 parts of carbon per part of mercury in the flue gas, mercury removals of better than 90% was observed at temperatures of 121°C (250°F) (Figure 8). The coal contained low chlorine concentrations and the measured ratio of ionic to elemental mercury was about 75/25. In the same EPRI study, mercury rich activated carbon was sampled for desorption effects over a four week period. No significant mercury re-volatilization was detected. Without carbon injection, the pilot fabric filter mercury removal efficiency dropped to 30 to 50%.

Because the technique of using sorbents, such as activated carbon, is promising, additional research is underway by the electric utility industry and U.S. government agencies to establish their properties and better define their applications.

Clearly, mercury is a case where more measurement and analysis is needed to narrow down the results to a point where we can be confident in predicting either the emissions or how best to reduce them.

#### 4. Chlorides

Chloride concentrations vary widely in US coals, from virtually unmeasurable quantities to over 0.5% [13]. Generally, eastern high-sulfur coals have higher chloride concentrations than western subbituminous and lignite coals. During combustion in the furnace, over 95% of the chloride in the coal is initially released, primarily (90%) in the form of gaseous HCl. There is little interaction between the gaseous HCl and the ash. HCl will deposit onto the fly ash only below 60°C (140°F), the acid dewpoint for HCl. This is true regardless of the pH of the fly ash. Data indicate extremely low to nondetectable levels of chloride in fly ash from lignite, bituminous, and subbituminous coals. HCl reacts quickly in the atmosphere with ammonia and calcium and is generally not detected beyond 10 kilometers (several miles) from the stack.

Figure 9 shows some results of PISCES field measurements on chloride removal by different control technologies and combinations thereof, for both bituminous and subbituminous coal.

HCl emissions are not considered to be a major health concern. For a power plant emitting 200 tons of HCl per year with a stack height at GEP (good engineering practice), ground level concentrations over a one-hour maximum average would be less than 1 microgram/ $\text{m}^3$  under adverse meteorological conditions. This is negligible compared to the threshold limit value for occupational health effects of 7000 micrograms/cubic meter.

## 5. Sampling Chemical Species

The case of mercury is a good illustration of the fact that evaluating trace substance emissions is critically dependent on the ability to sample and measure these chemical species reliably, when a vast majority of those listed in the Clean Air Act Amendments only appear in trace amounts in plant process streams. Without the requisite understanding of a method's capabilities and limitations, misleading results are not only possible, but highly probable.

To assist the field measurement efforts, site-specific risk assessments were conducted with results from early testing to define minimum risk concentrations, and in turn, determined the sensitivity levels or detection levels that sample monitoring methods must attain for input towards more reasonable risk estimates. Methods, to the extent commercially available, were selected to meet these target concentrations at future test sites. Unfortunately, methods with the required sensitivity were not available for all substances.

To furnish utilities with interim guidance, EPRI has produced a compendium of available methods for measuring trace substances in a variety of process streams, including flue gas. The document contains information on precision and detection quantification limits, where available. This information will help utilities establish and conduct sampling programs based on the most up-to-date methods, and assist them in understanding the limitations of the various measurement methods. Publication of this compendium is expected by the end of 1993.

Future PISCES efforts will involve both laboratory development and field evaluation studies of specific methods for measuring important chemicals in fuels and flue gas. Besides mercury, of particular interest are improved sampling techniques for benzene and speciation of important trace elements such as arsenic and chromium.

Concerning organics, while PISCES has sampled several VOCs, formaldehyde, and PAHs, preliminary EPRI risk assessments indicate that they do not pose significant risk. Their presence is in many cases at or below detection limits of current EPA-recommended measurement methods. While VOCs are measurable, their risks are also very low.

## 6. Emission Factors

When emission factors are computed with the PISCES field sampling-preliminary results, two observations can be drawn (Figure 10). First, the variability of elemental measurements from the recent field studies show far less scatter than those reported in the 1989 EPA report. And second, the average emission factor values are less than those found in that same EPA report. In fact, Figure 10 shows that they could be 1 to 2 orders of magnitude apart. In the case of chromium and nickel, it is entirely conceivable that the higher literature values in the EPA report may be due to the use of stainless steel sampling probes employed to collect this historical data. Such probes were a common device for gas sampling prior to the mid-1980's. Erosion and corrosion by-products from these probes might have easily contaminated the samples.

## 7. Status of Field Measurement Programs

By the end of 1993, EPRI will have acquired field test data from more than 20 power plant sites. The data now available are presently being analyzed and compared. In addition, the US Department of Energy (DOE) Pittsburgh Energy Technology Center (PETC) has begun a complementary program at approximately 8 more locations. DOE-PETC are sampling for a similar set of chemicals as the EPRI FCEM program and using similar sampling and analytical protocol based on the EPRI procedures.

### III. RISK ASSESSMENT

The PISCES program is one major component of EPRI's utility trace substances R&D. It is designed to interface closely and interactively with the second key component - the risk assessment CORE project (Figure 11). CORE (Comprehensive Risk Evaluation) is an effort to integrate the state of our knowledge about trace substances, their behavior in the environment, and particularly the ways in which they might impact human health. The CORE project has two key goals. First, given the measurement information from PISCES and other projects, what can be said about the emissions and fate of trace substances from the U.S. power industry as a whole? And second, in light of what has been learned about atmospheric processes, ecosystems, and human health response, what can be concluded about the health risks due to these substances from power plants? What does this imply for the industry of today, and the industry of the 21st century?

In order to clarify these questions, CORE is carrying out an integrated assessment of these trace substances from the time they are emitted from a power plant up to the point that human populations might be exposed to them some time later. This assessment is relying on tools in the EPRI risk assessment arsenal to evaluate the risks due to the national capacity. These tools include TRUE, a multimedia risk assessment model, and the Core Risk Assessment Framework. The latter brings together the data from PISCES, calculates emissions from each power plant in the nation, computes downwind deposition and concentrations by substance, and allows us to estimate human health risks by a number of means.

As part of this Framework, EPRI has developed a number of advanced applications applicable to future assessments of human health risk. These include a database of population distributions around every power plant, a probabilistic model of human activity patterns, the effects of indoor environments on exposures, a quantitative model of uncertainties in risk assessments, and a national assessment of mercury exposure from the industry. These results, together with EPRI's efforts to determine the composition and biological effects of utility flyash, the chemistry of trace substances in plumes and in the atmosphere, and the ecological cycling of mercury, are being brought together in the Air Toxics Synthesis Report, scheduled for late 1993.

#### **IV. COLLABORATIVE EFFORT TO IMPROVE THE STATE OF KNOWLEDGE**

The current R&D pace in this important area could not have been maintained and would be much less focused without the cooperative spirit among key organizations and agencies: EPRI, DOE, UARG, EPA. Each separate organization has played a complementary and constructive role towards a collectively defined goal or completing the CAAA-mandated utility study.

The need for better scientific data on utility emissions and impacts, as confirmed by PISCES and other work in this area, was a factor in the congressional decision to allow more time for specific study. The results of the industry-government coordination of respective research efforts should enable both parties to make decisions based on the best scientific and technical information available.

## REFERENCES

- [1] "Cancer Risk From Outdoor Exposure to Air Toxics," U.S. Environmental Protection Agency, External Review Draft, September 1989.
- [2] Smith, I., "Trace Elements From Coal Combustion: Emissions," IEA Coal Research, IEACR/011, June 1987.
- [3] Clarke, L. and Sloss, L., "Trace Elements-Emissions from Coal Combustion and Gasification," IEA Coal Research, IEACR/49, July 1992.
- [4] Behrens, G.P. and Chow, W., "Use of A Multi-Media Database for Chemical Emission Studies of Conventional Power Systems," Presented at the Air & Waste Management Association Annual Meeting, Pittsburgh, Pa., June 1990.
- [5] Porcella, Donald, EPRI, private communications.
- [6] Nriagu, J.O. and Pacyna, J.M., "Quantitative Assessment of Worldwide Contamination of Air, Water and Soils by Trace Metals," Nature, Vol. 333, May 12, 1988, Pages 134-139.
- [7] Donnelly, JR and Felsvang, KS, "Joy/Niro SDA MSW Gas Cleaning System: New Developments," paper presented at the Air & Waste Management Association Annual Meeting, Anaheim, Ca., June 1989.
- [8] Teller, Aaron and Quimby, Jay, "Mercury Removal from Incineration Flue Gas," paper presented at the 84th meeting of the Air & Waste Management Association, Vancouver, BC. June 16-21, 1991
- [9] Volland, Craig S., "Mercury Emissions From Municipal Solid Waste Combustion," paper presented at the 84th meeting of the Air & Waste Management Association, Vancouver, B.C. June 16-21, 1991.
- [10] Guest, Terrence L., and Knizak, Ota, "Mercury Control at Burnaby's Municipal Waste Incinerator," paper presented at the 84th meeting of the Air & Waste Management Association, Vancouver, B.C. June 16-21, 1991.
- [11] Riley, et. al., "Removal of Heavy Metals and Dioxin in Flue Gas Cleaning After Waste Incineration," paper presented at the 84th meeting of the Air & Waste Management Association, Vancouver, BC, June 16-21, 1991.
- [12] Chang, R. and Owens, D., "Developing Methods for Mercury Removal from Power Plants," presented at the Second International Conference on Managing Hazardous Air Pollutants, Washington, DC, July 1993.
- [13] Coal Conversion Systems Technical Data Book, U.S. DOE, Division of Coal Conversion, under DOE Contyact No. EX-76-C-01-2286, March 1982.

