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Systems Study of Conventional Combustion Sources in the Iron and Steel Industry

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Systems Study of Conventional Combustion Sources in the Iron and Steel Industry

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I. SUMMARY

A. BACKGROUND, DEFINITIONS AND ASSUMPTIONS

Process emissions from the iron and steel industry have been studied in the past, with little attention given to the contribution to air pollution of the conventional fossil fuel combustion equipment currently installed in steel mills. This study determines this contribution, compares it to process emissions and considers potential means to control the boiler emissions.

The study identified the pollutant sources according to equipment size, regional distribution, fuel, firing type, age and other factors of significance to air pollution emissions. Estimates of installed capacity were made for the base year, 1970, and projections were made for 1975 and 1980.

This study includes only watertube boilers (WT). The data-base was obtained from a variety of sources. Sales data were made available by the American Boiler Manufacturers Association (ABMA) [1-1] and several individual boiler manufacturers. Statistics compiled from the yearly boiler surveys, published by Power magazine [1-2] were used for checking purposes. Data on the boilers actually in operation were obtained from government agencies and telephone interviews with about 70 iron and steel plants across the country. The data were summarized by six regions (Figure 1-1).

These geographical regions are similar to those used in the Intermediate Size Boiler Study [1-5]. The rationale behind the choice of these regions was two-fold. First, the states in these areas are considered to have similar air pollution conditions, and secondly, such a regional grouping allowed comparison with air pollution resulting from boilers in U.S. industries in general.

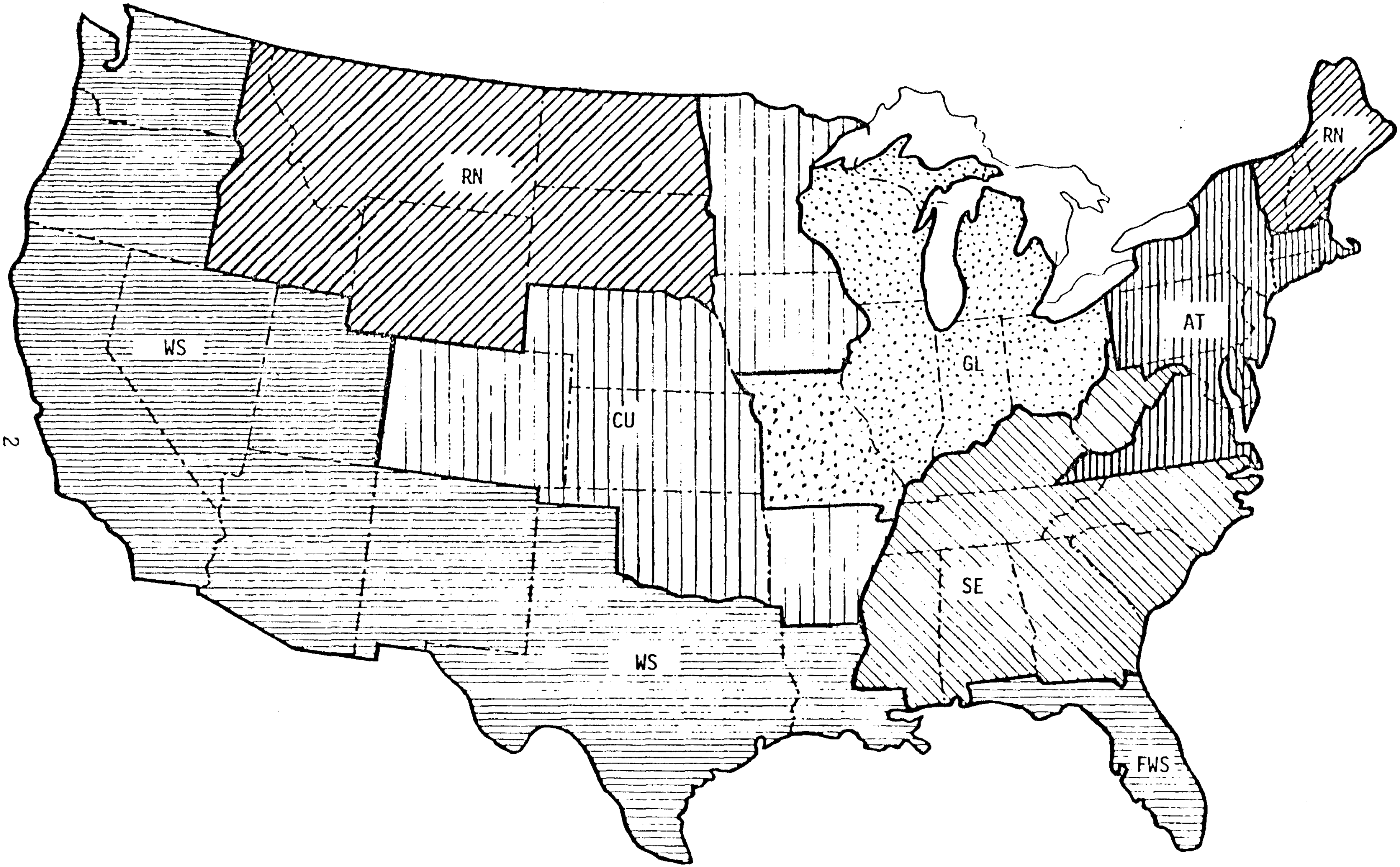

Figure 1-1. Regional Boundaries

Assumptions

(1) In order to obtain a complete 1970 inventory from this sample, the assumption was made that employment in the iron and steel industry was proportional to the boiler capacity in the industry.

(2) It was assumed that the number of units and the wide scope of the study permitted the application of average operating characteristics, emission factors, fuel prices, etc.

(3) No controls for SO_2 and NO_x were assumed in developing the emission estimates. The process particulate emissions are shown partially controlled, based on estimates and available statistics. The boiler particulate emissions are shown uncontrolled.

(4) In developing projections one of the main assumptions used was that the ratio of the boiler capacity used for non-power purposes to the total tons of raw steel produced in 1970 [1-3] would remain constant over the years. Projected production figures were obtained from the Battelle study of the integrated iron and steel industry [1-4].

(5) The energy required to produce the projected raw steel [1-4] for 1975 and 1980 was determined by means of linear regression of historical data [1-3]. The fraction of the total energy generated in-house was used to arrive at the boiler capacity required for power generation.

(6) Fuel distribution for the projected years was based on the fuel patterns developed in the Walden study of intermediate-size boilers [1-5] and projections of raw steel requirements made by Battelle [1-4].

(7) No changes in boiler operating factors, such as boiler efficiency, load factor, fuel sulfur content, were assumed in the boiler projections.

B. BOILER INVENTORIES

The total estimated capacity of boilers installed in the iron and steel industry in 1970 was 103.5 million pounds of steam an hour (pph), representing approximately 1,600 units. Table 1-1 shows a summary of this inventory by region and fuel.

Projections of boiler capacities were made in the following manner. The energy required to produce the raw steel projected by the Battelle Systems Study of the Integrated Iron and Steel Industry [1-4] was determined. The total energy required for the iron and steel industry was derived from this figure. The estimated boiler capacity required to produce this energy was obtained by projecting the percentage of the total power generated in-house. This gave 1975 and 1980 figures for the boiler capacity to be used for power generation. The assumption was then made that the ratio of boiler capacity used for non-power purposes to the total tons of raw steel produced in 1970 would remain constant over the years. Using the Battelle projections of raw steel production [1-4] the boiler capacity needed for process and space heating was derived for 1975 and 1980. By summing the capacities required for power generation and for process and space heating the total projected boiler capacities were found to be 116.8 and 125.0 million pounds per hour for 1975 and 1980, respectively. Regional projections of fuel use and the various boiler sizes were derived from the Walden study of intermediate-size boilers [1-5]. The projected boiler inventories are shown in Table 1-2.

C. FUEL CONSUMPTION AND BOILER EMISSIONS

The annual fuel consumption of boilers was calculated by using the following formula:

$$\text{Btu/yr} = \frac{\text{capacity (lb/hr)} \times \text{load factor} \times 8760\ \text{(hours/yr)} \times 975\ \text{(Btu/lb)}}{\text{efficiency}}$$

TABLE 1-1

1970 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY*
(10^3 pph)

Boilers	Fuels	AT	GL	WS	SE	Total
$WT_{\leq 100,000}$ pph	CL	1,729	3,956	73	1,439	7,197
	RO	2,247	1,148	182	135	3,712
	GS	5,013	2,425	1,277	1,170	9,885
	BFG	5,878	3,829	1,131	1,260	12,098
	COG	2,420	1,404	985	495	5,304
$WT_{100,001-250,000}$ pph	CL	1,317	4,698	42	864	6,921
	RO	1,712	1,364	106	81	3,263
	GS	3,820	2,879	739	702	8,140
	BFG	4,478	4,546	655	756	10,435
	COG	1,844	1,667	570	297	4,378
$WT_{>250,000}$ pph	CL	1,070	3,709	77	1,810	6,666
	RO	1,391	1,077	192	170	2,830
	GS	3,104	2,273	1,344	1,470	8,191
	BFG	3,639	3,589	1,190	1,584	10,002
	COG	1,498	1,316	1,037	622	4,473
TOTAL		41,160	39,880	9,600	12,855	103,495

*Regions CU and RN were not included because of negligible participation in the primary iron and steel industry.

TABLE 1-2

PROJECTED BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY BY SIZE
(10^6 pph)

	AT		GL		WS		SE		Total	
	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
WT ≤100,000 pph	21.1	23.5	15.6	17.0	4.5	4.7	5.5	5.8	46.7	51.0
WT 100,001-250,000 pph	14.4	15.6	16.5	17.9	2.3	3.7	2.9	3.1	36.1	40.3
WT >250,000 pph	11.3	11.2	12.7	12.6	4.0	4.0	6.0	5.9	34.0	33.7
	46.8	50.3	44.8	47.5	10.8	12.4	14.4	14.8	116.8	125.0

The 1970 fuel consumption pattern is shown in Figure 1-2. It is noted that almost half of the fuel used consists of fuels generated elsewhere in the iron and steel plant.

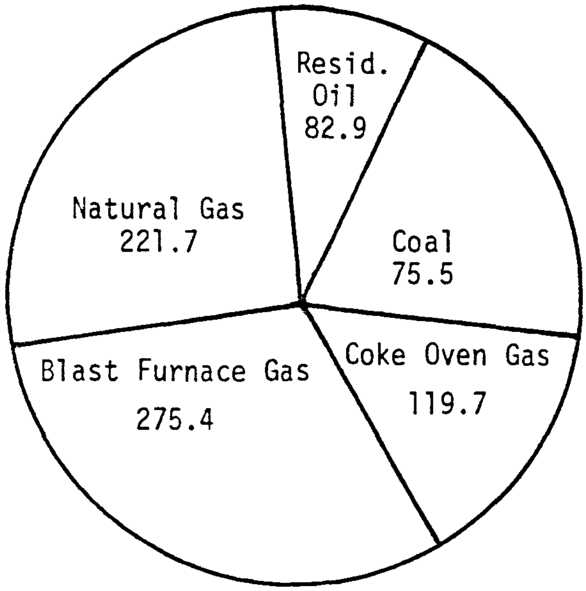

Figure 1-2. 1970 Fuel Consumption by Boilers in the Iron and Steel Industry in 10^{12} Btu.***

Uncontrolled boiler emissions were calculated according to the following equations:

$$SO_2 \text{ (tons)} = \frac{\text{fuel consumption (Btu/yr)} \times \text{emission factor (lb/Btu)} \times \text{\% sulfur}^{*}}{2000 \text{ (lb/ton)}}$$

$$NO_x \text{ (tons)} = \frac{\text{fuel consumption (Btu/yr)} \times \text{emission factor (lb/Btu)}}{2000 \text{ (lb/ton)}}$$

$$\text{Particulates (tons)} = \frac{\text{fuel consumption (Btu/yr)} \times \text{emission factor (lb/Btu)} \times \text{\% ash}^{**}}{2000 \text{ (lb/ton)}}$$

For the conventional fuels the emission factors, sulfur and ash contents used for industrial intermediate-size boilers, were applied [1-5].

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*Only in the case of coal- or oil-fired boilers

**Only in the case of coal-fired boilers

***Distillate oil use in the iron and steel industry is negligible.

The corresponding factors for blast furnace gas and coke oven gas were obtained by studying the process which creates these gases (see Appendix C). The estimated air pollution emissions for 1970 and the projected figures for 1975 and 1980 are summarized in Tables 1-3, 1-4 and 1-5.

From these results it is clearly evident that the combustion of the fossil fuels (as compared to the non-conventional fuels) produce the major fraction of the emissions. Blast furnace gas and coke oven gas are relatively clean fuels when compared to coal and fuel oil.

D. PROCESS EMISSIONS

Process emissions in the iron and steel industry emanate from two distinct types of sources:

(i) emission produced during the handling of raw materials and the subsequent processing of these materials to produce steel, i.e., the conventional process emissions.

(ii) emissions resulting from non-boiler fuel combustion needed to meet the energy demands during the manufacturing steps

(i) Conventional Process Emissions

The conventional process emissions were determined by calculating the emissions for each of the following processes in the iron and steel industry:

(1) Sinter plants
(2) Pellet Plants
(3) Coke manufacture
(4) Blast furnaces
(5) Steel furnaces
- Open hearth
- Basic oxygen furnace (BOF)
- Electric arc furnace
(6) Scarfing
(7) Materials handling

TABLE 1-3

SUMMARY OF PROJECTED SO_2 EMISSIONS (10^3 tons)

	1970			1975			1980		
	Fossil Fuels	Non-Conventional Fuels	Total	Fossil Fuels	Non-Conventional Fuels	Total	Fossil Fuels	Non-Conventional Fuels	Total
AT	81.2	37.7	118.9	67.8	36.8	104.6	76.1	39.6	115.7
GL	206.9	28.5	235.4	228.3	35.2	263.5	249.9	37.1	287.0
WS	6.0	16.8	22.8	7.3	9.1	16.4	8.1	9.7	17.7
SE	49.0	9.2	58.2	42.9	11.0	53.9	45.0	11.7	56.7
TOTAL	343.1	92.2	435.3	346.3	92.1	438.4	379.1	98.1	477.2

TABLE 1-4

SUMMARY OF PROJECTED PARTICULATES EMISSIONS (10^3 tons)

	1970			1975			1980		
	Fossil Fuels	Non-Conventional Fuels	Total	Fossil Fuels	Non-Conventional Fuels	Total	Fossil Fuels	Non-Conventional Fuels	Total
AT	73.2	2.4	75.5	51.2	2.1	53.3	55.3	2.1	57.4
GL	227.6	1.9	229.5	247.8	2.1	249.9	276.4	1.9	278.3
WS	4.0	.7	4.7	5.5	.1	6.0	6.1	.6	6.7
SE	67.9	.6	68.5	62.4	.7	63.1	65.6	.6	66.2
TOTAL	372.7	5.6	378.3	366.9	5.4	372.3	403.4	5.2	408.6

TABLE 1-5

SUMMARY OF PROJECTED NO_x EMISSIONS (10^3 tons)

	1970			1975			1980		
	Fossil Fuels	Non-Conventional Fuels	Total	Fossil Fuels	Non-Conventional Fuels	Total	Fossil Fuels	Non-Conventional Fuels	Total
AT	32.4	12.9	45.3	36.1	12.4	48.5	41.8	12.4	54.2
GL	49.8	10.4	60.2	56.0	12.2	68.2	62.4	12.1	74.5
WS	4.4	5.2	9.6	6.8	3.0	9.8	8.5	3.3	11.8
SE	15.8	3.3	19.1	15.9	4.0	19.9	17.0	4.0	21.0
TOTAL	102.4	31.8	134.2	114.8	31.6	146.4	129.7	31.8	161.5

the emission calculations were based on the input/output data for each source [1-4], and where reliable statistics were available, controlled particulate emissions were calculated. Thus the particulate process emissions, as shown in this report, may be considered partially controlled, whereas no control was assumed for process emissions of SO_2 and NO_x.

Process emission projections were based on projections of production figures obtained from the Battelle report [1-4] and analysis of the various manufacturing steps which cause them. The results are summarized in Table 1-6.

TABLE 1-6

CONVENTIONAL PROCESS EMISSIONS OF THE IRON AND STEEL INDUSTRY (10^3 tons)

	1970			1975			1980		
	SO_2	Part.	NO_x	SO_2	Part.	NO_x	SO_2	Part.	NO_x
Sirter Plants	32	96	24	39	117	29	42	124	31
Pellet Plants	*	*	*	*	*	*	*	*	*
Coke Manufacture	*	152	*	*	155	*	*	159	*
Blast Furnaces	*	*	*	*	*	*	*	*	*
Steel Furnaces									
Open Hearth	35	312	25	31	189	22	25	8	18
B.O.F.	2	28	*	2	36	*	3	46	*
Electric Arc	*	28	*	*	15	*	*	20	*
Scarfing	*	63	*	*	73	*	*	86	*
Materials Handling	*	446	*	*	533	*	*	612	*
TOTALS	69	1,125	49	72	1,118	51	70	955	49

*Emissions less than 500 tons

(ii) Fuel Combustion Process Emissions

Five fuels are extensively used in the iron and steel industry to supply process energy: fuel oil, natural gas, tar and pitch, coke oven gas and blast furnace gas. The latter three fuels are produced within the steel mill as by-products and their production depends on the coke rate and ultimately on pig iron requirements.