TABLE 1

## Chemicals for PISCES Field Emissions Monitoring

### INORGANICS

*Arsenic* (incl. +3,+5)

Barium

*Beryllium*

*Cadmium*

Chlorine/Hydrochloric acid

*Chromium* (incl. +6)\*

Cobalt

Copper

*Radionuclides\**

*Fluorine / Hydrofluoric acid*

Lead

Manganese

*Mercury* [incl. methyl-, 0, +2\*]

Molybdenum

Nickel

Phosphorus/Phosphate

Selenium

Vanadium

### ORGANICS

Benzene

Toluene

*Formaldehyde*

*Dioxins/Furans\**

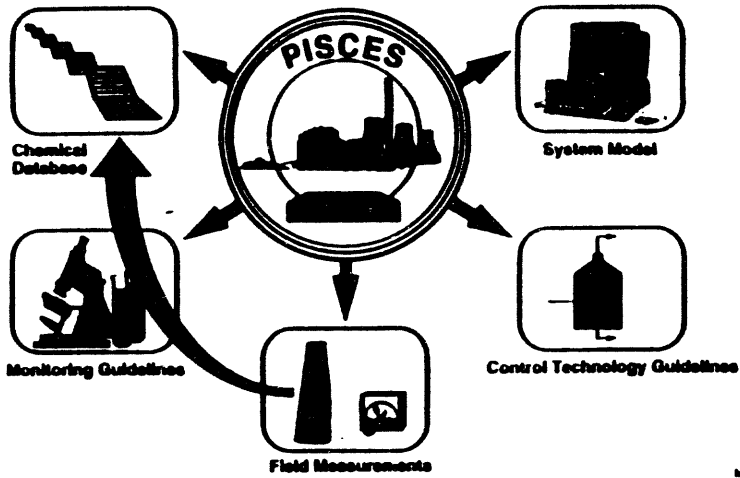
Polynuclear Aromatics

(e.g., Benzo-a-pyrene)

\* Measured at Selected Plants

FIGURE 1

# POWER PLANT INTEGRATED SYSTEMS: CHEMICAL EMISSION STUDIES



M100 14

FIGURE 2

## Comparison of Stack Emission Rate with Inlet Mass Rate Midwest Plant — ESP & Wet Limestone FGD

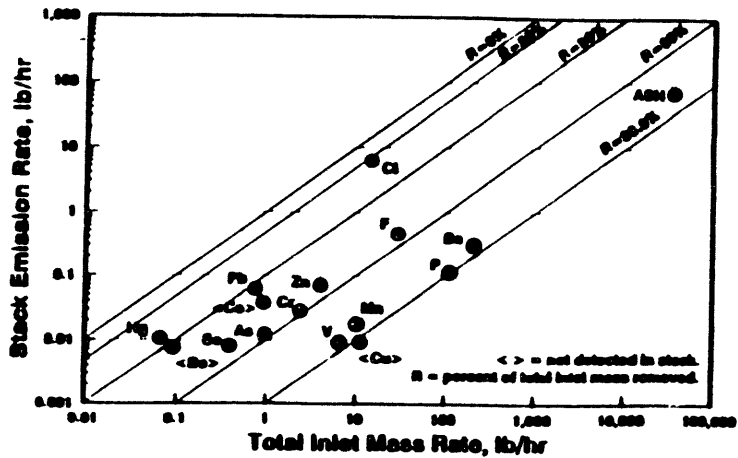


FIGURE 3

## Chromium Literature and FCEM Values

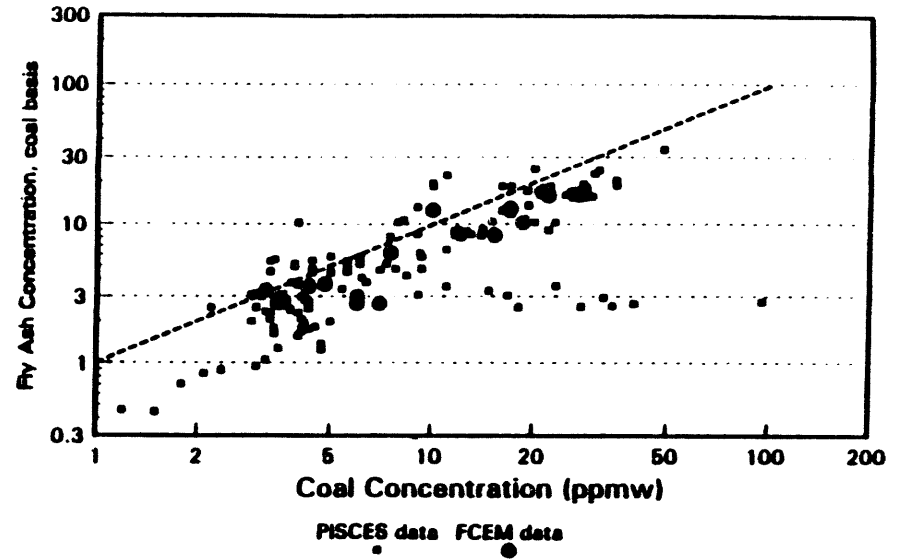


FIGURE 4

## ESP Removal Efficiency: 3 FCEM Sites Arsenic, Chromium, Mercury

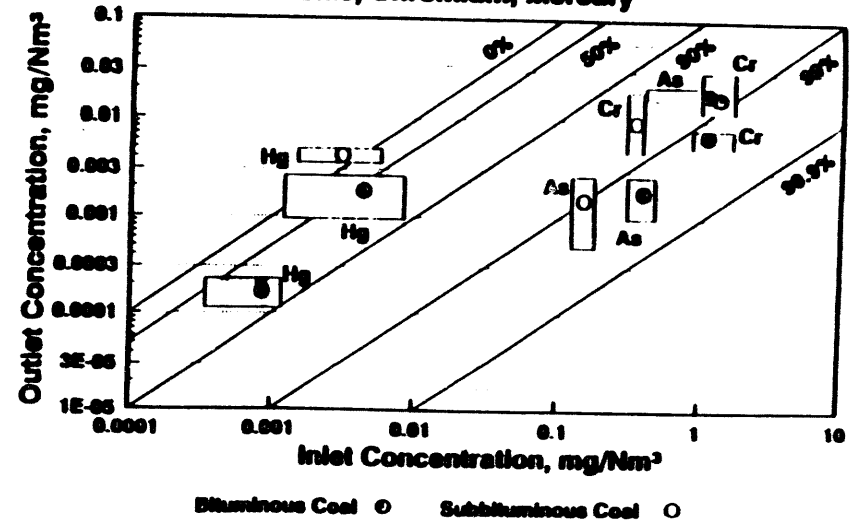


FIGURE 5

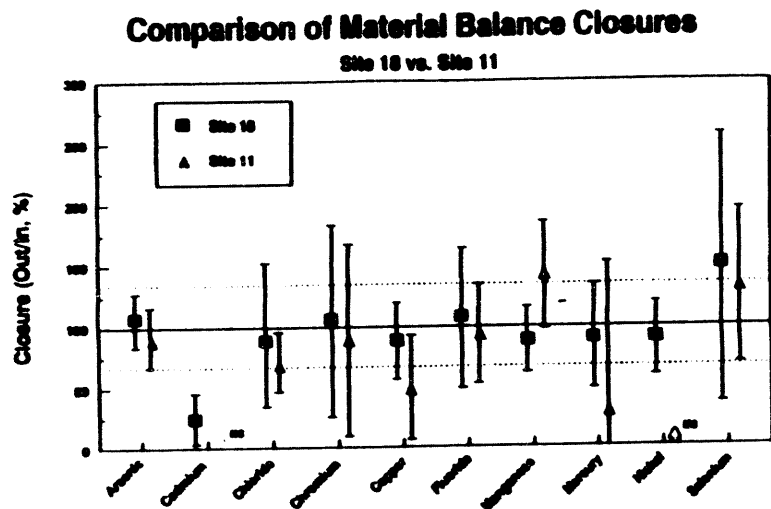


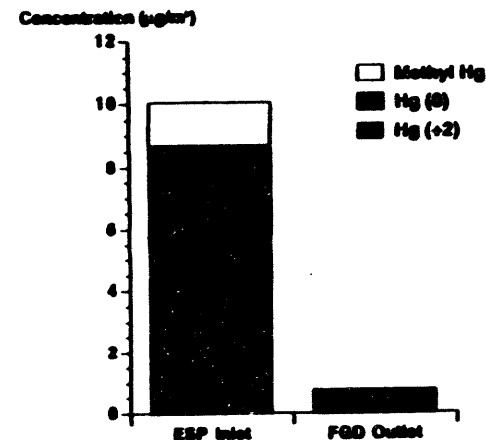
FIGURE 6

## THE SPECIAL CASE OF MERCURY

	<u>OTHER AIR TOXICS</u>	<u>MERCURY</u>
<b>EMISSIONS</b>	• Particle-bound	• Vapor
<b>DEPOSITION</b>	• Wet - Dry	• Dry(0), wet(1)
<b>EXPOSURE ROUTE</b>	• Inhalation (Ingestion)	• Ingestion (Inhalation)
<b>MODE OF ACTION</b>	• Carcinogens (teratogens)	• Neurotoxin
<b>SENSITIVE INDIVIDIS</b>	• General Population	• Fetuses, children
<b>DOSE-RESPONSE</b>		• Human
<b>EVIDENCE</b>	• Animals (human epidemiology, occupational exposures)	

FIGURE 7

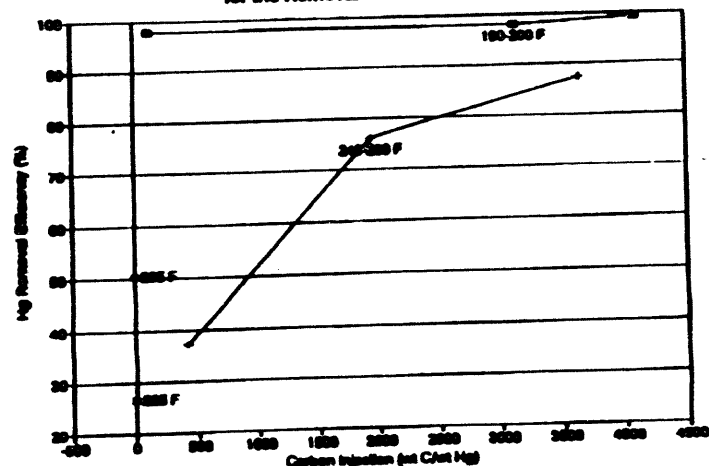
## MERCURY EMISSIONS SPECIATION ESP/FGD (wet) Performance