1970 fuel oil and natural gas consumption figures were available in the annual reports of the American Iron and Steel Institute (AISI) [1-3]. Future consumption of these fuels was determined by projecting time series available in the AISI reports as well as the ratios between fuel and pig iron, open hearth steel and raw steel production.

A summary of the calculated emissions is shown in Table 1-7.

E. COMPARISON OF BOILER AND PROCESS EMISSIONS

Figure 1-3 shows the boiler and process emissions in the iron and steel industry from 1970 to 1980.

It must be emphasized that SO_2 and NO_x emissions are shown uncontrolled, representing the actual situation in 1970. The particulate emissions are shown uncontrolled for boilers and partially controlled for process emissions. This is due to the lack of data on air pollution control equipment installed on boilers in the iron and steel industry. The comparison between boiler and process particulate emissions is therefore not as straightforward as the comparison for the other two pollutants. The fact remains, however, that the boilers in the iron and steel industry are major contributors to the total SO_2 and NO_x emissions, and represent a significant portion of the total particulate emissions.

F. CONTROL STRATEGIES

The analysis of control of emissions from boilers was approached in terms of strategies for both control of the separate three pollutants and also in terms of combined emissions. The principal control approaches examined were:

1. Fuel Switching
2. Flue Gas Treatment
   - Particulate Collectors
   - SO_2 Removal Systems
   - NO_x Removal Systems

TABLE 1-7

PROCESS EMISSIONS FROM NON-BOILER FUEL COMBUSTION IN THE IRON AND STEEL INDUSTRY
(tons)

	1970			1975			1980		
	SO_2	Part.	NO_x	SO_2	Part.	NO_x	SO_2	Part.	NO_x
Blast Furnace Area	-	2,220	160	-	2,400	170	-	2,200	170
Coke Oven Underfiring	106,725	2,515	5,900	95,000	2,300	6,000	97,000	2,500	6,000
Heating and Annealing Furnaces and Heating Ovens for Wire Rods	194,000	7,170	5,600	196,500	8,300	6,700	205,500	9,300	7,700
TOTALS	300,725	11,905	11,660	291,500	13,000	12,870	302,500	14,000	13,870

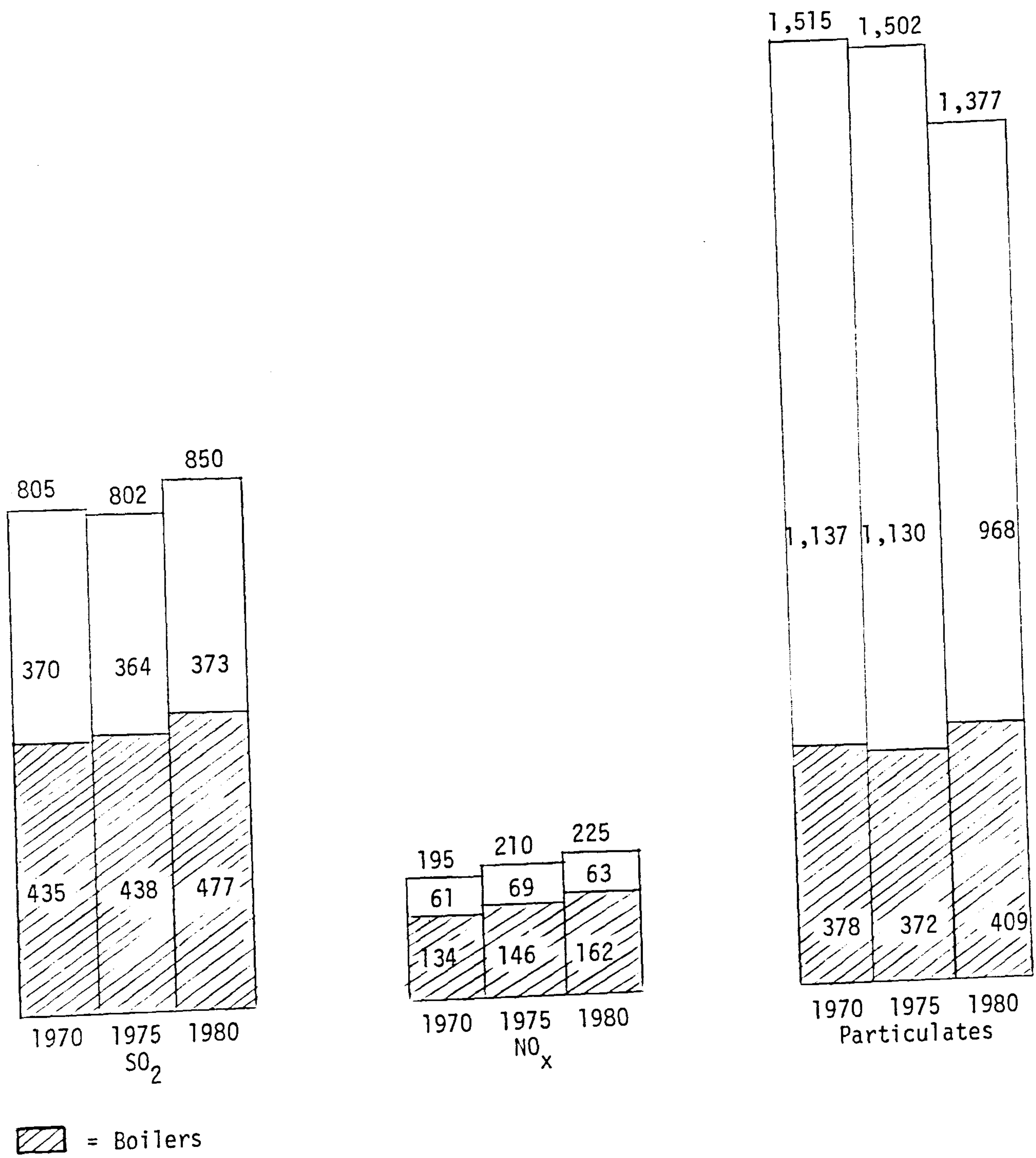

Figure 1-3. Boiler and Process Emissions 1970-1980 (10^3 tons).

3. Combustion Design
   - Fuel Additives
   - Combustion Modifications and Control
     - Low Excess Air (LEA)
     - Flue Gas Recirculation (FGR)
4. Strategies of Particular Application to the Iron and Steel Industry

Estimates of the applicability, pollution reducing potential and cost of implementing each control strategy were obtained.

G. COST EFFECTIVENESS

The cost effectiveness of applying the following three control strategies were examined:

1. Fuel Switching
2. Flue Gas Treatment - Alkaline Scrubbing
3. Maximum Reduction-Reasonable Cost Total Program, i.e., combination of fuel switching, fuel additives and combustion modifications.

Fuel switching emerged as the most effective strategy. However, flue gas treatment approximates fuel switching in its combined effect on the simultaneous removal of all of the pollutants, although the initial capital costs of flue gas treatment are much higher than fuel switching. These results are shown in Table 1-8.

The relative effectiveness of fuel switching depends on the price of fuel, which in turn depends on its availability. No models for availability were introduced in the cost effectiveness analysis.

Should, however, the price of fuel increase rapidly due to demand, so that fuel switching would not become as attractive, it was concluded that the iron and steel industry was in a fairly favorable position to adopt other control strategies because of the high load factors of the boilers and the general level of maintenance available in the industry.

TABLE 1-8

ALTERNATIVE STRATEGIES FOR BOILERS IN THE IRON AND STEEL INDUSTRY

	SO_2		NO_x		Particulates		Cost $\$ 10^6$	
	Emissions 10^3 tons/Y	% Reduction	Emissions 10^3 tons/Y	% Reduction	Emissions 10^3 tons/Y	% Reduction	Capital	Annual Operating
1975 Projected Base Level	438	-	146	-	372	-	-	-
Fuel Switching	134	69	129	11	17	95	11.6	39.0
Flue Gas Treatment	22	95	117	20	17	95	238	137

H. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

Three major conclusions emerge from this study:

(a) Steam raising boilers are a significant source of air pollution in the iron and steel industry. These boilers emit about 1/3 the particulate loadings of the process emissions but produce annually about half of the total SO_2 and two thirds of the NO_x.

(b) A significant fraction of the particulate and SO_2 emissions from the boilers result from the combustion of conventional fossil fuels. This is a result of the relative cleanliness (with respect to particulates and sulfur) of coke oven gas and blast furnace gas as compared to the conventional fossil fuels.

(c) Mainly as a consequence of (b), it is concluded from the control strategy cost effectiveness analyses that fuel switching would be the most effective means of control.

2. Recommendations

Examination of the results of the development of emission estimates and projections and analysis of control strategies point to two principal sets of recommendations:

(1) Improvement on the present study
(2) Implementation of fuel switching

a. Improvements of the Present Study

The first set reflects uncertainties and limitations resulting from assumptions, idealizations and imperfect data inputs inherent in the analytic procedures employed in the study.

Anticipating that strategy evaluation appears more meaningful on the basis of combined effects on all three pollutants, it would be valuable to develop a parallel means to combine the emissions into a single quantity using some weighting factor to account for permissible levels of exposure.

Other improvements are more direct. The study should be updated and checked against actual future developments. More fine structure should be introduced. There is need to improve the emission factor data and the information concerning the fraction of units controlled. This information is required particularly for the process emissions where very little information is available and yet these "rough" emission estimates would suggest that the iron and steel industry is a significant industrial polluter.

The fuel switching analysis depends on several key assumptions regarding fuel price and availability. Re-examination considering supply price forecasts should be made.

b. Implementation of Fuel Switching

Fuel switching was shown to be the preferred control strategy as long as fuel prices do not increase. However, recent trends in prices, particularly for low sulfur fuels, would suggest rapid increases in the near future. Because fuel switching has many attractive features other than low annual operating cost, it is important to seek means to maintain the price of fuel and the adequacy of supply at levels where this strategy remains effective.

REFERENCES TO SECTION I

1-1. American Boiler Manufacturers Association, Annual Reports on Water-tube Boiler Sales, 1947-1970.

1-2. Annual Boiler Surveys by Power Magazine, 1940-1970.

1-3. Statistical Reports, American Iron and Steel Industry, 1968-1970.

1-4. A Systems Analysis Study of the Integrated Iron and Steel Industry, Battelle Memorial Institute, Columbus, Ohio, 1964.

1-5. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, Cambridge, Mass., 1971.

II. INTRODUCTION

This report describes the results, methodology, and data base for a study of air pollution from conventional combustion sources in the primary iron and steel industry. This work has been carried out under Contract No. EHS-D-71-21, sponsored by the Office of Research and Monitoring (OR&M) of the U.S. Environmental Protection Agency.

The purpose of this systems study was:

(1) to obtain a complete and current inventory of conventional stationary fossil fuel combustion equipment installed in the iron and steel industry,

(2) to project into the future the boiler inventory installed in this industry,

(3) to calculate SO_x, NO_x, and particulate emissions resulting from these types of conventional fossil fuel combustion equipment for the present and future,

(4) to compare these emissions to total process emissions in the iron and steel industry,

(5) to study the cost effectiveness and program required of control strategies, applicable to the boilers in the iron and steel industry.

The work was divided into the following phases:

I. Identification of the 1970, 1975, and 1980 boiler inventories, and calculation of the fuel consumed by these boilers and the air pollution resulting therefrom.

II. Identification of the 1970, 1975, and 1980 process emissions.

III. Comparison of the emissions from conventional boilers to process emissions.

IV. Techno-economic evaluation of air pollution control.

V. Program planning outline.

The boiler data for this study were obtained from a variety of sources, including the American Boiler Manufacturers Association (ABMA), Power magazine's yearly boiler surveys, government agencies, and telephone interviews with approximately 70 iron and steel plants. Fuel consumption and emission figures were derived from these boiler capacity data, using operating characteristics gathered in the above-mentioned sample.

The process emissions were calculated in two steps:

(1) Emissions produced during the handling of raw materials and the subsequent processing of these materials to produce steel were determined. Where it was possible to estimate the degree of controls the emissions were reduced accordingly. The calculations were performed by considering each of the following separate processing operations:

(a) Sinter plants
(b) Pellet plants
(c) Coke manufacture
(d) Blast furnaces
(e) Steel furnaces
(f) Scarfing
(g) Materials handling

(2) The emissions resulting from the combustion of fuel needed to meet energy demands during the above manufacturing steps were estimated.

The comparison between these partially controlled process emissions and the uncontrolled emissions resulting from the boilers in the industry indicated the need to control both sources. Alternate control strategies are suggested at the end of this report to control the significant emissions from the conventional fossil fuel combustion equipment in the iron and steel industry. A guideline to the determination of the cost effectiveness of each strategy is given.

III. INVENTORIES OF BOILER CAPACITIES, FUEL USE, AND EMISSIONS

A. DEFINITIONS

This section defines the various categories used to identify and classify fossil fuel burning equipment and to note some of the coding used in this report. Fossil fuel burning equipment is broken down according to:

(1) Size
(2) Region
(3) Fuel
(4) Firing type (for coal only)
(5) Age

1. Size

The watertube boilers have been reported in three size classes: less than or equal to 100,000 lb per hour (pph), between 100,000 and 250,000 pph and greater than 250,000 pph.

2. Regions

Four regions were used in this study (Figure 3-1). A summary description of these four regions follows:

The Atlantic region (AT) includes New York, Pennsylvania, Delaware, Maryland, Connecticut, and Massachusetts. This is a very dense, nearly continuous band of large, mature, urban areas. The urbanization is supported by an exceptionally broad economic base including a wide variety of types and sizes of manufacturing enterprises as well as the nation's educational, financial, and government centers. The region experiences moderately cold winters and uses oil for most of its space heating. The pollution problem is aggravated by shallow atmospheric mixing depths but relieved by relatively high wind speeds and the infrequency of low-level stability.

The Great Lakes region (GL) includes Michigan, Illinois, Indiana, Ohio, Minnesota, and Missouri. A second group of large, mature,

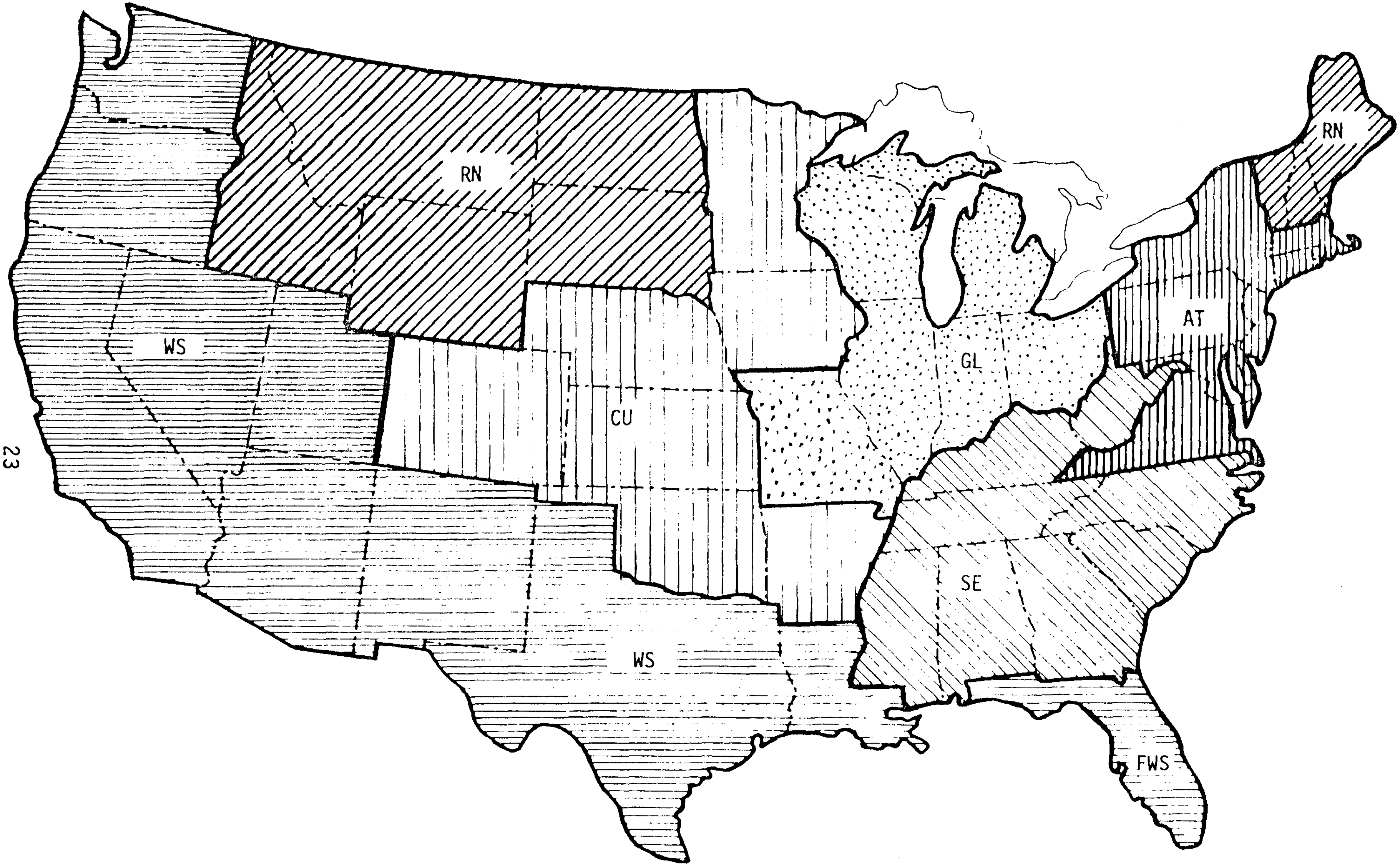

Figure 3-1. Regional Boundaries

urban areas, different only in degree from the Atlantic coastal megalopolis, having slightly less dense surroundings, somewhat wider spacing of urban centers, and an economy more characterized by large, mass-production industry. The two regions also differ in fuel use, with the Great Lakes region dividing its consumption among coal, oil, and gas. Although the region is characterized by relatively favorable atmospheric dilution, the population and industrial load results in high pollution levels.