11/10/90 20

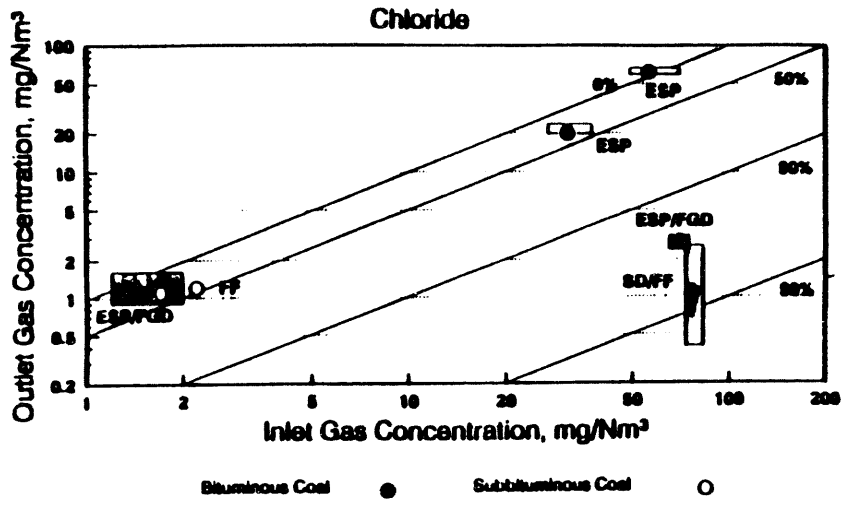
FIGURE 8

### Pilot Scale Evaluation of Carbon for the Removal of Trace Metals



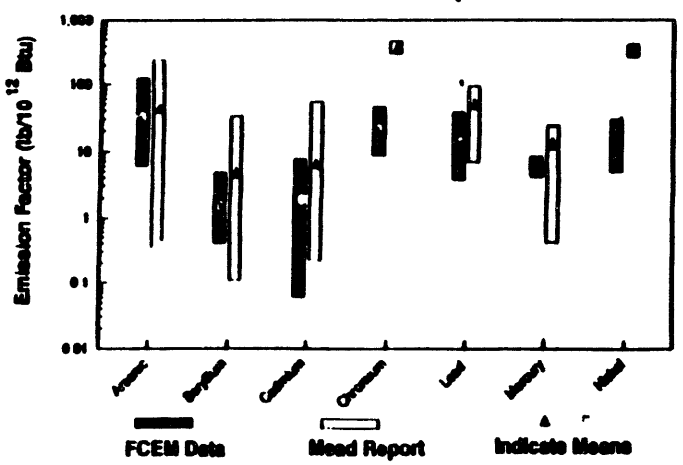


**FIGURE 9**  
**Control Device Removal Efficiency**  
**Chloride**



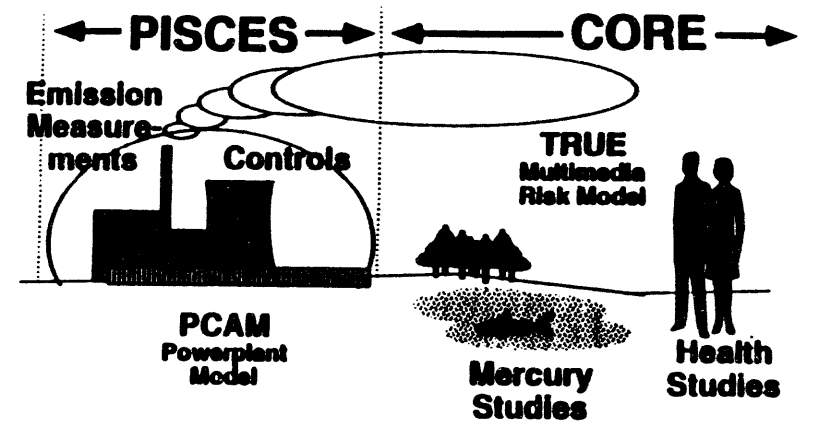
**FIGURE 10**

**Emission Factors for Bluminous Coal w/ ESP Control**  
**FCEM Data vs. Mead Report**



**FIGURE 11**

**EPRI AIR TOXICS RESEARCH**





**NO<sub>x</sub> CONTROL ACCOMPLISHMENTS  
AND  
FUTURE CHALLENGES FOR COAL-FIRED BOILERS**

**Presented at the  
Second Annual Clean Coal Technology Conference**

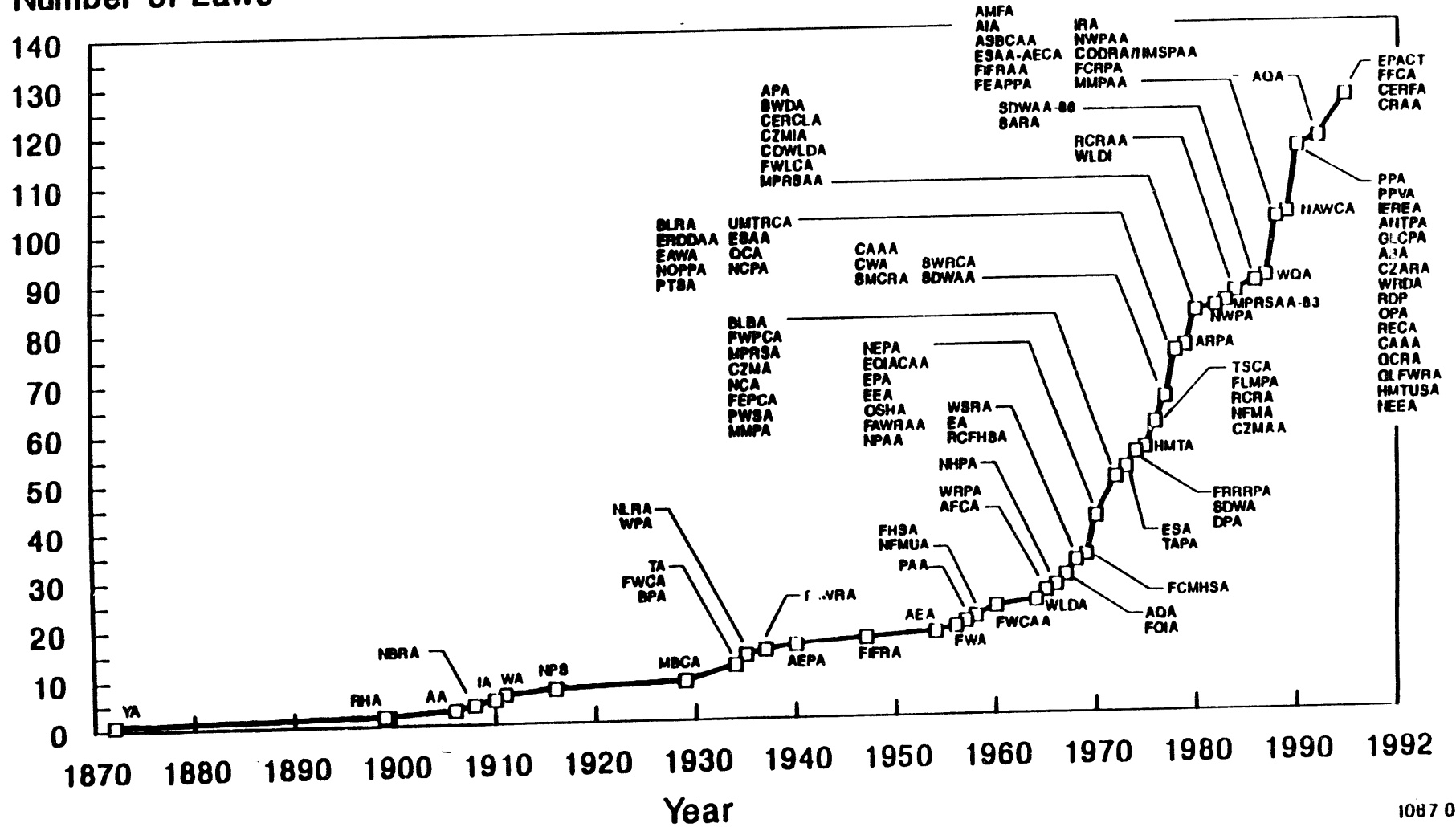
**September 9, 1993**

**Atlanta**

**David Eskinazi, EPRI**

# U.S. Laws on Environmental Protection

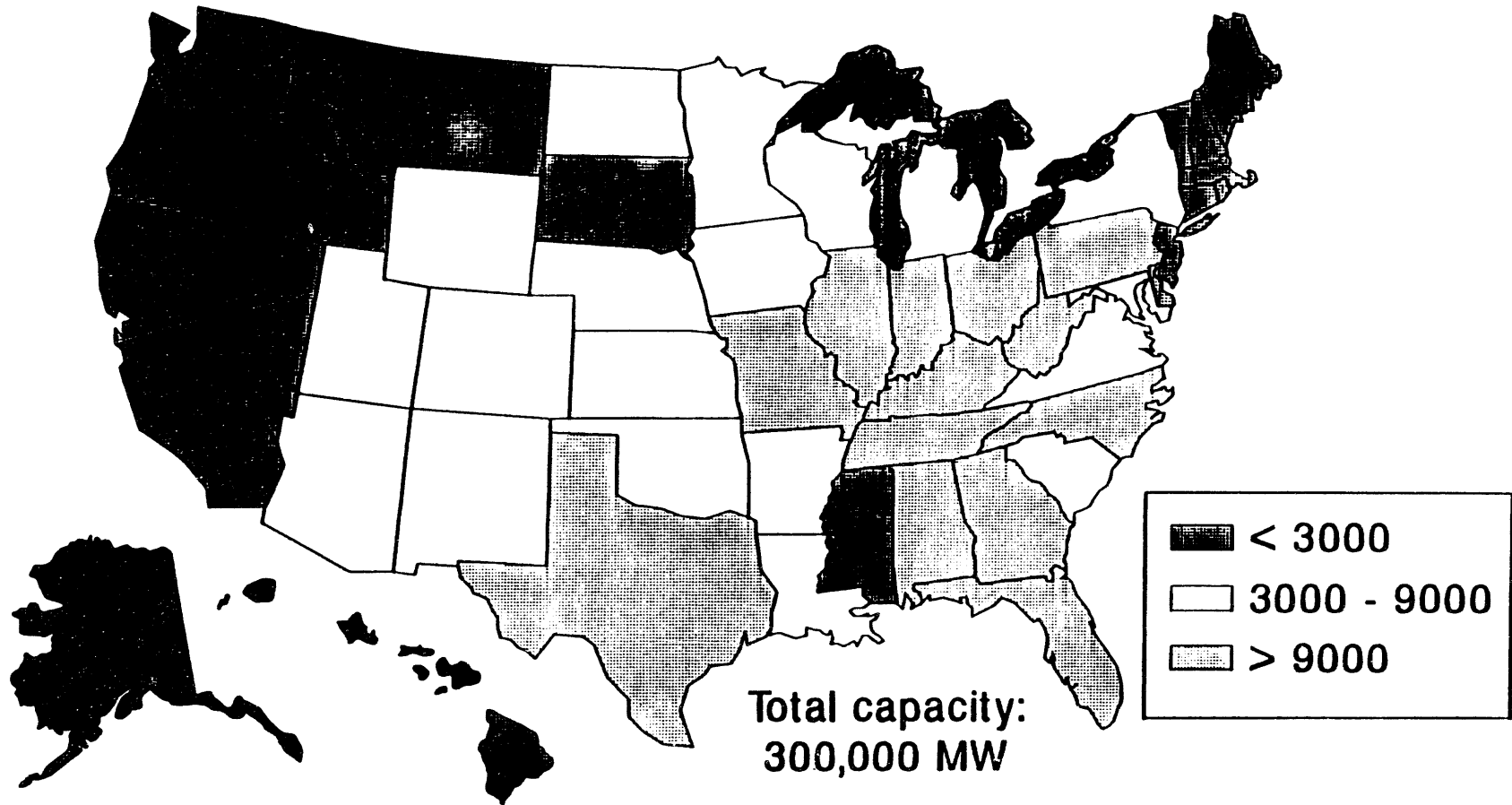
Number of Laws



# ACCOMPLISHMENTS

0751D.42

# U.S. COAL-FIRED GENERATING CAPACITY



Data: From DOE, December 1990.