The Southeast region (SE) includes Alabama, Georgia, Kentucky and West Virginia. This region has medium-size, widely separated, mature metropolitan areas, surrounded by a fairly dense statewide population. The cities are supported by manufacturing. The warmer climate reduces space heating emissions, but frequent atmospheric stagnation concentrates the pollutants which are emitted.

The Far West and South region (WS) includes Texas, Utah and California. This region has a group of large, new, fast-growing urban areas which are widely scattered over the otherwise sparsely-settled territory. Relatively little manufacturing and a warm climate tend to mitigate pollution from stationary combustion units. The large, disperse urban areas, however, generate high volumes of automobile exhaust, which in several areas are concentrated by poor atmospheric conditions.

Other states are not included in this survey because of a negligible participation in the primary iron and steel industry.

3. Fuels

The fuels considered were the conventional fossil fuels, coal (CL), residual oil (RO), and natural gas (GS) and the derived fuels: blast furnace gas (BFG) and coke oven gas (COG). Distillate oil use by industrial watertube boilers in the iron and steel industry is negligible.

4. Firing Type (for coal only)

No specific data on firing methods were collected for this study, and it was decided to distribute the coal firing methods according to the nationwide distribution of firing types of coal-burning intermediate-size watertube boilers [3-1]. This is necessary because the firing types reflect differences in emissions as well as control costs. The types considered were: pulverized coal (PV), cyclone firing (CY), overfed stoker (OF), spreader stoker (SS), and underfed stoker (UF).

5. Age

From the Walden sample, age data were collected in two categories: less than or equal to 20 years old, and older than 20 years. In the emission calculations, age was not taken into account, because the information required for this adjustment to the emission factors would really be too detailed for the scope of this study.

B. METHODOLOGY

This section indicates briefly the methodology used to arrive at the boiler inventories, the fuel consumed by these boilers and the resulting emissions. For a more detailed explanation, the reader is referred to Appendices A, B and D.

1. The Boiler Sample

The Walden sample of boilers in the iron and steel industry was obtained from the following major sources: The American Boiler Manufacturers Association, several boiler manufacturers, yearly boiler surveys published by Power magazine (1940-1970), government agencies, telephone interviews with approximately 70 iron and steel plants across the country, and detailed boiler data provided by three of the four largest integrated steel producers in the country: U.S. Steel, Bethlehem Steel, and Jones & Laughlin.

2. The 1970 Boiler Inventory

This sample represented about two thirds of the total employment in the iron and steel industry. In order to arrive at a complete inventory, the sample was summarized by state. Statewide employment in the iron and steel industry as obtained from County Business Patterns [3-2], and individual plant employment figures as obtained from the Dun & Bradstreet

Metalworking Directory [3-3] were used to proportion the sample in order to arrive at a complete 1970 inventory. The smaller cast iron and fire-tube boilers, used at some plants, were excluded from the totals (see Appendix A). This hardly affected total capacity figures in each region and only reduced the number of boilers slightly.

3. Operating Factors

The load factor of the boilers in the sample averaged about 77%. The weighted efficiencies for the various boiler sizes were: 73%, 78% and 84%, respectively for watertube boilers less than or equal to 100,000 pph, between 100,000 and 250,000 pph, and greater than 250,000 pph. The firing method distribution was that of intermediate-size water-tube boilers in general [3-1]. This distribution is shown in Table 3-1.

TABLE 3-1

PERCENTAGE OF WATERTUBE BOILERS USING VARIOUS FIRING METHODS FOR COAL COMBUSTION

				Stokers	
	Pulverized Coal	Cyclone	Overfired	Spreader Stoker	Under Fired
$WT_{<100}$	20	0	47	20	13
$WT_{100-250}$	59	2	29	8	2
$WT_{>250}$	92	5	0	2	1

4. Projections

It was found that about 500 kwh of energy is needed to produce a ton of steel in electric furnaces [3-4]. Using the projections of raw steel production published in the Battelle Systems Study of the Integrated Iron and Steel Industry [3-5], the energy required for these production figures was derived for 1975 and 1980. The ratio between energy used for production of raw steel to the total electric power consumed was linearly projected to 1975 and 1980 and the projected electric power consumed was calculated. The total was then split into energy purchased and generated, and the estimated boiler capacities required for power generation was derived from the latter figure.

To determine the boiler capacity needed for non-power purposes (process and space heating), the assumption was made that the ratio of non-power boiler capacity to the total tonnage of raw steel production in 1970 would remain constant at a value of .65 pph/ton of raw steel. Using the Battelle projections of raw steel production the boiler capacity needed for process and space heating was derived for 1975 and 1980. By summing the boiler capacities required for power generation and for process and space heating, the total projected boiler capacities were determined for 1975 and 1980. For further details, the reader is referred to Appendix B.

It is interesting to note at this point that our projections showed that purchased energy as a percentage of the total energy consumed in the iron and steel industry has been increasing significantly. In 1970 this percentage was about 76% and in 1975 and 1980 it is expected to be 85% and 93%, respectively, of the total required energy.

Regional fuel distributions were obtained for the fossil fuels from the growth projections of regional coal, oil and gas use of industrial intermediate boilers [3-1]. For the non-conventional fuels, the projected amounts were determined by studying the processes which creates them, using the Battelle projected figures as input to these processes (see Appendix C, Section II). The national proportion between blast furnace gas and coke oven gas in 1975 and 1980 was maintained for each region due to lack of regional projections in the Battelle study.

The relative growth of the various size groups for intermediate boilers as a whole was applied to the projected iron and steel boilers on a total basis [3-1].

The firing types for the projected years were assumed to be unchanged from the 1970 figures, due to lack of better data.

5. Fuel Use

Fuel use was calculated for the 1970, 1975 and 1980 boiler inventories by using the formula:

$$\text{Btu/yr} = \frac{\text{capacity (lb/hr) x load factor x 8760 (hours/yr) x 975 (Btu/lb)}}{\text{efficiency}}$$

6. Emissions

Uncontrolled boiler emissions were calculated for the 1970, 1975 and 1980 boiler inventories according to the following equations:

$$SO_2 \text{ (tons)} = \frac{\text{fuel consumption (Btu/yr) x emission factor (lb/Btu) x \% sulfur}^{*}}{\text{2000 (lb/ton)}}$$

$$NO_x \text{ (tons)} = \frac{\text{fuel consumption (Btu/yr) x emission factor (lb/Btu)}}{\text{2000 (lb/ton)}}$$

$$\text{Particulates (tons)} = \frac{\text{fuel consumption (Btu/yr) x emission factor (lb/Btu) x \% ash}^{**}}{\text{2000 (lb/ton)}}$$

The emission factors and sulfur and ash contents used are listed in Appendix D. The coal, oil, and natural gas emission factors are the same as those used for industrial intermediate-size boilers in the Intermediate Boiler Systems Study [3-1]. An explanation of the derivation of the emission factors for blast furnace and coke oven gas is found in Appendix D, Section II.

C. RESULTS

This section describes the results of the current and projected boiler inventories, fuel consumption patterns, and emissions, accompanied by a short discussion.

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*Only in the case of coal- or oil-fired boilers

**Only in the case of coal-fired boilers

1. 1970 Boiler Inventory and Fuel Consumption

The summary results of the 1970 boiler inventory are shown in Table 3-2.

TABLE 3-2

1970 REGIONAL ESTIMATES OF WATERTUBE BOILERS IN THE IRON AND STEEL INDUSTRY

Region	No. of Boilers	Capacity (10^3 pph)	Av. Capacity (pph)
Atlantic	783	41,160	53,000
Great Lakes	514	39,880	77,600
West and South	123	9,600	78,000
South East	172	12,855	74,700
TOTAL	1,592	103,495	(65,000)

The relatively lower average capacity of watertube boilers in the Atlantic region is due to a relatively higher number of small watertube boilers used here. This may be due to several factors:

(1) The age of industry in that region combined with the longevity of watertube boilers justifies the finding of smaller units which were used pre World War II.

(2) Expanding plants in the Atlantic region merely added additional small units, and have only recently started substituting one or two larger watertube boilers for the many small ones in use so far (see Appendix A, page A-4).

A more detailed inventory of the boiler capacity installed in the iron and steel industry in 1970 is shown in Table 3-3.

TABLE 3-3

1970 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY
(10^3 pph)

Boiler Size	Fuel	AT	GL	WS	SE	Total
$WT_{<100}$	CL	1,729	3,956	73	1,439	7,197
	RO	2,247	1,148	182	135	3,712
	GS	5,013	2,425	1,277	1,170	9,885
	BFG	5,878	3,829	1,131	1,260	12,098
	COG	2,420	1,404	985	495	5,304
$WT_{100-250}$	CL	1,317	4,698	42	864	6,921
	RO	1,712	1,364	106	81	3,263
	GS	3,820	2,879	739	702	8,140
	BFG	4,478	4,546	655	756	10,435
	COG	1,844	1,667	570	297	4,378
$WT_{>250}$	CL	1,070	3,709	77	1,810	6,666
	RO	1,391	1,077	192	170	2,830
	GS	3,104	2,273	1,344	1,470	8,191
	BFG	3,639	3,589	1,190	1,584	10,002
	COG	1,498	1,316	1,037	622	4,473
TOTAL		41,160	39,880	9,600	12,855	103,495

The 1970 fuel use estimates of boilers in the iron and steel industry are shown in Table 3-4.

It is interesting to compare these fuel figures to fuel consumption figures derived from the American Iron and Steel Institute (AISI) annual statistics [3-6]. It must be noted, however, that:

TABLE 3-4

1970 FUEL CONSUMPTION BY BOILERS IN THE IRON AND STEEL INDUSTRY

	AT		GL		WS		SE		Total	
Fuel*	units*	10^{12} Btu	units*	10^{12} Btu	units*	10^{12} Btu	units*	10^{12} Btu	units*	10^{12} Btu
CL	1,350	35.1	4,008	104.2	65	1.7	1,327	34.5	6,750	175.5
RO	314	45.5	208	30.2	28	4.0	22	3.2	572	82.9
GS	102	101.7	64	63.9	28	28.2	28	27.9	222	221.7
BFG	1,256	119.3	1,062	100.9	263	25.0	318	30.2	2,899	275.4
COG	98	49.0	74	37.0	44	21.8	24	11.9	240	119.7
Total	n.a.	350.6	n.a.	336.2	n.a.	80.7	n.a.	107.7	n.a.	875.2

*CL = coal in 10^3 tons

RO = residual oil in 10^3 barrels

GS = natural gas in 10^9 cubic feet

BFG = blast furnace gas in 10^9 cubic feet

COG = coke oven gas in 10^9 cubic feet

(1) The AISI covered only those plants included in SIC 3312 whereas this study covers all of SIC 331. Our AISI-derived figures are, therefore, 1.16 times higher than the published figures for fossil fuels. This factor is based on employment figures.

(2) Only for coal is the amount of fuel used for steam raising specified by the AISI; for other fuels estimates had to be made as to the amount of fuel used under boilers (Appendix A, page A-10).

(3) The AISI fuel use figures are based on a less complete sample than their steel production figures [3-7].

Table 3-5 shows the Walden and the AISI derived fuel consumption figures.

TABLE 3-5

VERIFICATION OF 1970 FUEL USE RESULTS FOR BOILERS IN THE IRON AND STEEL INDUSTRY (10^{12} Btu/yr)

	Walden	AISI-Derived	Percentage Difference*
Coal	176	143	23%
Residual Oil	83	55	53%
Natural Gas	222	203	9%
Blast Furnace Gas	275	236	17%
Coke Oven Gas	120	127	6%
Total	876	764	15%

* $\frac{\text{Walden-AISI}}{\text{AISI}} \times 100\%$

Note that the sum of the three gases is off by a mere 9%. The discrepancy for residual oil seems quite high. Walden studied the possibility of the boiler sample having included too many plants located in areas where residual oil is used a lot.

Table 3-6 shows that this was not the case. Over half of the actual employment was represented by the sample of boilers for the Atlantic region, whereas over two thirds of the actual employment was included in the sample for each of the three other regions. If anything, the bias would have worked the other way, i.e., Walden's figures for residual oil consumption would have been lower, not higher, due to the relatively low sample in the Atlantic region. In view of the above and of the admitted lack of confidence in the AISI fuel statistics, the Walden figures were accepted. Walden's total 1970 boiler fuel consumption figure is within 15% of the AISI total, and it is felt that these results are satisfactory.

TABLE 3-6

REGIONAL COMPLETENESS OF WALDEN BOILER SAMPLE (10^3 pph)

	Sample	Total	%
AT	21,407	41,160	52
GL	31,670	39,880	79
WS	6,190	9,600	64
SE	8,513	12,855	66
	67,780	103,495	65

2. Projected Boiler Inventories and Fuel Consumption

The results of the 1975 and 1980 boiler inventories are shown respectively in Tables 3-7 and 3-8.

Figure 3-2 shows the projected regional fuel use patterns for fuel burned under boilers in the iron and steel industry.

Tables 3-9 and 3-10 show the projected fuel use for boilers in the iron and steel industry in more detail.

Most boilers can be fired by two or three fuels. This is most commonly the case when plants have coke ovens or blast furnaces. One of the tasks of the fuel combustion engineers at these plants is to minimize the cost of fuel to the plant by maximum use of the coke oven and blast furnace gases, which would otherwise be wasted.

TABLE 3-7

1975 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY
(10^6 pph)

Boiler Size	Fuel	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	1.3	4.7	.1	1.4	7.5
	RO	2.5	1.4	.2	.2	4.3
	GS	9.1	3.4	2.4	1.7	16.6
	BFG	5.7	4.2	1.2	1.5	12.6
	COG	2.5	1.9	.6	.7	5.7
$WT_{100-250}$	CL	.9	5.0	.1	.8	6.8
	RO	1.7	1.5	.1	.1	3.4
	GS	6.2	3.6	1.2	.9	11.9
	BFG	3.9	4.4	.6	.8	9.7
	COG	1.7	2.0	.3	.3	4.3
$WT_{>250}$	CL	.6	3.8	.1	1.6	6.1
	RO	1.4	1.2	.2	.2	3.0
	GS	4.9	2.8	2.1	1.9	11.7
	BFG	3.0	3.4	1.1	1.6	9.1
	COG	1.4	1.5	.5	.7	4.1
TOTAL		46.8	44.8	10.8	14.4	116.8

TABLE 3-8

1980 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY
(10^6 pph)

Boiler Size	Fuel	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	1.4	5.4	.1	1.6	8.5
	RO	3.0	1.4	.2	.2	4.8
	GS	11.3	4.6	2.8	2.1	20.8
	BFG	4.9	3.6	1.0	1.2	10.7
	COG	2.8	2.0	.6	.7	6.1
$WT_{100-250}$	CL	.9	5.7	.1	.8	7.5
	RO	2.0	1.4	.2	.1	3.7
	GS	7.5	4.8	2.2	1.1	15.6
	BFG	3.3	3.8	.8	.7	8.6
	COG	1.9	2.2	.4	.4	4.9
$WT_{>250}$	CL	.7	4.0	.1	1.6	6.4
	RO	1.5	1.0	.2	.2	2.9
	GS	5.4	3.4	2.4	2.1	13.3
	BFG	2.4	2.7	.8	1.3	7.2
	COG	1.3	1.5	.5	.7	4.0
TOTAL		50.3	47.5	12.4	14.8	125.0

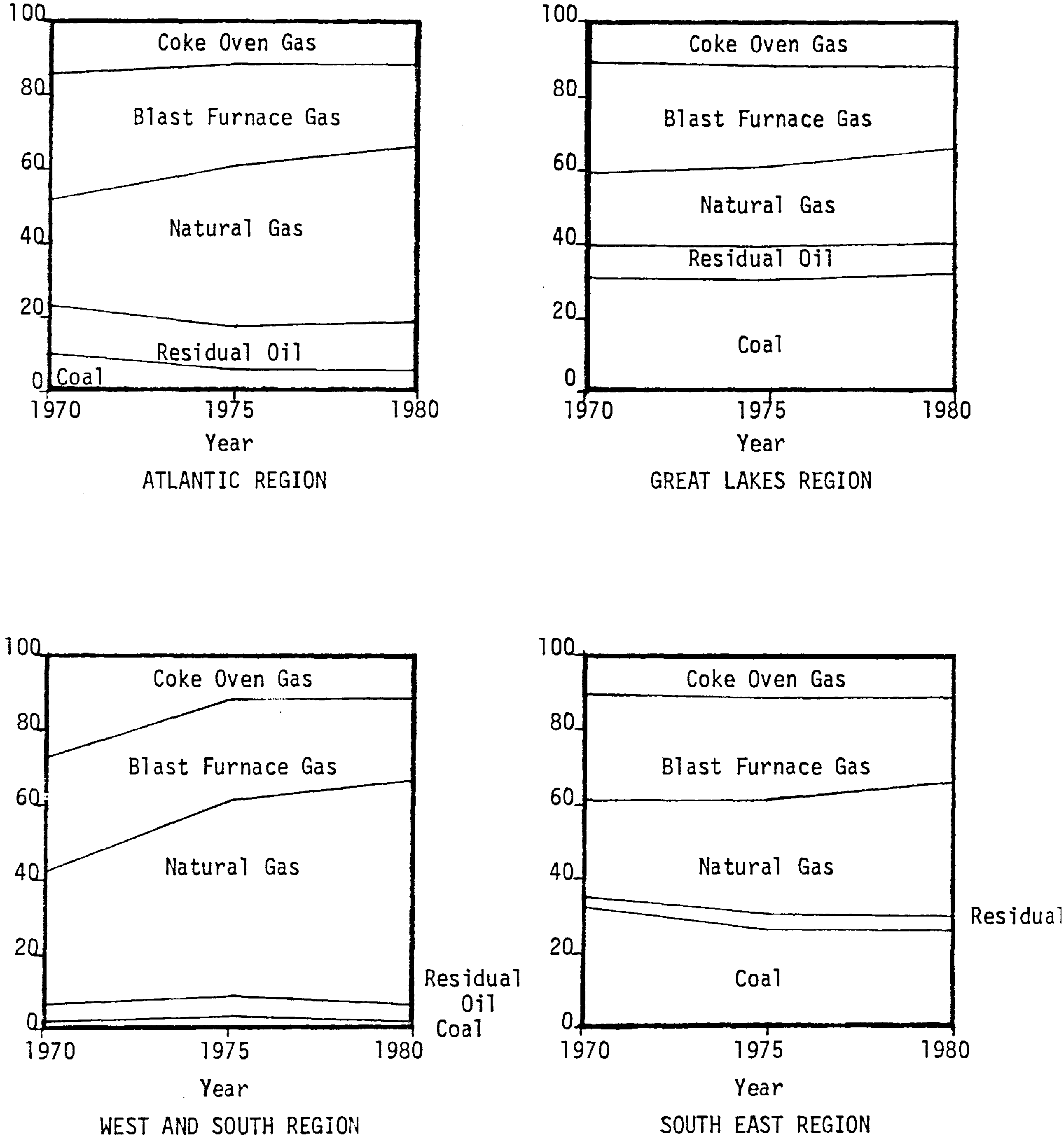

Figure 3-2. Fuel Burned Under Boilers in the Iron and Steel Industry, 1970-1980.

TABLE 3-9

1975 FUEL USE IN THE IRON AND STEEL INDUSTRY
(10^{12} Btu)

Boiler Size	Fuel	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	11.7	42.3	.9	12.6	67.5
	RO	22.5	12.6	1.8	1.8	38.7
	GS	82.0	30.6	21.6	15.3	149.5
	BFG	51.4	37.8	10.8	13.5	113.5
	COG	22.5	17.1	5.4	6.3	51.3
$WT_{100-250}$	CL	7.6	42.2	.8	6.7	57.3
	RO	14.3	12.6	.8	.8	28.5
	GS	52.3	30.4	10.1	7.6	100.4
	BFG	32.9	37.1	5.1	6.7	81.8
	COG	14.3	16.9	2.5	2.5	36.2
$WT_{>250}$	CL	4.7	29.8	.8	12.5	47.8
	RO	11.0	9.4	1.6	1.6	23.6
	GS	38.4	21.9	16.4	14.9	91.6
	BFG	23.5	26.6	8.6	12.5	71.2
	COG	11.0	11.7	3.9	5.5	32.1
TOTAL		400.1	379.0	91.1	120.8	991.0

TABLE 3-10

1980 FUEL USE IN THE IRON AND STEEL INDUSTRY
(10^{12} Btu)

Boiler Size	Fuel	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	12.6	48.6	.9	14.4	76.5
	RO	27.0	12.6	1.8	1.8	43.2
	GS	101.8	41.4	25.2	18.9	187.3
	BFG	44.1	32.4	9.0	10.8	96.3
	COG	25.2	18.0	5.4	6.3	54.9
$WT_{100-250}$	CL	7.6	48.1	.8	6.7	63.2
	RO	16.9	11.8	1.7	.8	31.2
	GS	63.2	40.5	18.5	9.3	131.5
	BFG	27.8	32.0	6.7	5.9	72.4
	COG	16.0	18.5	3.4	3.4	41.3
$WT_{>250}$	CL	5.5	31.3	.8	12.5	50.1
	RO	11.7	7.8	1.6	1.6	22.7
	GS	42.3	26.6	18.8	16.4	104.1
	BFG	18.8	21.1	6.3	10.2	56.4
	COG	10.2	11.7	3.9	5.5	31.3
TOTAL		430.7	402.4	104.8	124.5	1062.4

3. Current and Projected Boiler Emissions

The national boiler emissions are shown graphically in Figure 3-3 and summarized by region in Table 3-11. The figures shown are for uncontrolled emissions. This is accurate for SO_2 and NO_x. There is some control of particulate boiler emissions, but data on controls were not available for this study, causing the particulate emissions from boilers reported here to be slightly higher than they are in reality.

The Great Lakes region shows continuously increasing emissions from all three pollutants, and is by far the region most seriously affected by air pollution resulting from boilers in the iron and steel industry. Looking back at Table 3-2, the reader will note that this is not the region with the largest number of boilers or boiler capacity. The high emissions can be attributed to the intensive use of industrial coal in the Great Lakes region. The other three regions more or less follow the national trend (see Figure 3-3) with a slight decrease in particulate emissions during the period of 1970 to 1975, followed by a slow increase thereafter. The decrease is explained by a certain amount of fuel switching to cleaner fuels (see Figure 3-2) and the increase between 1975 and 1980 is due to the fact that the growth of the iron and steel industry will eventually counteract the effect of cleaner boiler fuels and cause a growth in air pollution emissions in those regions as well. NO_x emissions increase steadily in all four regions.

Table 3-12 shows the emissions by equipment size.

There is no very significant emphasis on any particular boiler size group as far as emissions are concerned. We can say, however, that boilers burning coal are the main sources for all three air pollutants. They represented 64%, 45% and 97%, respectively, of the total SO_2, NO_x and particulate emissions from boilers in the iron and steel industry in 1970.

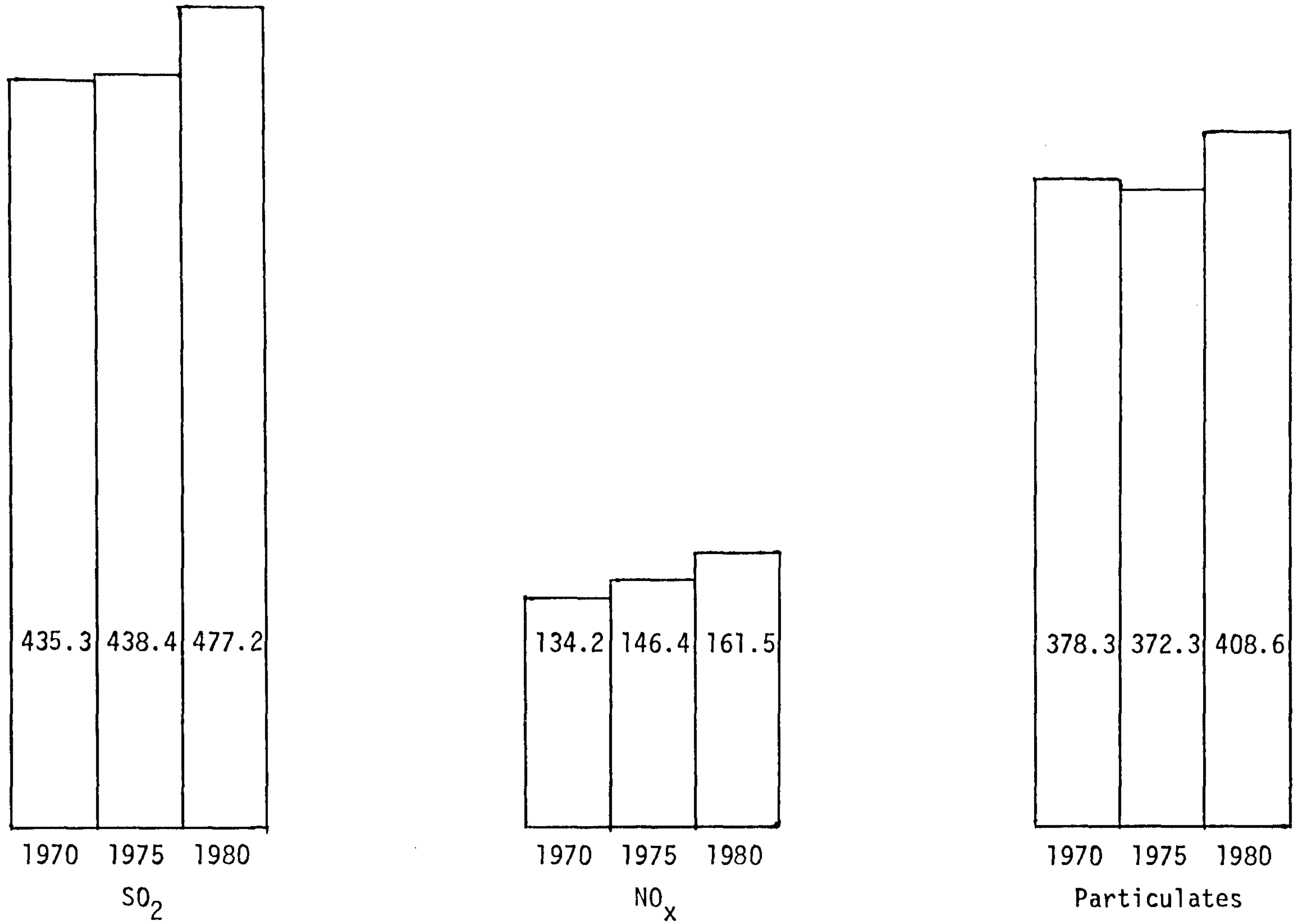

Figure 3-3. Projected Air Pollution from Boilers in the Iron and Steel Industry (thousand tons)

TABLE 3-11

CURRENT AND PROJECTED EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY
(thousand tons)

	SO_2			NO_x			Particulates		
Region	1970	1975	1980	1970	1975	1980	1970	1975	1980
AT	118.9	104.6	115.7	45.3	48.5	54.2	75.6	53.3	57.4
GL	235.4	263.5	287.0	60.2	68.2	74.5	229.5	249.9	278.3
WS	22.8	16.4	17.7	9.6	9.8	11.8	4.7	6.0	6.7
SE	58.2	53.9	56.7	19.1	19.9	21.0	68.5	63.1	66.2
Total	435.3	438.4	477.2	134.2	146.4	161.5	378.3	372.3	408.6

TABLE 3-12

1970 BOILER EMISSIONS BY BOILER SIZE

	SO_2	NO_x	Particulates
Watertube ≤ 100,000 pph	167.0	41.6	118.9
Watertube 100,001-250,000 pph	143.7	45.9	132.1
Watertube > 250,000 pph	124.6	46.7	127.3
	435.3	134.2	378.3

It is interesting to note that the 1970 boiler emissions in the iron and steel industry represent about 10%, 15% and 16%, respectively, of SO_2, NO_x and particulate emissions from industrial boilers in 1967 [3-1].

For more detailed breakdowns of the emissions from boilers in the iron and steel industry, the reader is referred to Appendix D.

REFERENCES TO SECTION III

3-1. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, Cambridge, Mass., 1971.

3-2. County Business Patterns, U.S. Bureau of Labor, 1969.

3-3. Dun & Bradstreet Metalworking Directory, 1971, Dun & Bradstreet, Inc., New York.

3-4. The Making, Shaping and Treating of Steel, 8th Edition, U.S. Steel Corporation, Pittsburgh, Pa., 1964.

3-5. A Systems Analysis Study of the Integrated Iron and Steel Industry, Battelle Memorial Institute, Columbus, Ohio, 1964.

3-6. Statistical Report, American Iron and Steel Institute, 1970.

3-7. Personal communication with Mr. Eckel of the American Iron and Steel Institute.

IV. PROCESS EMISSIONS

A. INTRODUCTION

The production of iron and steel is a complex process requiring many intermediate steps. During each of these steps, process emissions are produced from two distinct types of sources. First, handling of raw materials and subsequent processing of these materials produce emissions which fall within the conventional definition of process emissions. However, in order to meet its energy demands during the manufacturing steps, the iron and steel industry combusts significant quantities of fuel. This combustion forms the second source of process emissions. These two different types of process emissions will be discussed separately.

In general, the following major processing operations can be identified in the iron and steel industry:

(1) Sinter Plant
(2) Pellet Plants
(3) Coke Manufacture
(4) Blast Furnaces
(5) Steel Furnaces
    Open Hearth
    Basic Oxygen Furnace
    Electric Arc Furnace
(6) Scarfing
(7) Materials Handling

An estimation of process emissions from the above mentioned operations requires an understanding of the separate processes and the places of potential emissions. Appendix C briefly describes the operations, but for a more detailed description, the reader is directed to The Making, Shaping and Treating of Steel [4-1], and Battelle's Systems Study of the Integrated Iron and Steel Industry [4-2].

The following sections summarize the basic methodology used in estimating process emissions and also present the results of the use of the above mentioned methods. Detailed descriptions of the computations can be found in Appendix C.

B. METHODOLOGY

1. Conventional Process Emissions

Base Year 1970

Conventional uncontrolled process emissions (which do not include emissions resulting from fuel combustion associated with the process) were estimated from production figures taken from the AISI Statistical Report [4-3] and emission factors obtained from both the Nationwide Emission Factor Compilation [4-4] and Battelle's Systems Study of the Integrated Iron and Steel Industry [4-2]. The 1970 production figures and the emission factors are shown in Tables 4-1 and 4-2. Table 4-3 summarizes the control collection efficiencies utilized for estimation of the controlled conventional process emissions.

Uncontrolled and controlled emissions were obtained by multiplication of the relevant production figures, emission factors and collection efficiencies.

Projections to 1975 and 1980

Except in the case of the electric furnace, identical uncontrolled emission factors (Table 4-2) as those previously used, were utilized in estimation of projected emission. The particulate emission factor for the electric furnace was changed to 18 lb/ton product to reflect an expected increase in the average size of the steel change.

Only in the case of particulate emissions were changes in control (as compared to the base year 1970) considered. These changes reflected not changes in collection efficiencies, but rather expected changes in the fraction of units controlled. In the case of SO_X and

TABLE 4-1

1970 PRODUCTION OF RAW MATERIALS USED IN PRODUCTION

Operation	Production or Raw Materials Used in Production (tons)	
Sinter Plant	45.6×10^6	Sinter
Coke Plant	Coal 87.2×10^6	
Blast Furnace	Iron Ore	38.2×10^6
	Agglomerates	109.0×10^6
Steel Making		
Open Hearth	48.0×10^6	Raw Steel
Basic Oxygen Furnace	63.3×10^6	Raw Steel
Electric	20.2×10^6	Raw Steel

Source: AISI Statistical Reports [4-3]

TABLE 4-2

UNCONTROLLED EMISSION FACTORS - CONVENTIONAL PROCESS EMISSIONS

Operation	Particulate	SO_x	NO_x
Sinter Plants	Windbox 20 lb/ton sinter Discharge 22 lb/ton sinter	1.42 lb/ton sinter	1.04 lb/ton sinter
Coke Manufacture	By-product 3.5 lb/ton coal coking	--	
Blast Furnace	F = 70X + 40 lb/ton pig iron where $X = \frac{\text{ton arc}}{\text{ton arc + ton agglomerates}}$		
Open Hearth Furnace	With O_2 lancing 22 lb/ton pig iron Without O_2 lancing 12 lb/ton pig iron	1.40 lb/ton steel produced	For fuel oil: 250 lb/200 ton steel batch For nat. gas & coke oven gas: 150 lb/200 ton steel produced
Basic Oxygen Furnace (BOF)	46 lb/ton steel produced	0.06 lb/ton steel produced	
Electric Arc Furnace	With O_2 lancing 11 lb/ton steel produced Without O_2 lancing 7 lb/ton steel produced	0.02 lb/ton steel produced	
Scarfing	3 lb/ton steel produced		
Material Handling	10 lb/ton steel produced		

TABLE 4-3

PARTICULATE CONTROL EFFICIENCIES AND PERCENT OF OPERATIONS CONTROLLED - CONVENTIONAL PROCESS EMISSIONS

Operation	Control Efficiency			Percent Controlled
Sinter Plants	Windbox:	Dry cyclone	90%	
		Electrostatic precipitator (in series with dry cyclone)	95%	100%
	Discharge	Dry cyclone	93%	
	MEAN		90%	
Coke Manufacture				0%
Blast Furnace	1.	Preliminary cleaning settling chamber or dry cyclone	60%	
	2.	Primary cleaning gas washers & wet scrubbing	90%	100%
	3.	Secondary cleaning electrostatic precipitator or high energy washers	90%	
Open Hearth	Electrostatic precipitator		98%	
	Venturi scrubber		85-98%	41%
	Bag house		99%	
	MEAN		98%	
Basic Oxygen Furnace	Electrostatic precipitator		98%	100%
Electric Furnace	High efficiency scrubber		98%	
	Electrostatic precipitator		92-97%	79%
	Bag house		98-99%	
	MEAN		95%	
Scarfing	Precipitators		90%	75%
Material Handling	Precipitators		95%	32%

NO_x emissions, however, no attempt was made to estimate how much of the emissions would be controlled in future years. This decision was based simply on the speculative nature of the answer that would have been obtained.