# RETROFIT NO<sub>x</sub> CONTROLS

## Coal-Fired Boilers

<u>Technology</u>	<u>Emission Reduction Potential (%)</u>	<u>Capital Cost (\$/kw)</u>	<u>Operating Cost (mills/kWh)</u>	<u>Technology Application Issues</u>
LNB	40-55	5-20 <sup>2</sup>	<1	<ul style="list-style-type: none"> <li>▪ Primarily for wall-fired</li> <li>▪ Not for cyclones</li> </ul>
LNB <sup>1</sup> + OFA	30-65	10-25 <sup>2</sup>	<1	<ul style="list-style-type: none"> <li>▪ Upper furnace residence times and coal properties</li> <li>▪ Not for cyclones</li> </ul>
Reburn	40-60	20-50 <sup>2</sup>	1-3	<ul style="list-style-type: none"> <li>▪ Upper furnace residence times</li> </ul>
SNCR	35-60	5-20	<2	<ul style="list-style-type: none"> <li>▪ Flue gas temperature, duty cycle and size</li> </ul>
SCR	70-90	50-150	4-8	<ul style="list-style-type: none"> <li>▪ Coal properties space availability, by-products, and duty cycle</li> </ul>
NO <sub>x</sub> /SO <sub>2</sub>	70-90	300-400 <sup>3</sup>	11-15 <sup>3</sup>	<ul style="list-style-type: none"> <li>▪ Under development</li> </ul>

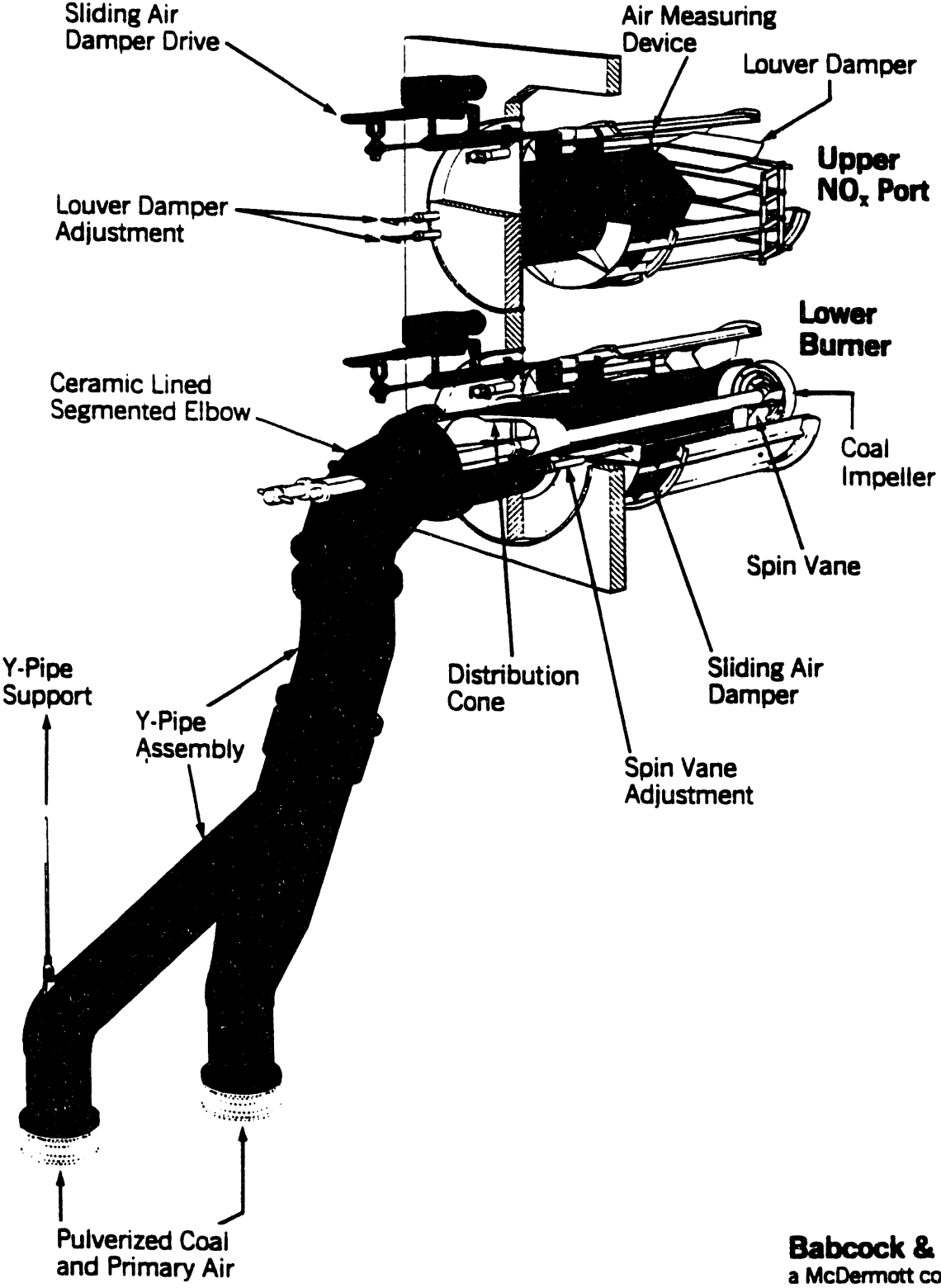
1. Includes coal and air nozzle modifications for tangential boilers.