Table 4-4 summarizes the fraction of units controlled that were used for estimation of the projected emissions.

Projected production figures for 1975 and 1980 were obtained from Battelle [4-2] and these figures are summarized in Tables 4-5, 4-6 and 4.7.

Additional computation had to be performed in order to estimate sinter production and coke production.

Battelle [4-2] reports, as shown in Table 4-5, the physical form of iron ore consumed in the U.S. and estimates to 1980. In order to estimate the total sinter production (as opposed to the production of sinter emanating only from iron ore) extrapolations were used of the fraction of additional material to iron ore utilized in the production of sinter. This fraction was calculated from AISI statistical data. It was found that over the last several years, this fraction has been constant at 0.075 and thus it was assumed that this fraction would hold constant to 1980.

Utilizing this fraction the following total sinter productions were calculated:

1975: 55.5×10^6 tons

1980: 59.1×10^6 tons

Coke rates (lb coke/T pig iron) were obtained from extrapolation of historical data in conjunction with an estimate of expected changes in blast furnace technology which would affect the coke rate (direct fuel oil and natural gas injection into the tuyeres which reduces the coke rate).

TABLE 4-4

PROJECTED PERCENT OF OPERATIONS CONTROLLED FOR PARTICULATE EMISSIONS - CONVENTIONAL PROCESS EMISSIONS

Operation	Percent Controlled 1975	Percent Controlled 1980
Sinter Plants	100%	100%
Coke Manufacture	0%	0%
Blast Furnace	100%	100%
Open Hearth	62%	100%
Basic Oxygen Furnace	100%	100%
Electric Furnace	100%	100%
Scarfing	75%	75%
Material Handling	32%	32%

TABLE 4-5

PHYSICAL FORM OF IRON ORE CONSUMED IN THE U.S. AND ESTIMATES TO 1980

	Lump Ore		Sinter[a]		Pellets		Total	
Year	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%
1960	62.0	54.1	41.5	36.3	11.0	9.6	114.5	100.0
1967	46.7	35.3	42.2	31.9	43.4	32.8	132.3	100.0
1975	31.7	20.0	46.0	29.0	80.8	51.0	158.5	100.0
1980	34.9	19.5	48.3	27.0	95.8	53.5	179.0	100.0

[a]Includes only iron ore used for making sinter

TABLE 4-6

PIG IRON REQUIREMENTS FOR THE U.S. IN 1960 AND 1967
AND PROJECTIONS TO 1980

Year	Raw Steel Production (10^6 tons)	Apparent Pig Iron Consumption (10^6 tons)
1960	99.3	66.5
1967	127.2	87.0
1975	157.0	106.8
1980	180.0	122.4

TABLE 4-7

PRODUCTION OF RAW STEEL IN THE U.S. BY TYPE OF FURNACE
AND PROJECTIONS TO 1980

Year	Open Hearth (10^3 tons)	Bessimer (10^3 tons)	Basic Oxygen Furnace (10^3 tons)	Electric Furnace (10^3 tons)	Total (10^3 tons)
1960	86,368	1,189	3,346	8,379	99,282
1967	70,690	--	41,434	15,089	127,213
1975	44,000	--	80,000	33,000	157,000
1980	36,000	--	99,000	45,000	180,000

The following estimated coke rates were used for emission computations:

1975: 1145 lb coke/T pig iron

1980: 1020 lb coke/T pig iron

It was assumed, however, that both in 1975 and 1980, 1.4 tons of coal would still be required to produce one ton of coke.

Emissions were obtained by multiplication of the relevant projected production figures, emission factors and control efficiencies.

2. Fuel Based Emissions

Five fuels are extensively used in the iron and steel industry to supply process energy. These are fuel oil, natural gas, tar and pitch, coke oven gas and blast furnace gas. The latter three fuels are produced within the steel mill as by-products and their production is dependent on the coke rate and ultimately on pig iron requirements. Fuel oil and natural gas, on the other hand, are purchased fuels whose usage is tied into the process in a fairly complex fashion.

In estimating emissions from fuels used in process areas it is necessary first to determine fuel consumption and then to apply emission factors. Fuel consumptions are available [4-3] but extrapolation to 1975 and 1980 will have to be made based on an understanding of how fuel usage is related to process requirements.

The AISI Statistical Reports [4-3] break down fuel consumption into the following "use" categories:

(i) Blast Furnace Area - Blast Furnaces
Other Uses

(ii) Steel melting furnaces

(iii) Heating and annealing furnaces

(iv) Heating ovens for wire rods

(v) Other

In addition, included under other uses in the blast furnace area, are reported the quantity of fuel used for coke oven underfiring.

Discussions with AISI officials [4-5] indicated that:

(i) Steel melting furnaces refer to fuel usage in open hearth furnaces

(ii) The category of "other" could be considered to refer mainly to the use of a particular fuel in steam raising boilers.

Base Year 1970

Table 4-8 summarizes fuel consumption data for 1970 extracted from the AISI Statistical Report [4-3].

Table 4-9 summarizes the uncontrolled emission factors used in estimation of the fuel based emissions. Detailed discussion of the sources of these emission factors can be found in Appendix C.

No data could be found on controls relating to the fuel based emissions and as such ALL ESTIMATIONS OF FUEL BASED PROCESS EMISSIONS REFER TO UNCONTROLLED EMISSION LOADINGS.

Uncontrolled emission loadings were computed by multiplication of the relevant fuel consumption rates and uncontrolled emission factors.

Projections to 1975 and 1980

As discussed in the brief introduction to the fuel based process emissions, fuel oil and natural gas are purchased fuels whose usage is tied into the process in a fairly complex fashion. On the other hand, coke oven gas, tar and pitch and blast furnace gas production rates are dependent on the coke rate and ultimately on pig iron requirements. These two groups of fuels will therefore be discussed separately.

TABLF 4-8

FUEL CONSUMPTION 1970

Fuel	Purpose								
	Blast Furnace Area								
	Furnaces	Other[a] Uses	Coke Oven Underfiring	Steel Melting Furnaces	Heating & Annealing Furnaces	Heating Ovens for Wire Rods	Other	Steam[b] Raising	Total
Fuel Oil 10^3 gals	146,031	19,801	5,000	416,822	377,593	1,648	273,558	288,359	1,235,453
Tar & Pitch 10^3 gals	42,500	--	--	176,902	--	--	41,503	41,503	260,905
Natural Gas 10^6 scf	44,474	10,262	4,000	57,797	306,097	4,403	170,483	176,745	593,516
Coke Oven Gas 10^6 scf	9,177	319,628	274,603	22,056	363,899	4,217	208,959	253,984	927,936
Blast Furnace Gas 10^6 scf	1,592,038	1,246,894	286,402	--	164,693	--	1,519,250	2,479,742	4,522,875
Liquid Pet. Gas 10^3 gals	--	--	--	--	6,555	--	12,220	12,220	18,775

[a] Includes coke oven underfiring

[b] Steam raising = Σ other - coke oven underfiring

TABLE 4-9A

UNCONTROLLED EMISSION FACTORS - FUEL BASED PARTICULATES AND SO_x PROCESS EMISSIONS

Fuel	Particulates	SO_x
Fuel Oil	0.42×10^3 lb/10^3 barrels	$0.68 \times 10^4 \times$ % sulfur (lb $SO_x/10^3$ barrels)
Natural Gas	15 lb/10^6 scf	0
Blast Furnace Gas	2.4 lb/10^6 scf	0
Coke Oven Gas	15 lb/10^6 scf	0.77 lb $SO_x/10^3$ scf

TABLE 4-9B

UNCONTROLLED NO_x EMISSION FACTORS - PROCESS BASED

	NO_x Emission Factors
Blast Furnace	0.4 lb/10^6 scf blast furnace gas
Coke Manufacture	0.135 lb/ton coal
Heating and Annealing Furnaces	0.086 lb/ton steel

Fuel Oil and Natural Gas

Fuel oil and natural gas are used throughout the steel mill as is evidenced by the 1970 fuel consumption shown in Table 4-8. Projections of fuel usage for future years were based on understanding of how fuel oil and natural gas were utilized in the different process areas.

The following underlying logic was used in these projections:

(i) Fuel oil and natural gas used in the blast furnaces are injected through the tuyeres [4-6]. As such these fuels reduce the blast furnace coke burden and lead to more efficient performance of the furnace. Since these fuels ultimately produce blast furnace gas, estimation of their consumption in future years is necessary in order to determine blast furnace gas production. The fuels used in the blast furnace area are dependent on required pig iron production and thus their consumption was correlated with pig iron production.

(ii) As indicated earlier, steel melting furnaces refer to open hearth furnaces. Thus fuel oil and natural gas consumption used in steel melting furnaces was correlated with open hearth production.

(iii) Heating and annealing furnaces are mainly utilized in steel production and thus fuel oil and natural gas consumption in these areas was correlated with raw steel production.

Using extrapolations of AISI Statistical Report data [4-3] and the above assumptions, ratios of fuel oil and natural gas consumptions relative to production were obtained for 1975 and 1980. These ratios are listed in Table 4-10. Actual fuel consumptions were then obtained by multiplication of the ratios listed in Table 4-10 and projected productions taken from Tables 4-6 and 4-7. Table 4-11 summarizes the projected fuel oil and natural gas consumptions for 1975 and 1980.

TABLE 4-10

EXTRAPOLATED RATIOS* OF FUEL CONSUMPTION
RELATIVE TO PRODUCTION

Fuel Oil:		
1. Blast Furnace Area	1975:	3.7 gals/ton pig iron
	1980:	10 gals/ton pig iron
2. Steel Melting Furnaces (Open Hearth)	1975:	8.3 gals/ton open hearth steel
	1980:	8.3 gals/ton open hearth steel
3. Heating and Annealing Furnaces	1975:	2.2 gals/ton raw steel
	1980:	2.2 gals/ton raw steel
Natural Gas:		
1. Blast Furnace Area	1975:	0.5×10^3 ft^3/ton pig iron
	1980:	0.5×10^3 ft^3/ton pig iron
2. Steel Melting Furnaces (Open Hearth)	1975:	1.1×10^3 ft^3/ton open hearth process
	1980:	1.1×10^3 ft^3/ton open hearth process
3. Heating and Annealing Furnaces	1975:	2.7×10^3 ft^3/ton raw steel
	1980:	3.05×10^3 ft^3/ton raw steel

*Extrapolated from historical data in Table C-12

TABLE 4-11

PROJECTED FUEL OIL AND NATURAL GAS CONSUMPTION FOR 1975 AND 1980

Fuel	Year	Purpose			
		Blast Furnace	Steel Melting	Heating & Annealing	Steam Raising
Fuel Oil 10^3 gals	1975	396,000	366,000	396,000	377,000
Fuel Oil 10^3 gals	1980	1,224,000	300,000	396,000	377,000
Natural Gas 10^6 scf	1975	53,400	49,500	424,000	210,000
Natural Gas 10^6 scf	1980	61,400	39,400	549,000	278,000

Identical emission factors to those previously used (Table 4-9) were used in the estimation of UNCONTROLLED emissions for 1975 and 1980. Due to lack of information, no attempt was made to estimate what controls would be implemented by 1980.

Coke Based Fuels - Coke Oven Gas, Blast Furnace Gas and Tar and Pitch

Coke oven gas, blast furnace gas and tar and pitch are dependent on the coke rate. However estimation of process emissions resulting from the combustion of these fuels are dependent in certain cases (i.e., NO_x emissions) on the burning rates of these fuels in the different processes using the fuels. Thus, as was done with fuel oil and natural gas it is necessary to estimate the fuel quantities combusted in the different processes.

Estimates of the projected coke based fuel consumptions were obtained by the following sequence of steps:

1) Coke rates for 1975 and 1980 were estimated to be respectively 1145 and 1020 lb coke/ton pig iron. (For detailed calculations see Appendix C)

2) Based on historical data, which showed little variation with time, the total volumetric production rate of coke oven gas/ton coke was estimated to be 15,000 scf/ton coke. Thus using the coke rate, the volumetric production rate and Battelle's [4-2] estimated pig iron requirements, projected coke oven gas production rates could be calculated. These are shown in Table 4-12.

3) Blast furnace gas production rate, on the other hand, varies with the coke rate. The data of Heynert [4-7], reproduced in Figure 4-1 were used to estimate blast furnace production rates/ton coke. However, comparisons between reported data from the AISI Statistical Reports [4-3] and data from Heynert's correlation showed that the correlation predicted about a 40% higher blast furnace gas production than was reported by AISI. Part of this disparity could probably be attributed

TABLE 4-12

PROJECTED TOTAL PRODUCTIONS OF COKE "BASED" FUELS

Fuel	1975	1980
Coke Oven Gas	9.2×10^{11} scf	9.35×10^{11} scf
Blast Furnace Gas	5.07×10^{12} scf	4.56×10^{12} scf
Tar and Pitch	$2.!4 \times 10^{8}$ gals	1.62×10^{8} gals

to losses which are unaccounted for in the AISI data, although complete understanding for the differences was not discovered. Consequently, a conservative attitude was taken and estimates of blast production rates/ ton coke were calculated as 60% of the values obtained from Figure 4-1. For further discussion on this subject, see Appendix C.

In estimating blast furnace gas production, equivalent coke rates of 1175 and 1100 lb coke/ton pig iron were used for 1975 and 1980. This equivalent coke rate corresponds to the sum of the actual coke rate (1145 and 1020 lb coke/ton pig iron) plus the fuel oil and natural gas injected into the tuyeres/ton pig iron. This approach was taken since the fuel oil and natural gas are also partially combusted to form blast furnace gas. The results are shown in Table 4-12.

3) Tar and pitch production rates were obtained from extrapolations of historical data which indicated that 3.5 and 2.6 gals/ton coke would respectively be produced in 1975 and 1980. Total productions are shown in Table 4-12.

4) Fractional allocation of the total fuel production among the different process units was performed by assuming that the fractional fuel consumption as obtained from historical data would remain constant through to 1980. The fractional allocations are shown in Table 4-13 for coke oven gas, blast furnace gas,and tar and pitch.

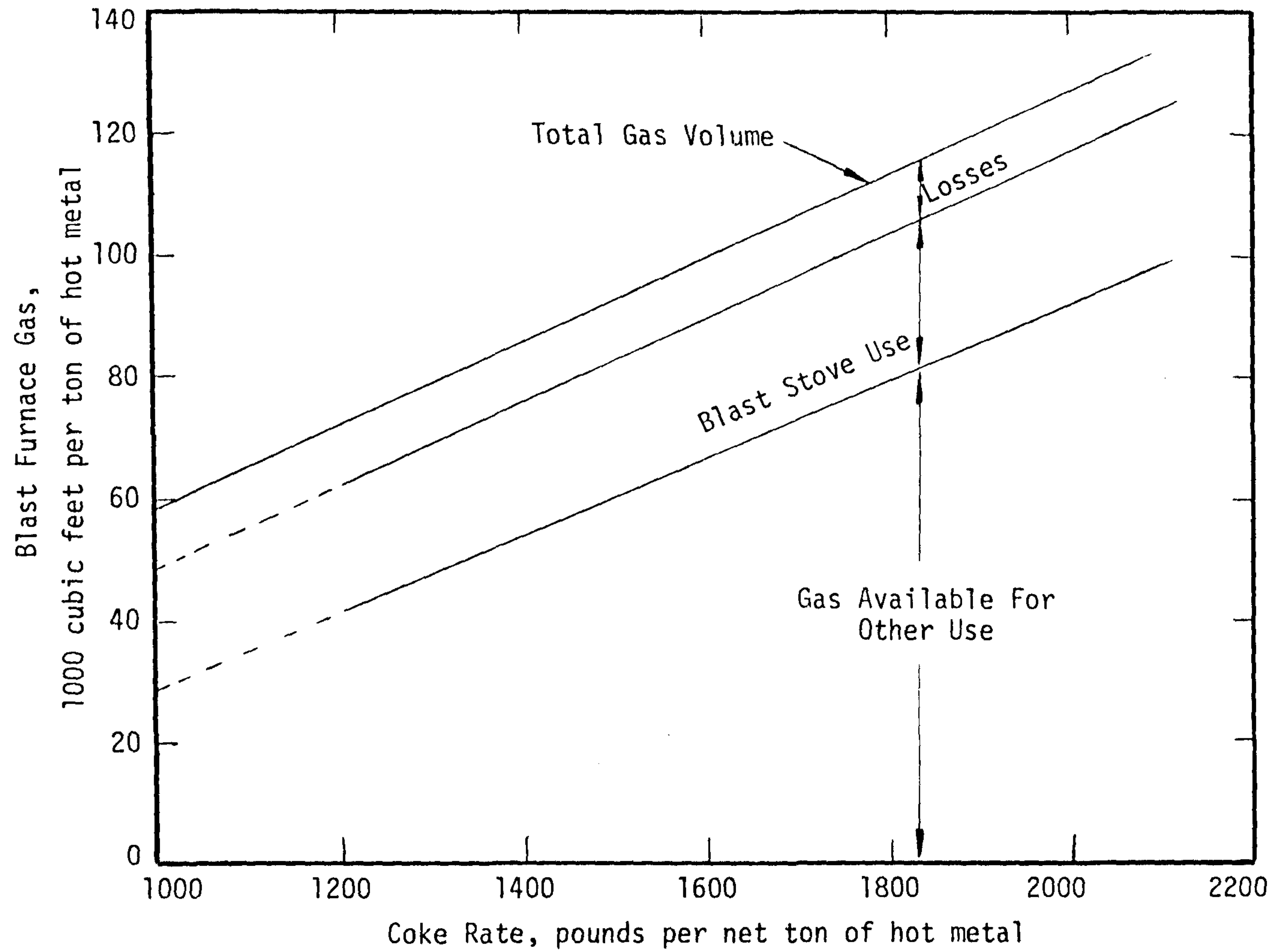

Figure 4-1. Effect of Coke Rate on Volume of Blast Furnace Gas Produced.

TABLE 4-13

FRACTIONAL ALLOCATION OF COKE "BASED" FUELS

Fuel	Blast Furnaces	Coke Oven Underlying	Steel Melting Furnaces	Heating & Annealing Furnaces	Comments
Blast Furnace Gas	0.345	0.076	--	.038	Rest in steam raising
Coke Oven Gas	0.01	0.269	0.03	0.40	Rest in steam raising
Tar and Pitch			0.66		Rest injected in blast furnace and used in steam raising

Fuel consumptions in the different process units were obtained by multiplication of the total production by the fractions summarized in Table 4-13.

5) Uncontrolled emissions were estimated by multiplication of the appropriate fuel and emission factor (summarized in Table 4-9).

C. RESULTS AND DISCUSSION

Base Year 1970

Table 4-14 summarizes the process emissions - both conventional and fuel based - for 1970.

Three sources of process emission data were available for comparison. The results of the Midwest Research Institute [4-8] show 1,442,000 tons of particulate process emissions. This compares very favorably with the estimates of this study.

Battelle's [4-2] estimates on sulfur emissions from the iron and steel industry can be shown to correlate well with the results of this study on SO_x emissions.

Similarly, Esso's [4-9] calculations on NO_x emissions agree fairly well with the results of Table 4-14.

Perusal of the results displayed in Table 4-14 show that about 1/2 of all the particulate emissions emanate from material handling. An accurate estimate of the particulate emission factor for material handling was not possible and the emissions from materials handling should therefore be considered in the light of this difficulty.

Furthermore, the results show that most of the particulate and NO_x emissions come from conventional process emissions, whilst most of the SO_x emanates as a result of the fuel combusted to the heat in the process.

TABLE 4-14

SUMMARY OF 1970 PROCESS EMISSIONS
(tons)*

	Non-Fuel Process Emissions			Fuel Process Emissions From Combustion			Total		
	SO_x	Part.	NO_x	SO_x	Part.	NO_x	SO_x	Part.	NO_x
Sinter Plants	32,000	96,000	24,000				32,000	96,000	24,000
Coke Manufacture		152,000		107,000	3,000	6,000	107,000	155,000	6,000
Blast Furnaces					2,000	negl.		2,000	negl.
Steel Furnaces (Open Hearth)	35,000	312,000	25,000				35,000	312,000	25,000
B.O.F.	2,000	28,000					2,000	28,000	
Electric Arc	negl.	28,000					negl.	28,000	
Heating & Annealing Furnaces				194,000	7,000	6,000	194,000	7,000	6,000
Scarfing		63,000						63,000	
Material Handling		446,000						446,000	
TOTAL	69,000	1,125,000	49,000	301,000	12,000	12,000	370,000	1,137,000	61,000

*Tons rounded to the nearest thousand

Projections to 1975 and 1980

Tables 4-15 and 4-16 summarize the projected estimates of process emissions in 1975 and 1980.

Once again it is emphasized that except partially in the case of particulate emissions, the emission results shown in Tables 4-15 and 4-16 are uncontrolled emission loadings. In addition, the reader is reminded of the problems associated with estimating an emission factor for materials handling.

TABLE 4-15

SUMMARY OF 1975 PROCESS EMISSIONS
(tons)*

	Non-Fuel Process Emissions			Fuel Process Emissions From Combustion			Total		
	SO_x	Part.	NO_x	SO_x	Part.	NO_x	SO_x	Part.	NO_x
Sinter Plants	39,000	117,000	29,000				39,000	117,000	29,000
Coke Manufacture		155,000		95,000	2,000	6,000	95,000	157,000	6,000
Blast Furnaces					2,000	negl.		2,000	negl.
Steel Furnaces (Open Hearth)	31,000	189,000	22,000				31,000	189,000	22,000
B.O.F.	2,000	36,000					2,000	36,000	
Electric Arc	negl.	15,000					negl.	15,000	
Heating & Annealing Furnaces				196,000	8,000	7,000	196,000	8,000	7,000
Scarfing		73,000						73,000	
Material Handling		533,000						533,000	
TOTAL	72,000	1,118,000	51,000	291,000	12,000	13,000	363,000	1,130,000	64,000

*Tons rounded to the nearest thousand

TABLE 4-16

SUMMARY OF 1980 PROCESS EMISSIONS
(tons)*

	Non-Fuel Process Emissions			Fuel Process Emissions From Combustion			Total		
	SO_x	Part.	NO_x	SO_x	Part.	NO_x	SO_x	Part.	NO_x
Sinter Plants	42,000	124,000	31,000				42,000	124,000	31,000
Coke Manufacture		159,000		97,000	2,000	6,000	97,000	161,000	6,000
Blast Furnaces					2,000	negl.		2,000	negl.
Steel Furnaces (Open Hearth)	25,000	8,000	18,000				25,000	8,000	18,000
B.O.F.	3,000	46,000					3,000	4,600	
Electric Arc	negl.	20,000					negl.	20,000	
Heating & Annealing Furnaces				205,000	9,000	8,000	205,000	9,000	8,000
Scarfing		86,000						86,000	
Material Handling		612,000						612,000	
TOTAL	70,000	955,000	49,000	302,000	13,000	14,000	372,000	968,000	63,000

*Tons rounded to the nearest thousand

REFERENCES TO SECTION IV

4-1. The Making, Shaping and Treating of Steel, 8th Edition, U.S. Steel Corporation, Pittsburgh, Pa., 1964.

4-2. A Systems Analysis Study of the Integrated Iron and Steel Industry, Battelle Memorial Institute, Columbus, Ohio, 1964.

4-3. Statistical Report American Iron and Steel Institute, 1970.

4-4. McGraw, M. J. and Duprey, R. L., Compilation of Air Pollution Emission Factors, Preliminary Document EPA, Research Triangle Park, N.C., April 1971.

4-5. Private conversation with Mr. Eckel, American Iron and Steel Institute, New York, N.Y.

4-6. A Systems Analysis Study of the Integrated Iron and Steel Industry, Battelle Memorial Institute, Columbus, Ohio, 1964.

4-7. Heynert, Von G., et al., "Charge Preparation and Its Effect on Operating Results of the Blast Furnace," Stahl und Eisle 81, 1, 1961.

4-8. Systems Study on Particulate Emissions, Midwest Research Institute; Information obtained from R. C. Lorentz, EPA, Durham, N.C.

4-9. Systems Study of Nitrogen Oxide Control Methods for Stationary Sources, Esso Research and Engineering Co., Government Research Laboratory.

V. COMPARISON OF BOILER EMISSIONS TO PROCESS EMISSIONS

Table 5-1 summarizes the current and projected national air pollution emissions from the iron and steel industry, resulting from the calculations in Sections III and IV of this report.

TABLE 5-1

SUMMARY OF AIR POLLUTANTS IN THE IRON AND STEEL INDUSTRY
(10^3 tons)

	SO_2		NO_x		Particulates	
	Boilers	Process	Boilers	Process	Boilers	Process
1970	435	370	134	61	378	1,137
1975	438	363	146	64	372	1,130
1980	477	372	162	63	409	968

The emission figures shown for boilers represent uncontrolled emissions, since insufficient data were available to determine the fraction of the emissions which were controlled. The uncontrolled figures are realistic for SO_2 and NO_x emissions from boilers. The particulates resulting from fuel combustion under boilers, however, are partially controlled, but the emission figures shown have not been adjusted accordingly.

The figures shown for process emissions represent partially controlled emissions for particulates (see Table 4-3) and uncontrolled SO_2 and NO_x emissions.

The above table shows that boilers are the source of a significant fraction of the SO_2 and NO_x emissions in the iron and steel industry, and further that they emit a fair portion of total particulates as well.

Figure 5-1 was obtained by summing the 1970 percentages of contribution to air pollution for each source and air pollutant type.

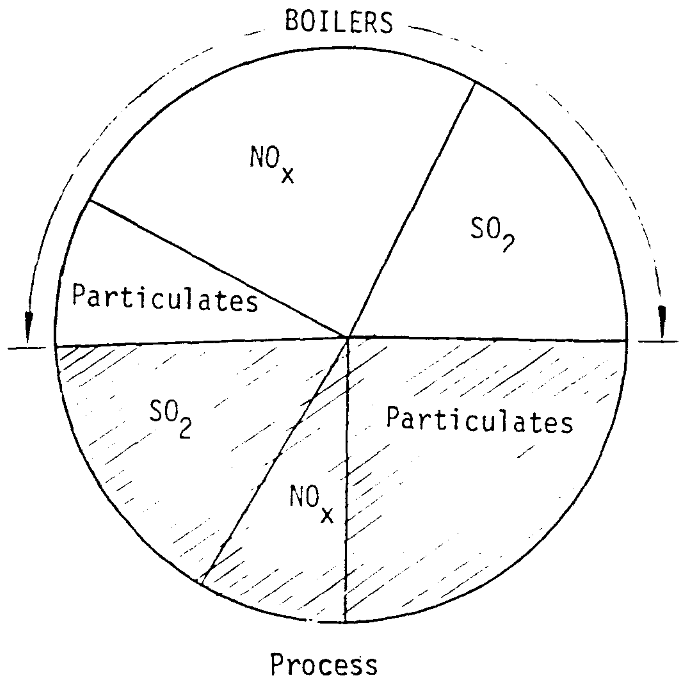

Figure 5-1. Relative Contribution of Boiler Emissions in the Iron and Steel Industry in 1970.

The particulate emissions from boilers are slightly overstated due to the fact that they are shown uncontrolled. From this figure it is concluded that the air pollution control priorities in the iron and steel industry should be as follows:

(1) Control further the particulate emissions resulting from the manufacturing processes
(2) Control SO_2 emissions resulting from boilers
(3) Control NO_x emissions resulting from boilers
(4) Control SO_2 emissions resulting from the manufacturing processes
(5) Control NO_x emissions resulting from the manufacturing processes
(6) Control further the particulate emissions resulting from boilers

It has been found that almost 40% of the process particulate emissions result from material handling (see Appendix C, Table C-24). It should be stressed that this is a rough estimate and that in reality these emissions may be lower. Even under those circumstances, however, the process particulate emissions are of first importance.

In the case of SO_2 and NO_x emissions, the boilers contribute the most significant portion of the total emissions. It is furthermore found that boiler emissions of SO_2 and NO_x in the iron and steel industry are also significant in comparison to total SO_2 and NO_x emitted by industrial boilers [5-1] (see Table 5-2).

TABLE 5-2

1975 AND 1980 BOILER EMISSIONS
IRON AND STEEL AS A PERCENTAGE OF ALL INDUSTRY
(10^3 tons)

	1975			1980		
	Iron and Steel	All Industry	%	Iron and Steel	All Industry	%
SO_2	438	3,800	12	477	3,988	12
NO_x	146	1,127	13	162	1,268	13

In short, the above comparisons indicate the need to control air pollution resulting from boilers in the iron and steel industry. Suggested strategies and their cost effectiveness are discussed in the following sections.

REFERENCES TO SECTION V

5-1. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, Cambridge, Mass., 1971.

VI. STRATEGIES FOR EMISSION CONTROL

A. INTRODUCTION

The development of an inventory of boiler equipment and fuel by various categories and their derivation of combustion emissions and projections has been presented and discussed. Attention is now directed to possible means to control these emissions. In general, some methods are effective by preventing or reducing the formation of certain pollutants where others work to remove from the flue gases undesirable products of combustion that were generated in the boiler.

Considered in sequence below are the following broad groups:

(1) Fuel switching to reduce formation of particules, SO_2 and NO_x during combustion
(2) Mechanical methods for removal of particulates from flue gas
(3) Chemical process controls for removal of SO_2 (and NO_x) from flue gas
(4) Changes in combustion design to reduce formation of particulates and NO_x
(5) Other control strategies of particular application to the iron and steel industry.

The evaluation of control means, singly or combined into broad based strategies requires inputs relevant to the overall applicability of the approaches, the state of development of the approach and specific operating and cost data. This section of the report presents such data pertinent to each of the major classes of potential control approaches.

B. FUEL SWITCHING

1. General Approach

The parameters of fuel switching are well known and do not warrant explanation in great detail. Without restriction of cost, availability or boiler design, the following generalizations can be employed as guidelines in examining possibilities of fuel switching:

a. Natural gas, now and in the foreseeable future, is the closest approach to a perfect fuel; very low in particulate and SO_2 emissions; not nearly so advantageous in NO_x emissions, but better than other fuels in most cases.

b. Distillate oil is lowest of all liquid fuels considered with respect to particulates, SO_2 and NO_x emissions, but for each pollutant somewhat higher than gas.

c. Low-sulfur residual oil and residual oil are considered equal in emissions factors for particulates and NO_x, but differ by a factor of about 4 to 5 with respect to sulfur content and, therefore, in SO_2 emissions. The emission of all three pollutants is greater than for the above fuels.

d. Coal has generally the highest pollutant potential of any fossil fuel with respect to particulates, SO_2 and NO_x, when uncontrolled. Even with particulate control equipment, it still may rank highest in this category.

2. Fuel Prices

Table 6-1 shows the 1967 prices in dollars per million Btu of various fuels used in the industrial sector according to region [6-1].

3. Capital Costs Involved in Fuel Switching

The capital costs of conversion consist of the cost of (1) new equipment and alterations at the furnace for satisfactory combustion of the fuel and (2) storage, handling, pumping and piping of the fuel.

The capital costs developed below were converted into an annual basis assuming a useful life of 20 years. Inclusion of the cost of money, taxes, insurance, etc., resulted in annualization at the rate of 14.3% of capital cost.

TABLE 6-1

FUEL RATES
(1967 Basis)

Region	Gas (I)*	Gas (F)*	Residual Oil S<.5	Residual Oil S≤1.	Residual Oil S>1.	Distillate Oil	Coal S≤1.	Coal S>1.
			USER GROUP IS INDUSTRIAL					
AT	0.45	1.03	0.59	0.51	0.40	0.84	0.43	0.37
GL	0.38	0.58	0.62	0.54	0.53	0.81	0.38	0.34
WS	0.37	0.52	0.63	0.55	0.37	0.79	0.50	0.38
CU	0.28	0.54	0.53	0.45	0.42	0.76	0.45	0.38
SE	0.36	0.50	0.63	0.55	0.37	0.77	0.36	0.35
RN	0.37	0.70	0.58	0.50	0.40	0.80	0.46	0.38

*I = Interruptible
F = Firm

Data in $\$/10^6$ Btu

There appears to be no limit on types of coal burning installations which can be replaced by gas/oil burners, assuming the age and condition of the existing unit is such that a new package type boiler would not be a more practical replacement.

Table 6-2 lists the total cost of converting coal fired boilers and includes both the cost of conversion and cost for fuel handling equipment [6-2].

C. FLUE GAS TREATMENT

1. Particulate Control

a. Equipment Type

There are four types of categories of particulate control equipment in general use today. These are:

TABLE 6-2

TOTAL CAPITAL COST OF CONVERTING COAL-FIRED BOILERS

Year - 1975

Size	Average Capacity	Type of Burner	Cost of Conversion to Gas	Cost of Conversion to Oil/Gas	Cost of New Boiler Gas	Cost of New Boiler Oil/Gas
WT1	37,000	Stoker	$ 25,000	$ 35,000	$221,000	$255,000
WT2	163,900	Stoker	107,000	170,000	652,000	725,000
WT2	163,900	Pulverized	50,000	120,000	652,000	725,000
WT3	274,900	Stoker	152,000	260,000	830,000	940,000
WT3	274,900	Pulverized	65,000	165,000	830,000	940,000
FT	4,600	Stoker	8,000	20,000	17,500	27,500
CI	625	Stoker	1,000	4,000	3,000	5,000

(1) Dry Cyclone

1. Employs centrifugal forces to separate by differential density.

2. May consist of single unit, or multiples in parallel or series.

3. Except on the largest particulates, not capable of the highest efficiencies.

(2) Wet Scrubber.

1. Depends on intimate mixing of scrubbing liquid to impinge on and entrap particulates carried by gas stream.

2a. Low to medium pressure drop characteristic of very many designs involving liquid sprays, fixed or movable packing in towers.

2b. Medium to high pressure drop characteristic of a number of venturi designs which, except for fabrication details, are very similar.

3. Can be designed for very high efficiencies.

4. Likely to have the greatest maintenance expense due to erosion and corrosion.

(3) Electrostatic Precipitator

1. Generates an electric field to charge the particulates which are then attracted to elements of opposite polarity in the precipitator.

2. Capable of the highest efficiency.

3. Will generally have the lowest pressure drop of any design; may be limited in some cases by certain flue gases which do not have favorable ionization characteristics.

4. Usually the highest cost method.

5. Efficiency can be affected by gas characteristics, e.g., adversely by low SO_2 concentration.

(4) Fabric Filter

1. Generally consists of multiple parallel cloth enclosures as bags or tubes through which the gas passes, leaving the particulates trapped on the cloth medium.