2. Process capital costs only.

3. Includes SO<sub>2</sub> control.

0751D.37

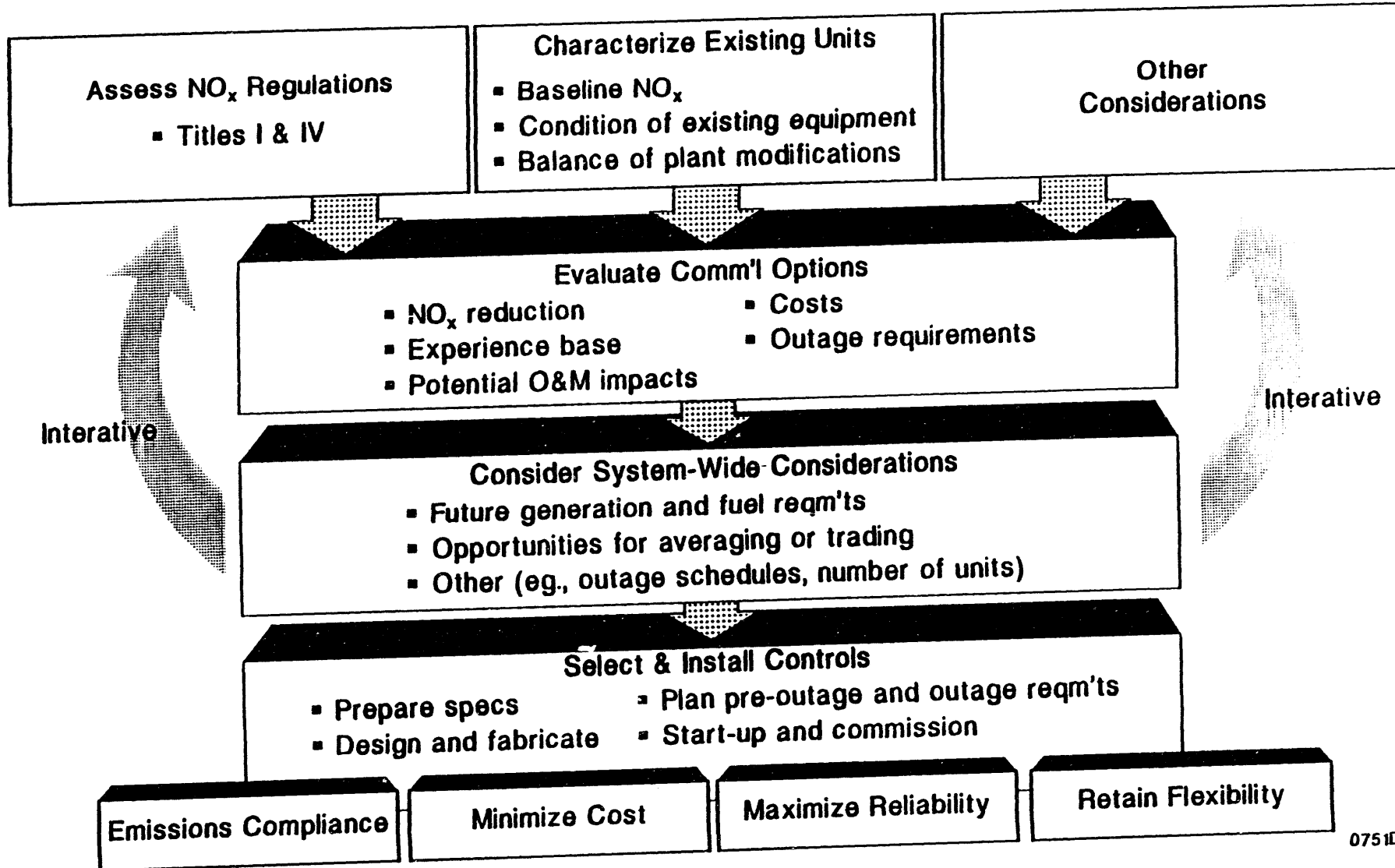
# Low NO<sub>x</sub> Cell Burner



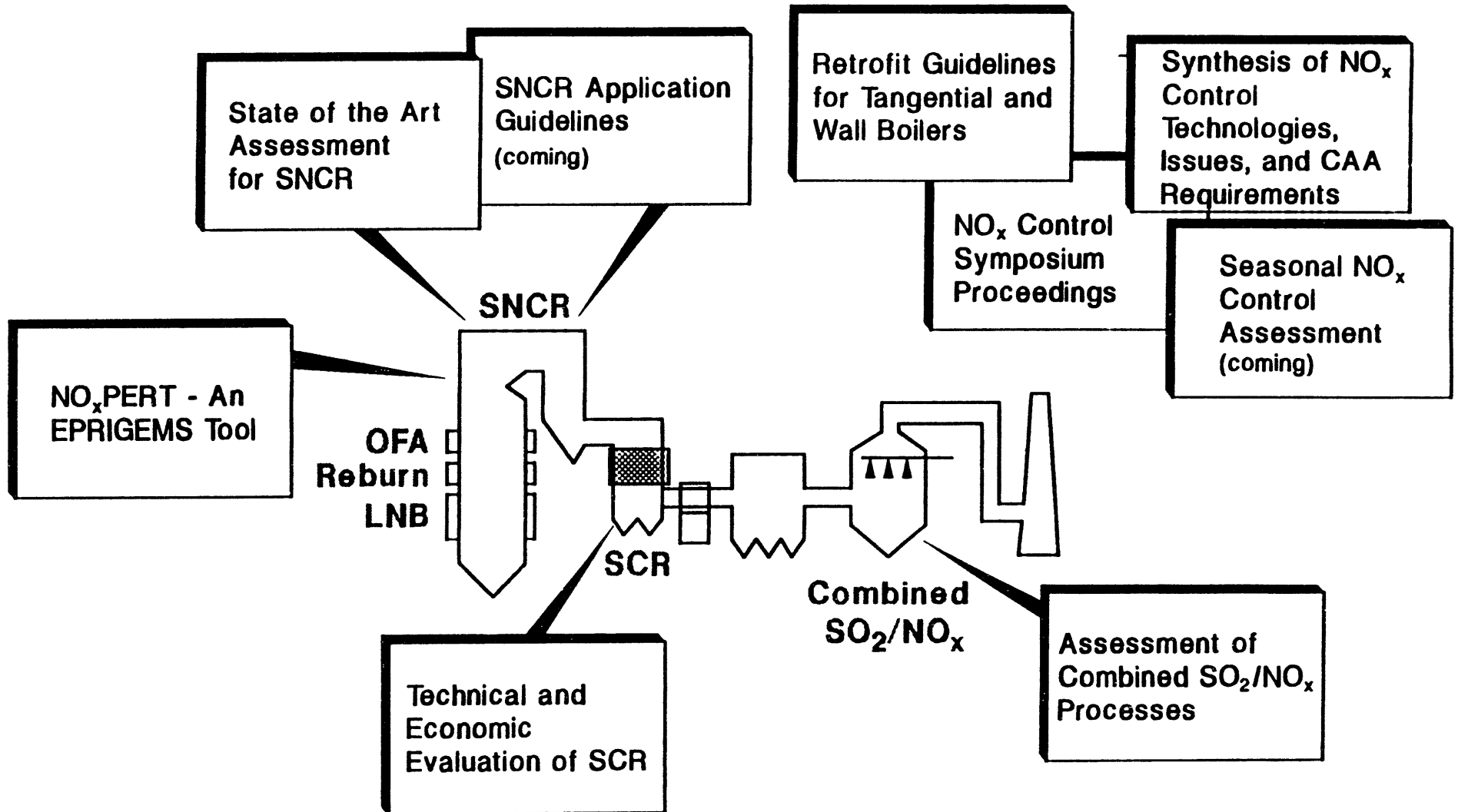
**Babcock & Wilcox**  
 a McDermott company  
 August 1990



# NO<sub>x</sub> COMPLIANCE PLANNING



# RETROFIT NO<sub>x</sub> CONTROLS FOR COAL-FIRED BOILERS 1993 EPRI Products



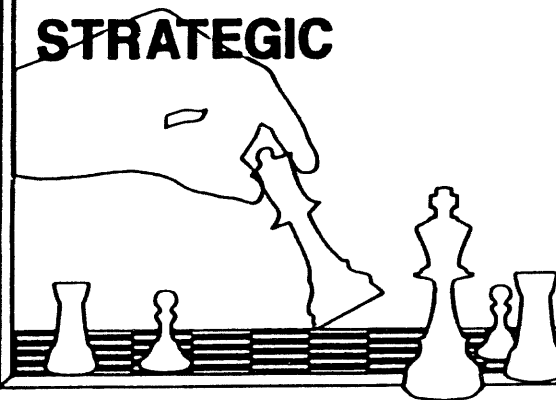
# CHALLENGES

# EMERGING NO<sub>x</sub> ISSUES

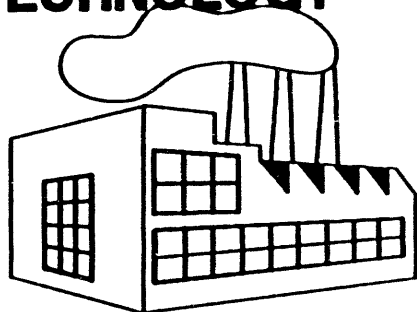
**REGULATORY**



**STRATEGIC**



**TECHNOLOGY**



**COST**



# REGULATORY

- Title IV
- Title I
- Future

# STRATEGIC

- Advanced generation  
vs. refurbishment
- Fuel selection
- Integration with heat rate  
of other environmental goals

# TECHNOLOGY

- Commercial development and acceptance
- Supplier design and manufacturing capabilities
- Optimization and troubleshooting
- New developments

# **COST**

- **Extent of balance of plant modifications**
- **Documenting operating costs**
- **Reducing capital costs**



## STATE EXTERNALITY TRENDS

**Joseph Van den Berg**  
**Director, Technical Services**  
**Edison Electric Institute**

# Electrifying a Competitive Future

# 60 Years of Progress!

# *The Obligation to Serve*



To be ready to serve you, your Electric Company must keep ahead of the growth of our community.

Public service carries with it the obligation to serve, instantly and constantly.



When you press a button or flick a switch, you want - and must have - *SERVICE* - at once, and for as long a time as you need it.

To give this service we constantly increase our facilities, planning years ahead; raising new money for extensions and betterments, and spending that money in your service.

Our obligation is to serve you. We shall continue to fulfil it to the best of our ability.

**Name of Light and Power Company**

**CITY AND STATE ADDRESS**

# Taxes, like chickens, always come home to roost

*Once an incident of little moment, taxes  
have today become a factor of great  
concern to every citizen and business.*

This is true of electric light and power users, and of the companies that sell them the service. A national average of ten cents of every dollar paid by users of domestic electric service in 1931 merely passed through the hands of power companies and on into the treasuries of local, county, school or other district, state or federal tax-collecting agencies. Out of every dollar collected for service in 1931 by this company      cents were paid out in taxes.

Users of our service pay not only their own taxes, but also pay additional taxes through their light and power bills, just as they pay extra taxes through rent, food, clothing and everything else they buy.

**It should be remembered that placing special or extra tax burdens on electric light and power companies, or their product, directly increase the tax burden of users of electric service.**

**Name of Light and Power Company**

**CITY AND STATE ADDRESS**

**MOTHER: COME OUT OF THE KITCHEN**



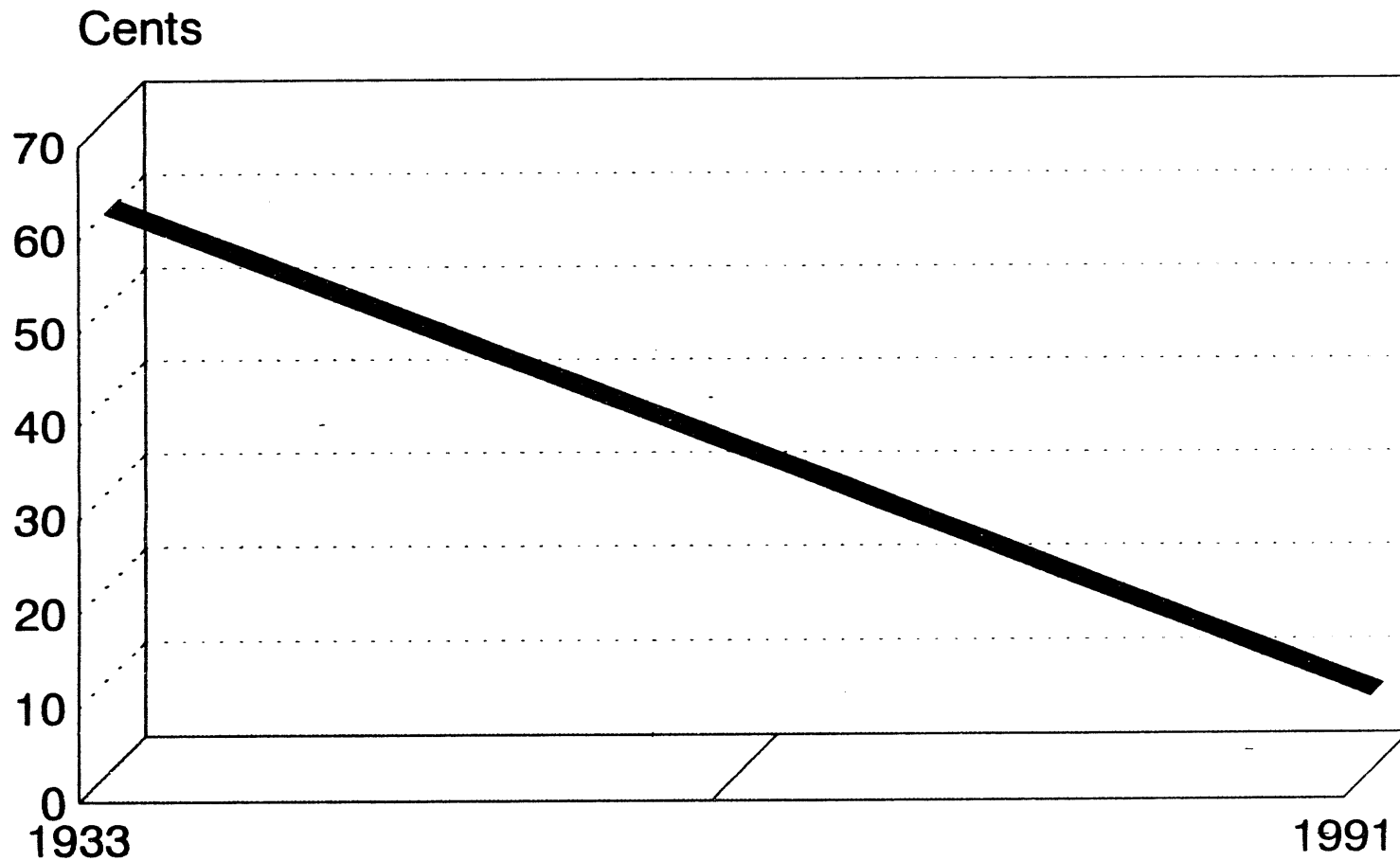
**ELECTRIC COOKING SAVES**  
**ANTIQUES ARE NOW USED IN PARLORS**  
**NOT KITCHENS**