2. As with the electrostatic, capable of high efficiency: above 99% for submicron particles.

3. Greatest limitation of application is design and selection of proper filter medium for adequate life span.

b. Cost Analysis

The capital cost of a specific type of collector of given size depends on the manufacturer, location, and types of process for which it is designed. Examination of data from manufacturers and in the literature showed that reasonable general cost curves could be used to represent typical installations.

The annual operating costs of the four types of control equipment are listed below in general equation form [6-3]:

Dry Cyclone (or DC)

$$G = S[(A \times C) + (117.0 \times 10^{-6}) \frac{PHK}{E} + (M \times C)]$$

Wet Scrubber (or WS)

$$G = S[(A \times C) + (117.0 \times 10^{-6}) \frac{PHK}{E} + (188.0 \times 10^{-6}) \frac{HKQh}{F} + WHL + (M \times C)]$$

Electrostatic Precipitator (or ESP)

$$G = S[(A \times C) + (117.0 \times 10^{-6}) \frac{PHK}{E} + JHK + (M \times C)]$$

Fabric Filter (or FF)

$$G = S[(A \times C) + (117.0 \times 10^{-6}) + (M \times C)]$$

where

G = dollars/year

P = flue gas pressure drop	DC	4.3	in. W.C.
	WS (hi ΔP)	20	in. W.C.
	WS (lo ΔP)	6	in. W.C.
	ESP	1	in. W.C.
	FF	5	in. W.C.

Q = liquor circulation rate 0.50 gal/hr-acfm

h = total liquor head requirement 70 ft H_2O

W = make-up liquor requirement 0.05 gal/hr-acfm

J = power requirements 0.26×10^{-3} kw/acfm

S = design capacity of collector, acfm of flue gas

H = annual operating time, hours

L = liquor cost, collars/gal

E = fan efficiency

F = pump efficiency

A = annual capital cost factor, per year

M = annual maintenance factor, per year

K = power cost, dollars/kwhr

C = capital cost, dollars/acfm

Values for the variables in the equations can be obtained from Reference [6-2].

2. Sulfur Oxide Removal

a. Process Description

(1) General

A preliminary review of air pollution abatement processes which would remove SO_2 and NO_x individually or simultaneously from the boiler flue gases revealed that there are presently no processes demonstrated for NO_x removal but that several exist for SO_2 abatement.

About two dozen SO_2 removal processes at various stages of development are now under investigation [6-4]. Most of the removal systems are of the regenerative type in which a sulfur by-product is recovered and the reactive chemicals are recycled. A few of the systems are the non-regenerative or throw-away type, where the reacted sulfur and additive are discarded.

There is no process that is applicable to all boilers. Location and fuel are considerations which make one process more applicable than others. Detailed economic evaluations are not available for most of the processes and the few that have been published are incomplete and are based on different assumptions.

(2) Throw-away Processes

(a) Nahcolite Dry Process ($NaHCO_3$)

The nahcolite process is being promoted by the Precipitation Pollution Control Company. The process uses the mineral nahcolite to remove the SO_2 from the flue gas. Powdered nahcolite is injected into the flue gas where upon the reaction to sulfate occurs and the product is removed from the flue gas in a dry dust collector.

The process can be easily applied to small boilers and has the attractive advantage of producing a dry but soluble inert, inorganic waste product.

(b) Na_2CO_3 Wet Process

The wet sodium carbonate process utilizes a solution of Na_2CO_3 to absorb the SO_2. The solution is sprayed into a wet scrubber for reaction with the SO_2. A process is being developed by the Chemico Co. that is capable of regenerating the waste solution.

The advantage of the soda ash scrubbing system is that is is simple, easy to operate and the waste disposal is not expected to be a major operating cost.

(c) TVA Dry Limestone Process

In this process, finely divided limestone is injected into a high temperature region of the furnace for calculation and reaction with the SO_2 [6-5]. The additive containing reactive sulfur is swept through the furnace and removed in some particulate collector.

The applicability of the dry TVA process depends on limestone costs, disposal costs and air quality regulations. The disadvantage of the TVA dry lime system is that great quantities of waste are produced due to the low chemical efficiency. Nevertheless, the dry TVA process has the lowest net annual operating cost for the pulverized coal fired boilers, because the combined spent additive and ash are handled and discarded in a dry state.

(d) Combustion Engineering Dolomite Process

The process promoted by Combustion Engineering, Inc. is one of the only two systems which have been tested on a prototype installation [6-6,6-7,6-8].

In this process, the SO_2 is absorbed in a lime slurry in a wet scrubber precipitating calcium sulfate and sulfite. The lime is obtained by the injection of finely pulverized dolomite limestone into the boiler where it is calcined.

The precipitate and fly ash are separated from the scrubbing liquor by a settling tank and the supernatant liquor is recycled to the scrubber. Primarily the C-E process applicability depends on the cost of the limestone, disposal cost and boiler design of existing units.

(c) $CaCO_3$ Scrubbing

An alternative to the above is to keep the sorbent out of the furnace and employ it in the scrubber only. This appeals especially to the boiler operator who generally is not anxious to put anything other than fuel and air into the furnace.

(3) Recycle Processes

Four recovery processes appear to be most promising as recycle type processes. These are:

(a) Chemico Process

The Chemico Process is presently being developed jointly by Chemical Construction Company and Basic Chemicals Co. [6-9]. The Chemico process is a wet system which uses a slurry of magnesium oxide to absorb the SO_2, forming a precipitate of $MgSO_3/MgSO_4$. The scrubbing liquor is concentrated and crystallized for shipment to a central recovery plant. At the recovery plant the $MgSO_3/MgSO_4$ is decomposed in a kiln to produce concentrated gaseous SO_2 and powdered MgO. The MgO is returned to the scrubbing system.

The disadvantage of the Chemico system is that the $MgSO_3/MgSO_4$ solution is relatively dilute and, to minimize shipping costs, should be concentrated and crystallized before it can be shipped to the central recovery plant, necessitating a filter, crystallizer and dryer at the boiler. However, the regenerated MgO is in a dry phase which is easily shipped back to the users. Overall, the Chemico process is one of the more practical systems that can be readily utilized in the regional centralized concept for small boilers.

(b) Stone & Webster/Ionics Process

The Stone & Webster/Ionics Process, which is being developed jointly by Stone & Webster Engineering Corporation and Ionics Company, is one of the most technologically advanced and promising SO_2 recovery processes [6-10]. The process was operated at a pilot plant in Tampa, Florida, and a prototype plant is now being designed. The pilot plant tests indicated satisfactory levels ($\geq$90%) of SO_2 removal were feasible and that further demonstration of the process was warranted.

The SW/I Process is based on sodium hydroxide absorption of the SO_2. The formed sodium sulfite-bisulfite solution is reacted with sulfuric acid (H_2SO_4), generated internally, to form sulfur dioxide and sodium sulfate solution. The sodium sulfate is processed in the electrolytic cell to general sodium hydroxide and sulfuric acid which are recycled to process. The SO_2, which is recovered as pure gas, can be used to manufacture sulfuric acid or elemental sulfur.

The disadvantage of the SW/I Process is that relatively dilute solutions have to be transported between the boiler and the recovery plant. The solutions could be concentrated and crystallized but it would mean higher capital expenditure at each boiler site and at the recovery plant.

(c) Wellman-Lord Process

The Wellman-Lord Process is also a wet scrubbing process; the absorbing solution is K_2SO_3 [6-11]. In the scrubber, $KHSO_3$ is formed which will crystalize and precipitate upon cooling.

The metabisulfate crystals ($K_2S_2O_5$) when heated with steam will give up one mole of SO_2 per mole of $K_2S_2O_5$ and forms an aqueous solution of K_2SO_3. The K_2SO_3 is recycled.

The Wellman-Lord Process has the same disadvantage as all the other aqueous regenerative processes; that is, relatively weak solutions have to be handled both to and from the recovery plant or concentrated and crystallized at the respective sites. The Wellman-Lord Process is being developed with minimum public disclosure of results and progress.

TABLE 6-3

SO_2 REMOVAL SYSTEMS

Designation	Description	Developer	Chem. Feed Rate*	SO_2 Removal Efficiency
A	Dry Sodium Carbonate (Na_2CO_3) and fabric filter	(Nahcolite Alternative)	110	60
B	Sodium Carbonate (Na_2CO_3) Scrubbing	---	110	95
C	Dry Calcium Carbonate ($CaCO_3$)	TVA	200	40
D	Dry Calcium Carbonate ($CaCO_3$) and Scrubber	C.E.	110	90
E	Calcium Carbonate ($CaCO_3$) Scrubbing	---	110	60

*Percent of stoichiometric requirement of the sulfur in the fuel.

(d) The Molten Carbonate Process

The molten carbonate process being developed by the Atomics International Division of North American Rockwell is still in the bench scale development stage and design details are sparse [6-12]. However, the molten carbonate process appears to be one of the most adaptable processes to the regional recovery plant concept for new installations.

In this process the SO_2 is adsorbed in a molten salt at approximately 800°F. The molten salt solution is regenerated by reducing the sulfate to sulfide and reacting the sulfide with CO_2 to produce carbonate salt and H_2S gas. The H_2S can be used to manufacture elemental sulfur.

There is a substantial drawback to this process in that the high operating temperature of the unusual adsorbent would almost completely preclude all boilers except those operating continually throughout the year. Thus, only large boilers in process industries are likely candidates for consideration.

b. Cost Information

Detailed cost information were available from the Intermediate-Size Boiler Study [6-2] for the five SO_2 removal systems detailed in Table 6-3.

Table 6-4 indicates estimates of capital cost for each process at a new installation and at an existing boiler plant. For schemes A and C, oversize particulate collection equipment was included because of the great increase over normal combustion-associated loads. For the schemes B, D, and E at a new boiler plant, it was assumed that the wet scrubber installed for SO_2 control would also be adequate for particulate control. Therefore, credit was given for omission of a particulate collector that would otherwise have been installed.

Table 6-5 shows total annual operating cost for each SO_2 control scheme. This includes all operating costs such as labor, maintenance, utilities, chemicals, etc. Also included was an allowance

TABLE 6-4

SULFUR DIOXIDE REMOVAL FROM FOSSIL FUEL BOILER FLUE GAS

(CAPITAL COST IN $1000)*

	A		B		C		D		E		F	
	Na_2CO_3 (Dry)		Na_2CO_3 (Wet)		$CaCO_3$ (Dry)		$CaCO_3$ (Dry) & Wet Scrubber		$CaCO_3$ (Wet)		CaO (Wet)	
Size and Fuel	New	Conversion	New	Conversion	New	Conversion	New	Conversion	New	Conversion	New	Conversion
275,000 lb/hr												
Coal, Pulverized	510	730	285	480	360	520	275	471	275	471	275	471
Coal, Stoker	510	730	285	480	---	---	---	---	275	471	275	471
Oil	610	710	268	375	356	550	377	470	377	470	377	470
164,000 lb/hr												
Coal, Pulverized	355	485	188	320	263	365	187	312	187	312	187	312
Coal, Stoker	355	485	188	320	---	---	---	---	187	312	187	312
Oil	425	470	182	250	328	400	258	320	258	320	258	320
37,000 lb/hr												
Coal, Pulverized	---	---	---	---	---	---	---	---	---	---	---	---
Coal, Stoker	---	---	110	152	---	---	---	---	---	---	110	150
Oil	190	206	88	105	169	190	---	---	135	158	135	158

*For comparison, new boiler costs alone are approximately $900,000 for the 275,000 pph size, $700,000 for the 164,000 pph size, and $230,000 for the 37,000 pph size.

TABLE 6-5

SULFUR DIOXIDE REMOVAL FROM FOSSIL FUEL BOILER FLUE GAS

(TOTAL ANNUAL OPERATING COST IN $1000)

Assuming 3% Sulfur

	A		B		C		D		E		F	
	Na_2CO_3 (Dry)		Na_2CO_3 (Wet)		$CaCO_3$ (Dry)		$CaCO_3$ (Dry) & Wet Scrubber		$CaCO_3$ (Wet)		CaO (Wet)	
Size and Fuel	New	Conver-sion	New	Conver-sion	New	Conver-sion	New	Conver-sion	New	Conver-sion	New	Conve sion
275,000 lb/hr [1]												
Coal, Pulverized	422	480	350	408	230	270	285	335	275	330	305	360
Coal, Stoker	420	475	320	390	---	---	---	---	260	305	275	365
Oil	385	410	260	290	200	232	230	255	220	248	240	270
164,000 lb/hr [2]												
Coal, Pulverized	345	280	190	230	142	170	165	195	160	191	170	210
Coal, Stoker	242	280	180	232	---	---	---	---	149	180	158	193
Oil	230	245	150	170	135	155	145	160	137	157	145	167
37,000 lb/hr [3]												
Coal, Pulverized	---	---	---	---	---	---	---	---	---	---	---	---
Coal, Stoker	76	85	60	55	---	---	---	---	55	63	56	64
Oil	77	81	46	51	55	61	---	---	52	58	54	60

[1] Divide costs by 13 to obtain cents/10^6 Btu

[2] Divide costs by 5.0 to obtain cents/10^6 Btu

[3] Divide costs by 0.67 to obtain cents/10^6 Btu

for annual capitalization expense, taken at 21% of total capital cost. The basic information used in the computation of these figures can be found elsewhere [6-2].

Application of these operating costs to a control cost effectiveness study on boilers in the iron and steel industry may at first appear unrealistic because of differences in percent of sulfur in the fuel and load factors. As is noted at the head of Table 6-5, the operating costs were calculated for a 3% sulfur fuel. The percent sulfur in the fuel affects mainly the raw material and disposal costs and as such the annual operating costs vary with percent sulfur in fuel.

Perusal of Table D-2 indicates that the coal and oil used in process boilers in the iron and steel industry contained on the average about 1.8% sulfur.

Furthermore, the data presented in Table 6-5 were calculated assuming that the boilers had the following load factors:

Capacity	Load Factor
<100,000 pph boiler	21%
100,001-250,000 pph boiler	35%
>250,000 pph boiler	55%

Comparison of the above load factors to the average load factor of 77% for process boilers in the iron and steel industry (see page 26) indicates that on the average the iron and steel boilers have load factors about twice those used in the estimation of the data in Table 6-5.

Fortunately, these two disparities between the two sulfurs result in approximately compensating effects so that as a simplifying conclusion it will be assumed that the annual operating costs of the various SO_2 control schemes as shown in Table 6-5 can be applied for cost effectiveness studies to the process boilers in the iron and steel industry. It is recognized that with the smaller boilers this compensating effect may not be quite as good because of their lower load factor.

3. NO_x Removal and Recovery

The normal range of NO_x concentration in the flue gas is approximately 300 to 700 ppm. At these low concentrations, other flue gas constituents such as CO_2, SO_2 and O_2 interfere with NO_x removal processes using sorption, scrubbing and catalytic conversion techniques. Several NO_x removal processes are being investigated. However, all of them are still at the laboratory bench stage of development and are not available for full scale installation.

Perhaps the most sophisticated process approach to the problem has been presented by Tyco Laboratories [6-8]. In their process both SO_2 and NO_x are removed from the flue gases by a process similar in nature to the old "chamber process" for the production of sulfuric acid. However, this process, too is still in the laboratory stage of development.

D. COMBUSTION DESIGN

The following two major types of control techniques will be considered in this section:

(i) Use of combustion additives
(ii) Changes in combustion design

1. Combustion Additives

As an approach to improving combustion and reducing pollutants, total effort in the field of combustion additives has been small when measured against development programs in equipment and fuels.

Perhaps it is because the concept has often been viewed as black art, in this case changing obnoxious chemicals into harmless ones. However, in today's view of the pollution situation, the use of chemical additives to reduce particulate, sulfur oxide and nitrogen oxide emissions from furnaces is a concept which deserves to be evaluated, particularly for small and medium size installations where flue gas treatment systems requiring substantial capital expenditure are not likely to be economically feasible.

The purpose here is to survey and evaluate additives presently used or proposed for use in furnaces.

The organometallic additives (e.g., methyl cyclopentadienyl manganese tricarbonyl) are claimed to reduce carbonaceous particulate emissions from furnaces by functioning as combustion catalysts.

Reliable data on additive loading and effectiveness in reducing particulate emissions is sparse. About the only information generally available are manufacturer's claims of additive effects and recently work done at NAPCA [6-13,6-14]. Published results [6-14] indicate that with only about 10% of the over 200 additives tested were reductions in particulate emissions observed.

Generally the suggested additive loadings could result in considerable emissions of toxic metallic particulates [6-14].

A second class of additives, presently used to reduce soot emissions, function by changing the pumping and atomizing characteristics of heavy fuel oils.

There are no additives which are currently in commercial use to reduce nitric oxide emissions from stationary combustion equipment. However, the injection of liquid water into the flame to act as an inert diluent has been tried [6-15]. The results indicate a decrease in NO_x with a simultaneous increase in particulate emissions.

Perhaps the most effective use of additives, at the present time has been demonstrated in the reduction of sulfur oxide emissions.

Successful additive action has been experienced in residual oil fired large boilers wherein finely divided MgO additive suspended in light oil is simultaneously injected at a controlled rate into the furnace. The SO_3 emission is decreased, corrosion is reduced substantially, and the ash found on tubes is soft, dry and easily removed [6-16].

Many of the manganese containing additives which are effective in reducing particulate emissions, have also been demonstrated to reduce SO_3 production [6-17,6-18].

Emission Control and Cost Data

From the foregoing discussion it can be concluded that the control effects and cost of additive addition are not well established.