Source: Duke Power Company Archives

EEI 1993

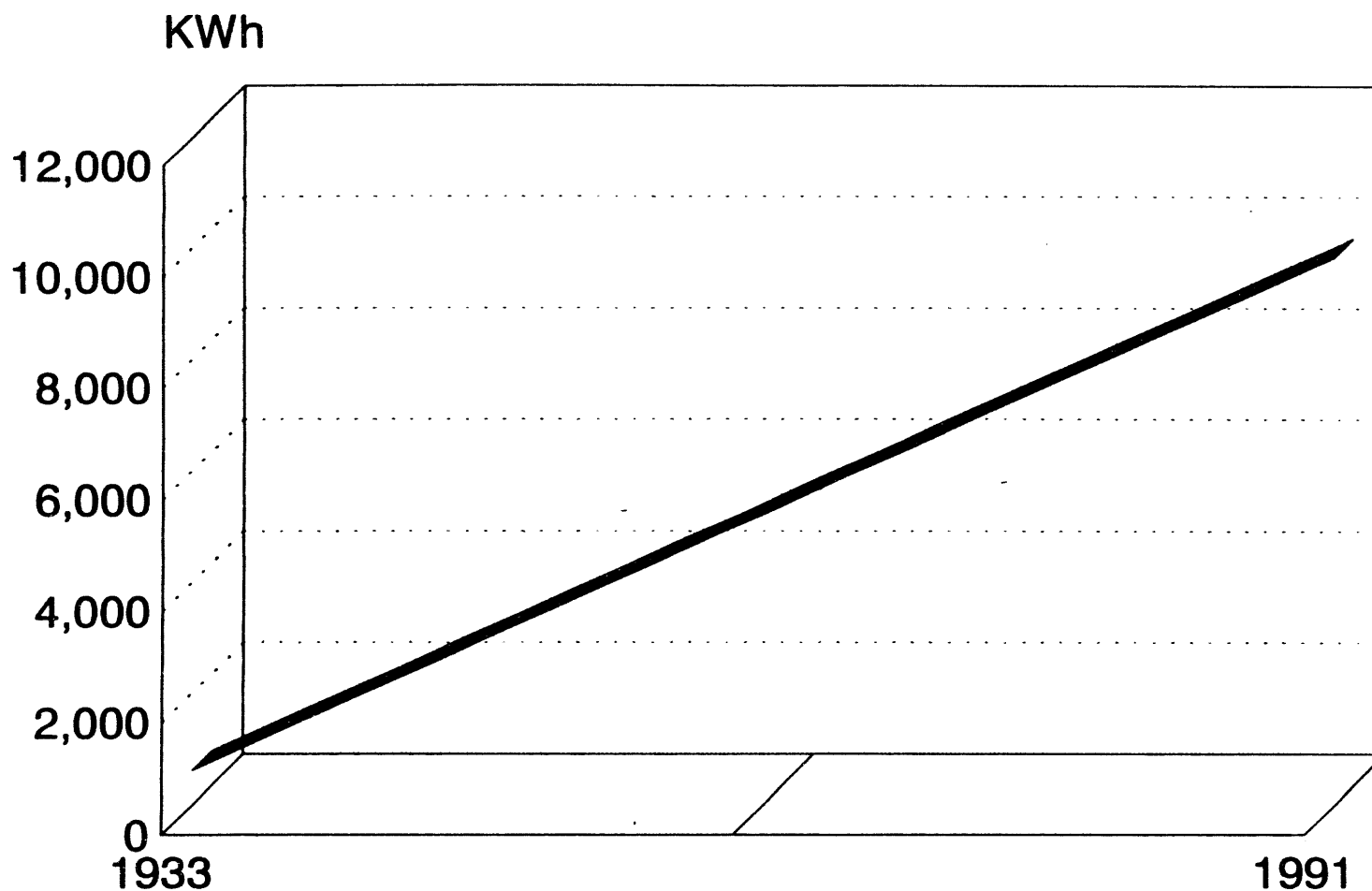
# Average Residential Cost Per KWh

Inflation Adjusted, in \$1992



Source: Electric Perspectives, May-June 1993

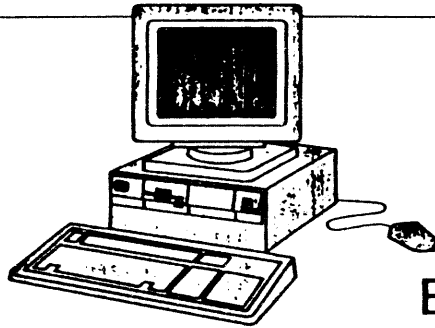
# Average Residential Electricity Consumption



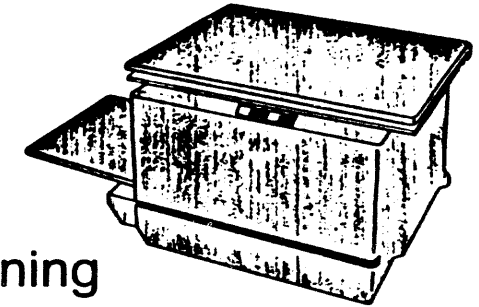
Source: EEI statistics  
Residential Energy Consumption statistics, EIA, Feb. 1993



# 30 Products That Changed Our Lives



Personal Computer



Bar Coding/Scanning

Microwave Oven

Integrated Circuits

Photocopying Machine

Automated Teller Machine

Hand-Held Pocket Calculator

Telephone Answering Machine

Fax Machine

Velcro Fastener

Birth Control Pill

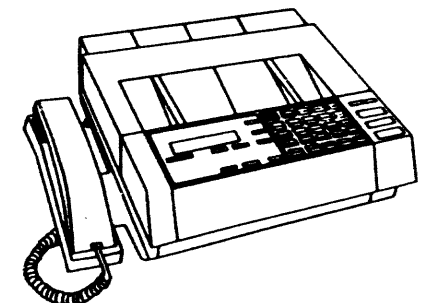
Touch-tone Telephone

Home Videocassette Recorder

Laser Surgery

Communications Satellites

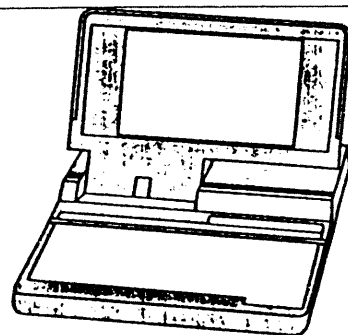
Apollo Lunar Spacecraft



Source: R&D Magazine, September 28, 1992

# 30 Products That Changed Our Lives

---



Computer Disk Drive

Organ Transplant Surgery

Fiber-optic Transmission Systems

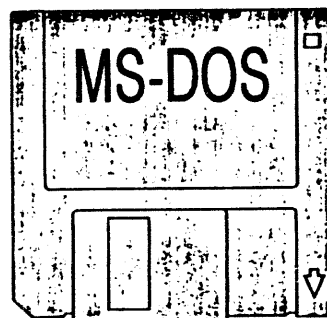
Disposable Diaper

Disk Operating System

(MS-DOS)

Magnetic Resonance

Gene-splicing Techniques



Microsurgery Techniques

Camcorder

Space Shuttle

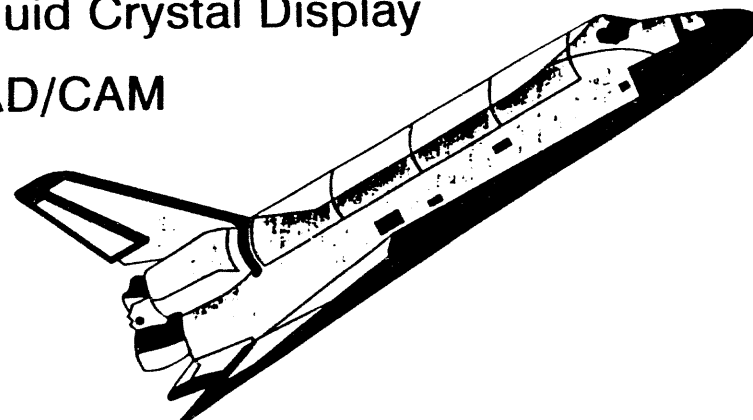
Home Smoke Alarm

Computer Aided Tomography

(CAT scan)

Liquid Crystal Display

CAD/CAM



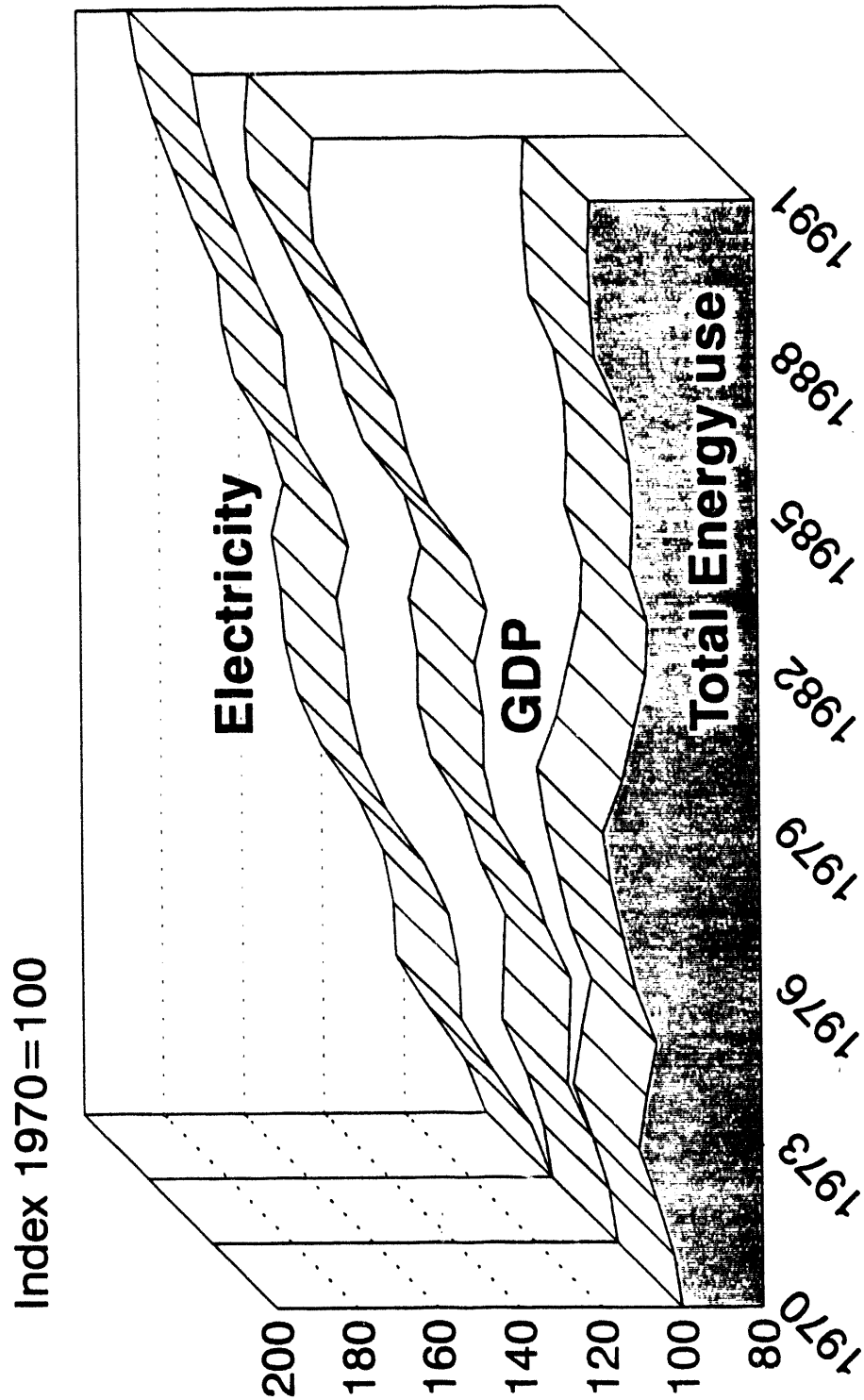
# Electrotechnology Benefits

---

- Increased Productivity and Improved Product Quality
- Lower Emissions in Most Cases
- Safer Work Environment
- Improves Competitiveness
- Less Overall Energy Consumed in Most Cases

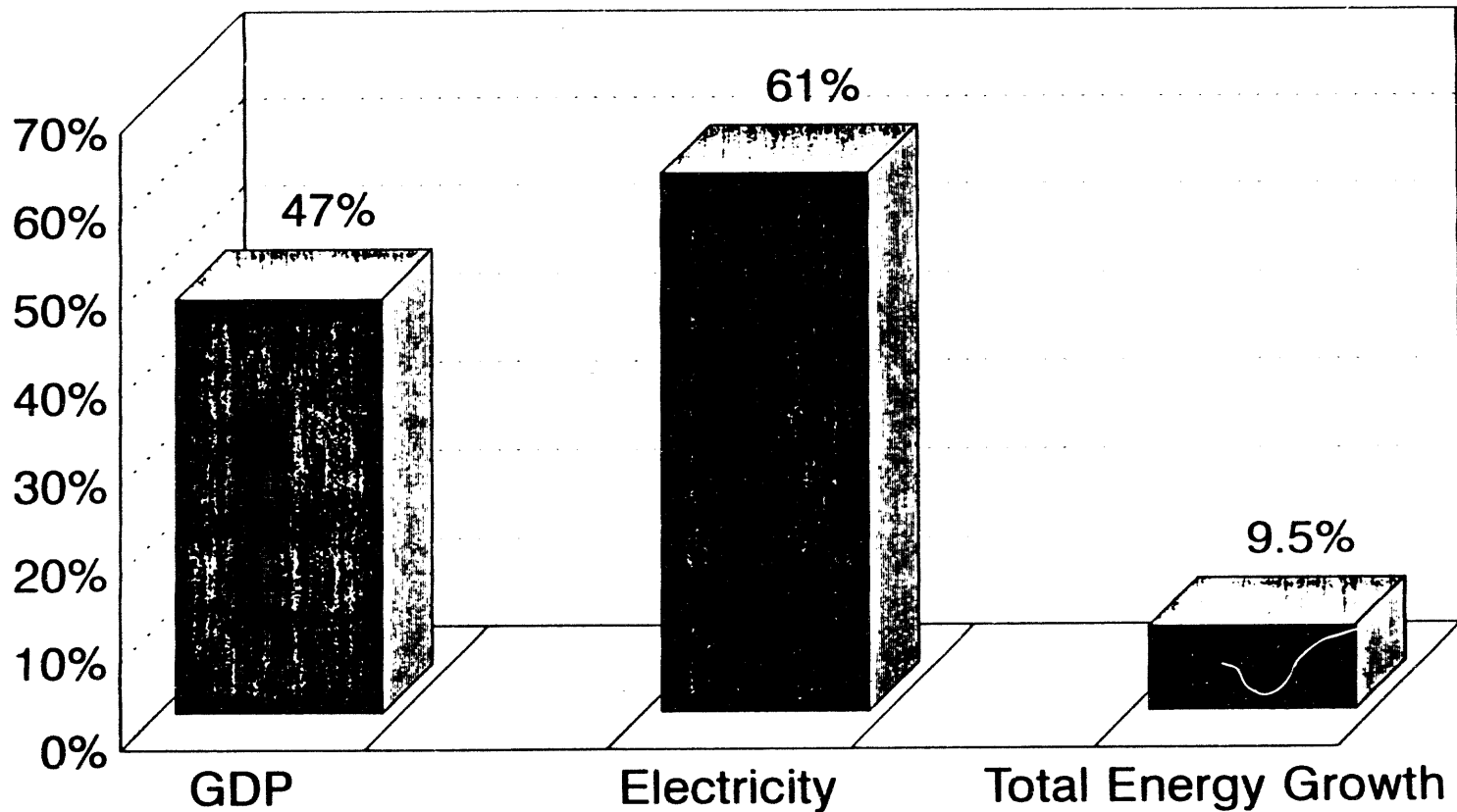
# Electricity, Energy, and Electricity Growth

1970 - 1991



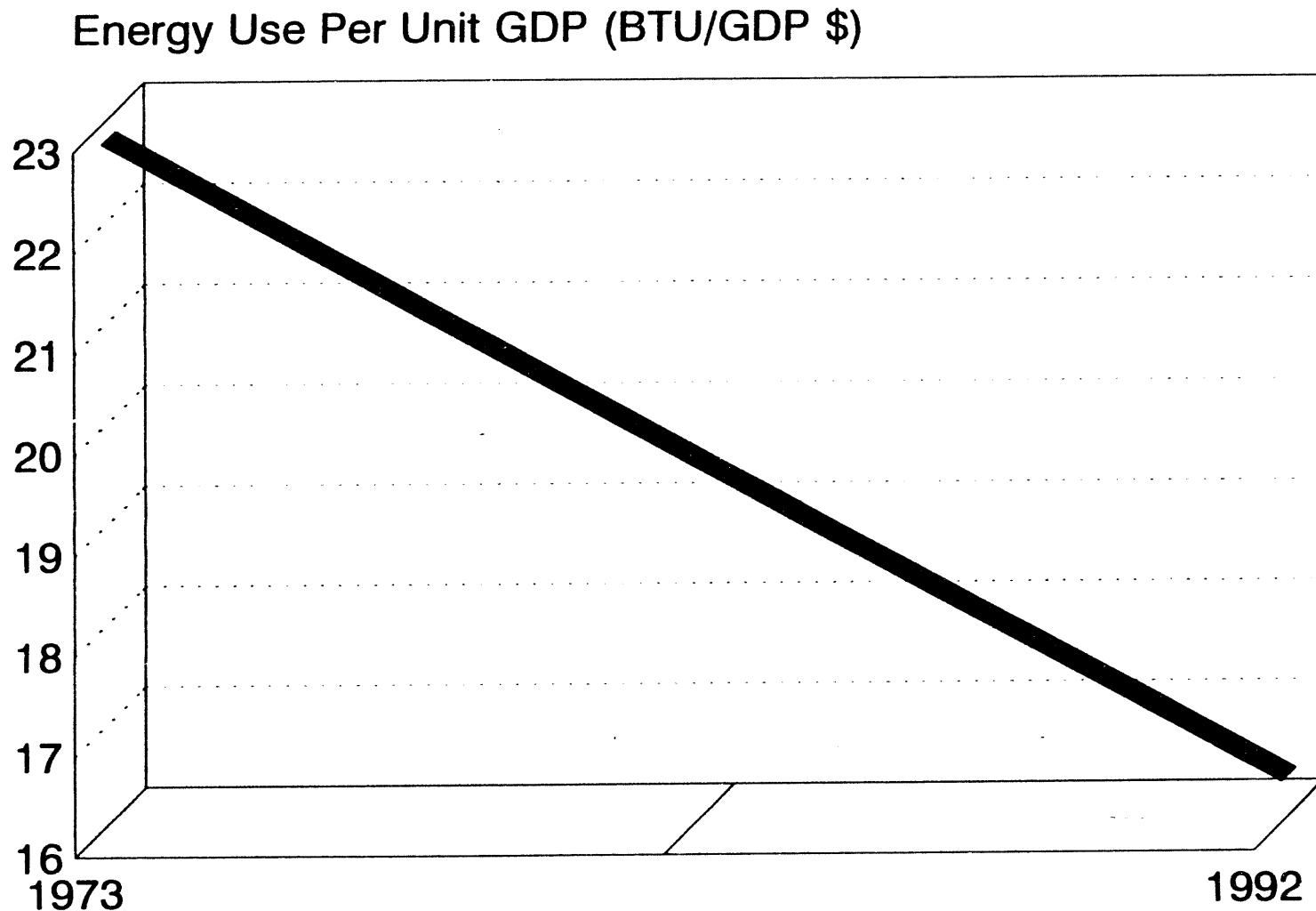
Source: U.S. Department of Commerce; Energy Information Administration

# Changes in GDP, Electricity Sales, and Total Energy Use 1973 - 1991

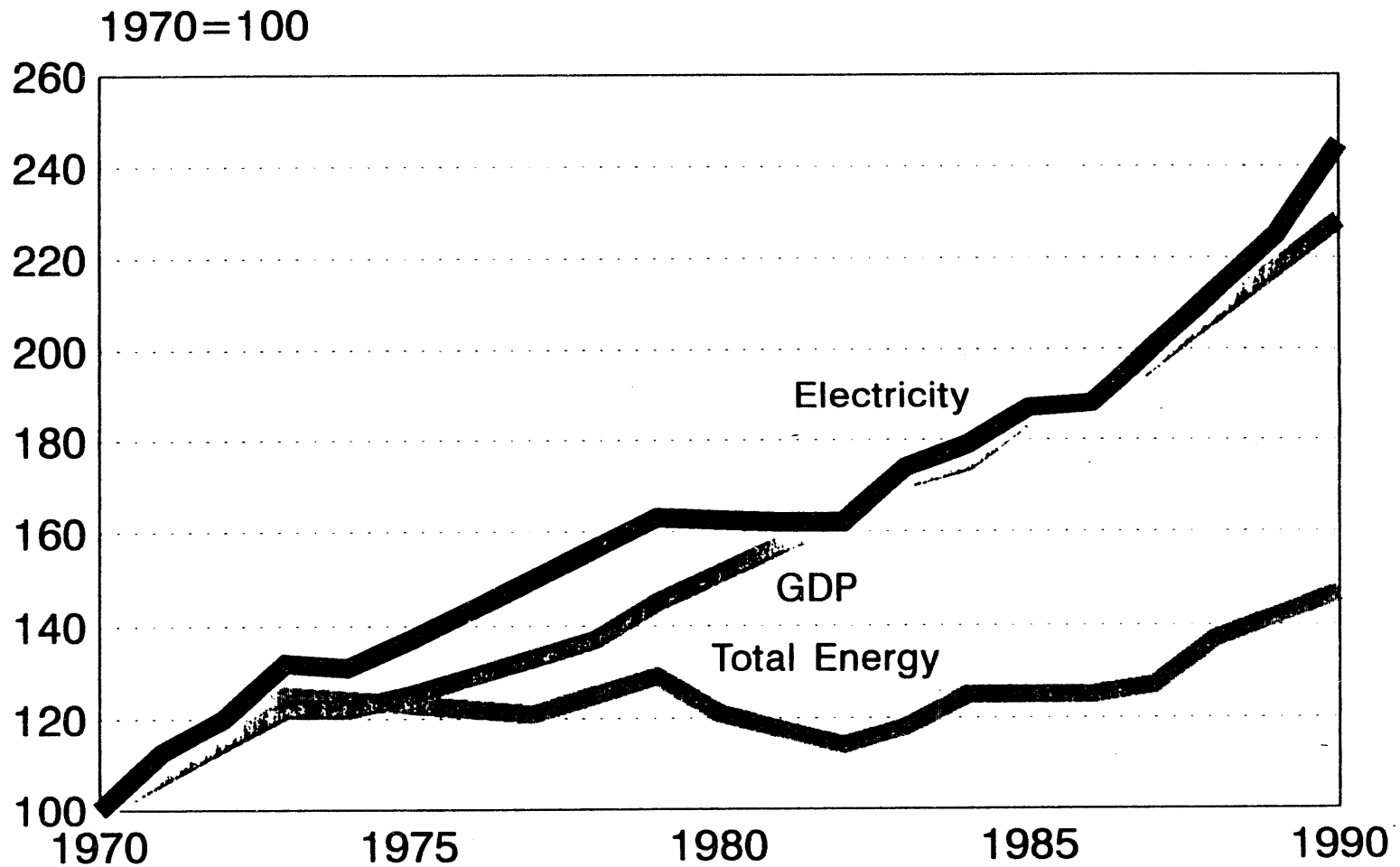


Source: U.S. Department of Commerce; Energy Information Administration

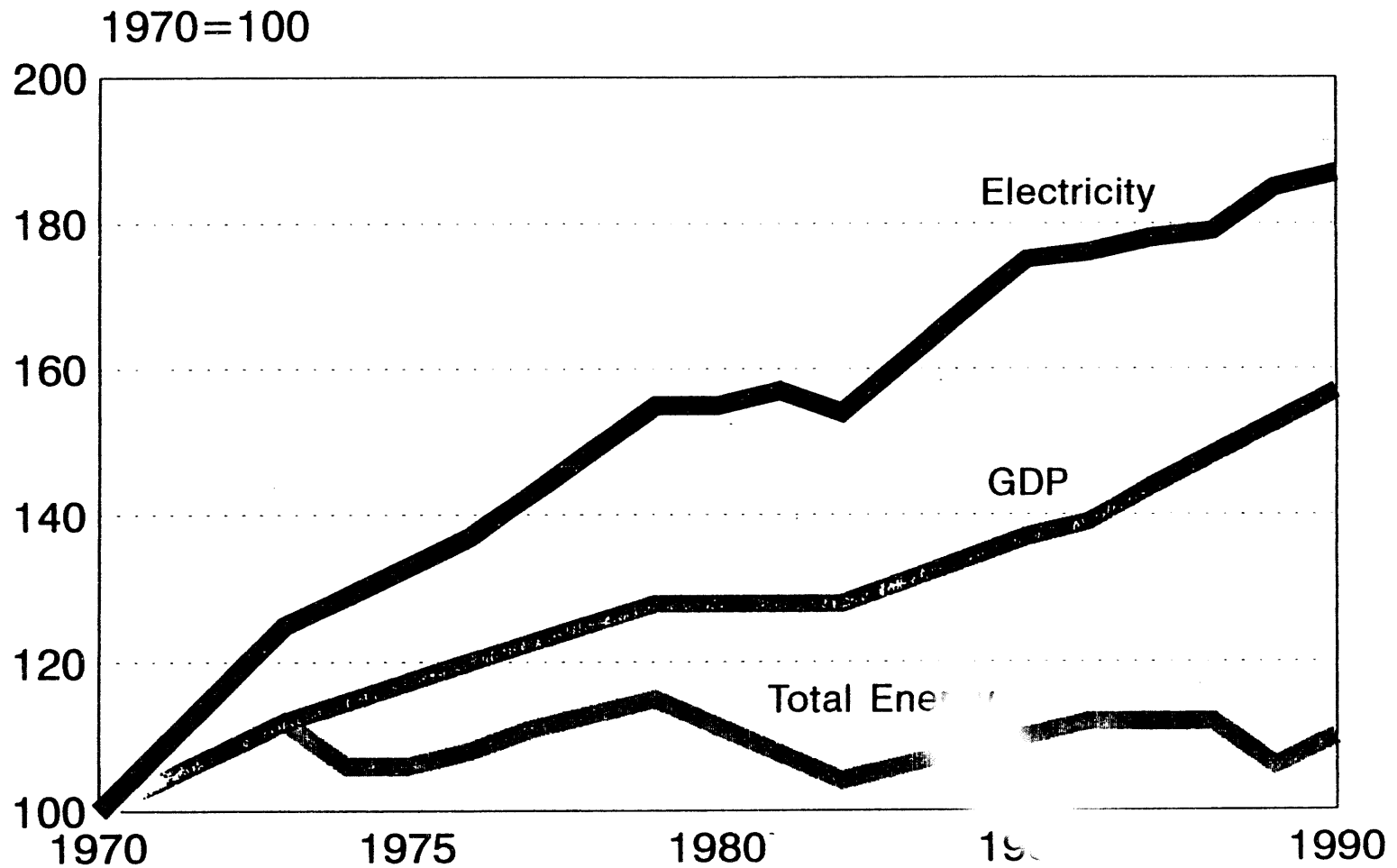
# U.S. Energy Use 1973 to 1992



# Changes in GDP, Electricity Sales, and Total Energy Use Japan Trends: 1970 - 1990



# Changes in GDP, Electricity Sales, and Total Energy Use Germany Trends: 1970 - 1990

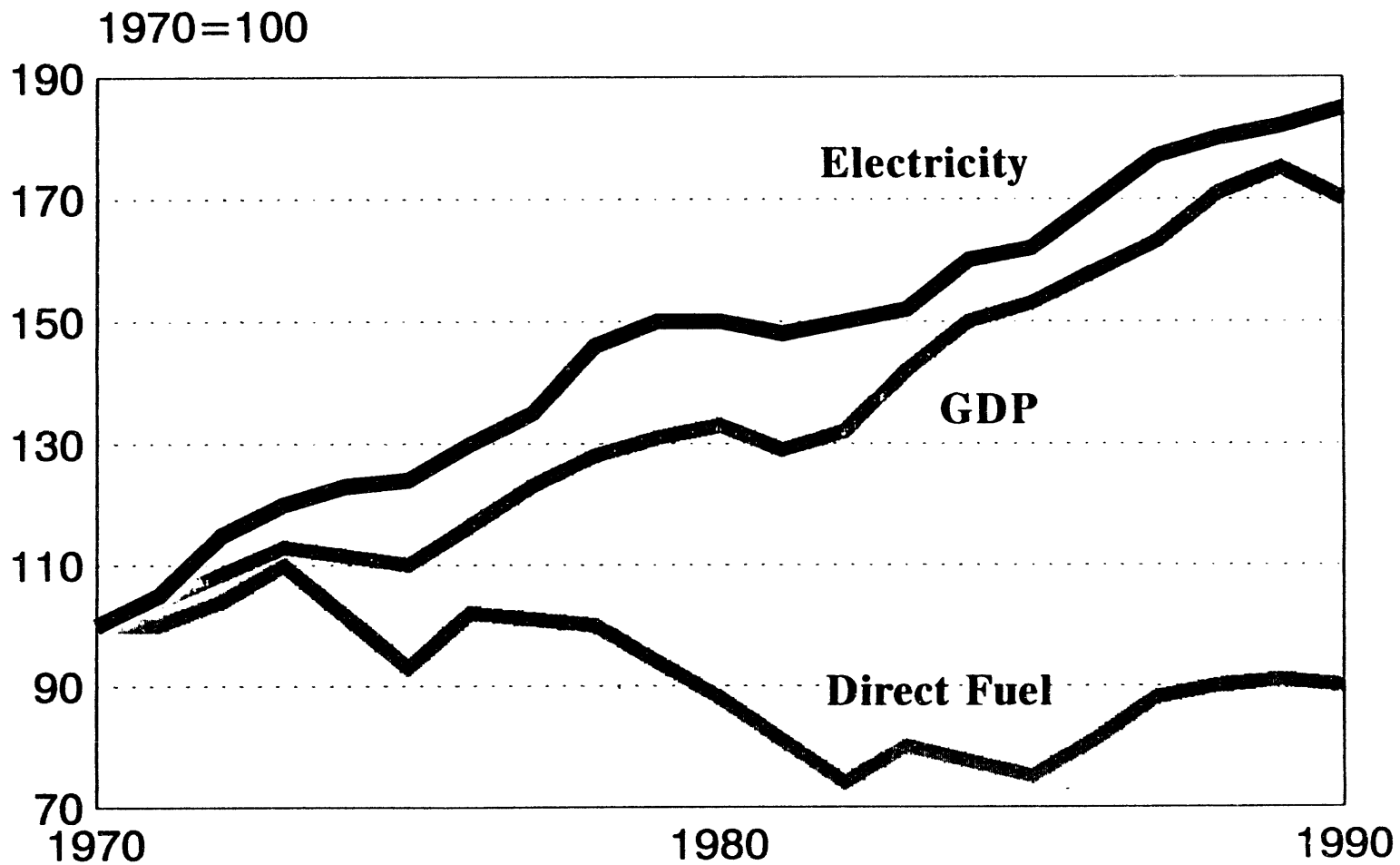


Source: Mills•McCarthy & Associates



# U.S. Trends 1970-1990

(Excludes Transportation)



# Electricity Consumption Follows GDP, Promotes Growth

---

*"To Foster Increased Productivity, Policy Should Stimulate Increased Efficiency of Electricity Use, Promote the Implementation of Electrotechnologies When They Are Economically Justified, and Seek to Lower the Real Costs of Electricity Supply."*

National Academy of Sciences, 1986

*"Historically, technical change exploiting the special qualities of electricity has contributed to increased productivity and thereby increases in gross national product. We can expect this trend to continue."*

National Academy of Sciences, 1986

***"Technology is the engine of economic growth. In the United States, technological advance has been responsible for as much as two-thirds of productivity growth since the Depression."***

Technology for America's Economic growth,  
A New Direction to Build Economic Strength,  
President Clinton, Vice President Gore, February 1993