Nevertheless, based on rough estimates of the Intermediate Boiler Study [6-12], it will be assumed that the following values will be attainable in 1975:

(1) 50% reduction in particulate emissions
(2) 0.3 cents per million Btu cost

2. Combustion Design

a. Process Description

Based on present knowledge and technology, the attack on NO_x emissions is likely to be different from that on particulates and SO_x. For the latter two, present sources and foreseeable progress appears to lie in fuel switching and/or flue gas treatment, although a certain amount of unburned carbon particulate emissions and SO_3 production probably will be reduced by redesign of the combustion package. For NO_x, on the other hand, redesign of the combustion package offers the greatest promise of improvement and will probably include changes in fuel/air mixing and metering, burning mechanisms, the furnace envelope and combustion controls.

The study done by Esso Research and Development Company for NAPCA "Control Techniques for Nitrogen Oxide Emissions from Stationary Sources" is the most recent and comprehensive view of the subject and the recommendation and analysis generally follows that work [6-19].

In general, three combustion modifications are currently considered as effective in reducing NO_x emissions. These are Low Excess Air (LEA), Flue Gas Recirculation (FGR) and Two Stage Combustion.

Low excess air, as the name implies, requires the use of 5% or less excess combustion air, rather than the usual 20-30% to markedly reduce the production of nitrogen oxides. Experimental data from large boilers indicates that a reduction of 33% in NO_x emissions is possible and it has been assumed that this reduction can be obtained for all boiler sizes.

The mechanics of implementing low excess air involve carefully metering combustion air and fuel, measuring either CO_2 or O_2 in the flue gas and introducing some feedback mechanism from this last measurement to effect control over the fuel/air ratio. Excellent fuel/air mixing at each burner and uniformity across the furnace is of greatest importance.

A second technique for reducing NO_x involves bringing a portion of the combustion flue gas back to the combustion chamber as part of the combustion air [6-19]. This approach appears to reduce O_2 concentration and temperature with effects as described above and also to reduce flame temperatures which has been shown to be an effective mechanism for NO_x reduction.

Implementation of this strategy is not too difficult, needing only flue gas recirculation fan, duct work and controls.

Extension of the above techniques have led to development of boiler operation with both low excess air and flue gas recirculation. This has been successfully demonstrated in commercial equipment and as a result of the compound effect a reduction of NO_x emissions by 50% has been assumed for the combined strategy [6-19].

Finally one of the advanced concepts summarized by Esso is that of two-stage combustion [6-19]. Work on commercial units has gone forward and a West Coast utility with an NO_x emissions problem has made considerable progress, aided by their boiler manufacturer.

b. Economic and Operating Characteristics

The Intermediate Boiler Study [6-2] presents the following capital cost estimates: (Table 6-6)

TABLE 6-6

ADD-ON COST OF COMBUSTION MODIFICATION

Boiler Size	Cost Per Boiler LEA	FGR	Both
WT-1 (<100,000 pph)	$3,000	$ 6,000	$ 8,000
WT-2 & 3 (100,001-500,000 pph)	4,000	20,000	22,000
Firetube and cast iron	3,000	3,000	4,200

A low annualization factor of 10% has been applied against the above capital cost because of the effects of assuming the life of such accessories will equal that of the boiler and because of low maintenance requirements. However, it will be assumed that LEA will realize enough savings through fuel economy that the annualized capital costs will be offset in the WT2 and WT3 boilers, but not in the WT1 boilers where the annualized capital costs was set equal to the total operating cost.

E. CONTROL STRATEGIES OF SPECIAL APPLICATION TO THE IRON AND STEEL INDUSTRY

A brief survey was undertaken of the possibilities of using some of the currently employed process particulate removal systems to assist in removal of particulates from boiler emissions. It was concluded that the process removal systems were operating at their design load and as such had no addition capacity for other particulate laden gas. Furthermore, the cost of transportation of the large volumes of boiler flue gas would generally be prohibitively high.

REFERENCES TO SECTION 6

6-1. Based on The Fuel of Fifty Cities, Ernst & Ernst, November 1968.

6-2. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, Cambridge, Mass., 1971.

6-3. Anon., Control Techniques for Particulate Air Pollutants, NAPCA Pub. No. AP-51, U.S. Dept. of HEW, Public Health Service, Consumer Protection and Environmental Health Service, 1969.

6-4. Dennis, R. and Bernstein, R.H., Engineering Study of Removal of Sulfur Oxides from Stack Gases, Report for Committee for Air and Water Conservation, American Petroleum Institute, August 1968.

6-5. Sulfur Dioxide Removal from Power Plant Stack Gas, Conceptual Design and Cost Study, Sorption by Limestone or Lime Dry Process, TVA Report, 1968.

6-6. Maurin, P.G. and Jonakin, J., "Removing Sulfur Oxides from Stacks", Chemical Engineering, April 27, 1970.

6-7. Plumley, A.L., Whiddon, O.D., Shutko, F.W. and Jonakin, J., "Removal of SO_2 and Dust from Stack Gases", presented at American Power Conference, Chicago, Illinois, April 25-27, 1967.

6-8. McLaughlin, J.F. and Jonakin, J., "Operating Experience with Wet-Dolomite Scrubbing", Annual Meeting of APCA, June 1969.

6-9. Willett, H.P., Quig, R.H., and Shah, I.S., "Venturi Scrubbing for SO_2 and Fly Ash Removal at Power Plant Sites with Centralized Reactant Reprocessing", presented at New England Section, APCA, Hartford, Connecticut, April 16, 1969.

6-10. Humphries, J.J., Zdonik, S.B. and Parsi, E.J., "Economic Factors in the Capital and Operating Costs of the Stone & Webster/Ionics SO_2 Removal and Recovery Process", presented at AIChE Symposium, Chicago, Illinois, November 29-December 1, 1970.

6-11. Terrana, J.D., and Hiller, L.A., "New Process for Recovery for SO_2 from Stack Gases", Wellman-Lord, Inc., Florida.

6-12. Oldenkamp, R.D., and McKenzie, D.E., "The Molten Carbonite Process for Control of Sulfur Oxide Emissions", North American Rockwell Corp., Atomic International Div.

6-13. Martin, G.B., "Use of Fuel Additives and Combustion Improving Devices to Reduce Air Pollution Emissions from Domestic Oil Furnaces", presented at the Third New and Improved Oil Burner Workshop of NOFI, Hartford, Conn., September 23-24, 1970.

6-14. Martin, G.B., Wasser, J.H. and Hanegebrauck, R.P., "Status Report on Study of Effects of Fuel Oil Additives on Emissions from an Oil-Fired Test Furnace", presented at Annual Meeting of APCA, St. Louis, Mo., June 14-19, 1970.

6-15. "The Treatment of Residual Fuel Oils", Dearborne Chemical Division, W.R. Grace Co., Merchandise Mart, Chicago, Ill., Technical Bulletin 12101.

6-16. Exley, L.M. Tamburrino, A.E. and O'Neal, A.J., Jr., "LILCO Trims Residual Oil Problems", Power, April 1966, pp 69-73.

6-17. Belyea, A.R., "Manganese Additive Reduces SO_3", Power, November 1966.

6-18. Kukin, I., "Advances in the Use of Chemical Treatment in Air Pollution Reduction Programs", presented at the Rocky Mountain Regional Meeting, National Petroleum Refiners Association, October 2-3, 1968.

6-19. Bartok, et al., Systems Study of NO_x Control Methods for Stationary Sources, Esso R&D Co. (NAPCA Contract No. PH 22-68-55), November 1969.

VII. COST EFFECTIVENESS AND ANALYSIS

A. INTRODUCTION

Lack of funding precluded a thorough cost effectiveness analysis of the application of many of the different control strategies discussed earlier. However, following the general guidelines of the Intermediate Boiler Study [6-1], cost effectiveness analyses were made for the application of the following three broad control strategies to the steam raising boilers in the iron and steel industry.

- (i) Fuel Switching
- (ii) Flue Gas Treatment
- (iii) Maximum Reduction - Reasonable Cost Total Program, i.e., combustion of fuel switching, fuel additives and combustion modification

The economic impact of the strategies has been examined in terms of both capital cost and also annual cost. The latter quantity includes such operating costs as fuel, labor, maintenance, water, etc., and the annualized capital cost. The latter factor represents the depreciation and depends on the number of years of useful life assumed and on the cost of money.

Exercise of judgment in assessing the multitude of strategies leads one quickly to the many positive aspects of fuel switching. The major advantage is the fact that this approach can very largely eliminate simultaneously, emissions of SO_2 and particulates and make a good showing in total NO_x emissions.

The control of all emissions, comparable to the results of fuel switching, can be accomplished by means of a flue gas treatment. Wet scrubbing employing a sodium carbonate solution was selected as being optimal.

Under maximum pressure or incentive to bring emissions to the lowest practical level over the short term say 1975, it is conceivable that a combination of individual strategies could be implemented, resulting in a maximum reduction - reasonable cost total program. Such an all encompassing program was comprised of the following strategies:

(1) Fuel switching from coal to low sulfur residual oil, distillate oil or gas according to size and region for reduction of particulates and SO_2 and some NO_x.

(2) Fuel additives for all oil firing in all sizes for additional particulate reduction

(3) Combustion modification by LEA, staged combustion, and FGR for significant NO_x reduction.

B. RESULTS

1. Fuel Switching

Fuel switching was based on the gross regional assumptions that coal-fired equipment would be converted to low sulfur residual oil firing in the Atlantic (AT) and Southeast (SE) areas and to gas firing in the balance of the 48 states. In addition, all units firing residual oil were switched to low sulfur residual. These assumptions were based on those used in the Intermediate Boiler Study [7-1].

The results obtained are shown in Table 7-1.

It should be emphasized, however, that variation in fuel prices due to supply and demand were not taken into account.

2. Flue Gas Treatment

Even though furnace gas contains no sulfur, flue gas treatment strategy was applied to all units in the cost effectiveness analysis. The rational behind this was that boilers in the iron and steel industry tend to use many different fuels during their operation, so that flue gas treatment would be required when other fuels were used.

Estimation of capital investment and annual operating costs were obtained simply by dividing separately the total boiler

TABLE 7-1

FUEL SWITCHING STRATEGY

	Emissions (10^3 tons/yr) 1975 Projections	Reduction	% Reduction of Each Pollutant	Cost** $ 10^6 Capital	Annual*
Particulates					
WT_1	124.6	115.7			
WT_2	130.6	126.5			
WT_3	117.1	113.1			
TOTAL	372.3	355.3	95		
SO_2					
WT_1	176.5	119.0		5.8	16.6
WT_2	143.5	103.5		3.0	11.1
WT_3	118.4	82.0		2,8	11.0
TOTAL	438.4	304.5	69	11.6	38.7
NO_x					
WT_1	49.1	5.7			
WT_2	49.5	4.9			
WT_3	47.8	6.0			
TOTAL	146.4	16.6	11		

*Includes a 14.3% writing off of the capital cost.

**Cost to reduce all three pollutants.

capacity in each of the three size groupings WT1, WT2 and WT3 by the average boiler sizes for which data were presented in Tables 6-4 and 6-5. This was a rough estimate of the total number of units in each size category. Costs were then obtained by multiplying these number of units by the average (by fuel and type of burner) conversion costs presented in Tables 6-4 and 6-5.

The results are shown in Table 7-2.

3. Maximum Reduction - Reasonable Cost Strategy

As discussed earlier this strategy consists of the combined application of three strategies. The results of the fuel switching strategy are presented in Table 7-1. Table 7-3 presents the cost effectiveness of applying combustion modifications and additives.

TABLE 7-2

FLUE GAS TREATMENT BY CONVERSION OF EQUIPMENT

	Emissions (10^3 tons/yr) 1975 Projections	Reduction	% Reduction of Each	Cost \$ 10^6 Capital	Annual Operating
Particulates					
WT_1	124.6	115.7			
WT_2	130.6	126.5			
WT_3	117.1	113.1			
TOTAL	372.3	355.3	95		
SO_2					
WT_1	176.5	167.5		125	52
WT_2	143.5	136.0		60	42
WT_3	118.4	113.0		53	43
TOTAL	438.4	416.5	95	238	137
NO_x					
WT_1	49.1	9.8			
WT_2	49.5	9.9			
WT_3	47.8	9.6			
TOTAL	146.4	29.3	20		

TABLE 7-3

COST EFFECTIVENESS OF APPLYING COMBUSTION MODIFICATIONS (LEA AND FGR) AND ADDITIVES TO ALL RESIDUAL OIL BOILERS

	Emissions (10^6 tons/yr)		% Reduction of Each Pollutant	Cost $ 10^6	
	1975 Projections	Reduction		Capital	Annual
Particulates					
WT_1	124.6	2.5		0	2.0
WT_2	130.6	.7		0	1.4
WT_3	117.1	.8		0	1.2
TOTAL	372.3	4.0	1	0	4.6
SO_2					
TOTAL	438.4	N.A.	-	-	-
NO_x					
WT_1	49.1	21.7		8.3	.8
WT_2	49.5	22.3		4.4	0
WT_3	47.8	20.9		2.6	0
TOTAL	146.4	64.9	44	15.3	.8

REFERENCES TO SECTION VII

7-1. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, Cambridge, Mass., 1971.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Three major conclusions emerge from this study:

(1) Steam raising boilers are a significant source of air pollution in the iron and steel industry. These boilers emit about 1/3 the particulate loadings of the process emissions, about 1/2 of the total SO_2 and 2/3 of the total NO_x.

(2) A significant fraction of the particulate and SO_2 emissions from the boilers result from the combustion of conventional fossil fuels. This is a result of the relative cleanliness (with respect to particulates and sulfurs) of coke oven gas and blast furnace gas as compared to the conventional fossil fuels.

(3) Mainly as a consequence of (2), it is concluded from the control strategy cost effectiveness analyses that fuel switching would be the most effective means of control.

B. RECOMMENDATIONS

Examination of the results of the development of emission estimates and projections and analysis of control strategies point to two principal sets of recommendations.

(1) Improvement on the present study
(2) Implementation of fuel switching

1. Improvements of the Present Study

The first set reflects uncertainties and limitations resulting from assumptions, idealizations and imperfect data inputs inherent in the analytic procedures employed in the study.

Anticipating that strategy evaluation appears more meaningful on the basis of combined effects on all three pollutants, it would be valuable to develop a parallel means to combine the emissions into a single quantity using some weighting factor to account for permissible levels of exposure.

Other improvements are more direct. The study should be updated and checked against actual future developments. More fine structure should be introduced. There is need to improve the emission factor data and the information concerning the fraction of units controlled. This information is required particularly for the process emissions where very little information is available and yet these "rough" emission estimates would suggest that the iron and steel industry is a significant industrial polluter.

The fuel switching analysis depends on several key assumptions regarding fuel price and availability. Re-examination considering supply price forecasts should be made.

2. Implementation of Fuel Switching

Fuel switching was shown to be the preferred control strategy as long as fuel prices do not increase. However, recent trends in prices, particularly for low sulfur fuels, would suggest rapid increases in the near future. Because fuel switching has many attractive features other than low annual operating costs, it is important to seek means to maintain the price of fuel and the adequacy of supply at levels where this strategy remains effective.

APPENDIX A

DATA ANALYSIS AND BOILER INVENTORY

From the various sources, state-by-state totals were compiled of the available capacity in the boiler data base. From the Dun & Bradstreet Metalworking Directory [A-1], the number of employees for each plant for which data were available were recorded. Where no employment figures were available, estimates were made. Table A-1 lists the capacities and number of boilers obtained for each state, and the approximate percentage this would represent of the total, based on employment. The percentage was arrived at for each state by using the ratio between the employment figures for the plants for which data were available and the total employment figure for SIC 331, as reported in the 1969 County Business Pattern publication for each state [A-2]. Exceptions were those cases where it was known that one or two large plants made up most of the total state capacity and where information on the boilers in use in these plants were available, i.e., in Maryland and Michigan.

Except for New Jersey, the states not listed have a negligible number of people employed in the iron and steel industry (less than 0.5% of the total U.S. employment in SIC 331). Based on a rough capacity/employment ratio of 250 (obtained by averaging some of the available data), we estimated New Jersey to have about 15 boilers with a total capacity of 1 million lb/hr. The other state totals were obtained by multiplying the reciprocal of the employment ratio, described before, by the capacity available in Walden's sample data. The results are listed in Table A-2 and add up to 103,495,000 lb/hr and 2,269 boilers. The total sample obtained represents about 64% of the total employment in the iron and steel industry.

In order to make a rough check of these estimates, the following exercise was performed. An age profile was drawn up from the sample of boilers where the boiler age was available. Assuming a two-year lag between the boiler sales as reported by the ABMA [A-3] and the date of

TABLE A-1

SAMPLE OF BOILERS IN THE IRON AND STEEL INDUSTRY

State	No.	Capacity (10^3 pph)	% of Total
Alabama	87	6,063	62
California	29	2,151	55
Colorado	22	1,445	100
Connecticut	3	49	6
Delaware	2	100	50
Georgia	2	50	100
Illinois	60	4,594	80
Indiana	97	8,874	93
Kentucky	1	negl.	negl.
Maryland	422	4,980	100
Massachusetts	13	104	21
Michigan	12	4,120	82
Minnesota	23	389	66
Missouri	4	240	80
New York	30	2,303	64
Ohio	187	13,453	73
Pennsylvania	285	13,871	46
Texas	8	1,002	39
Utah	23	1,592	99
West Virginia	20	2,400	80
		66,256	

TABLE A-2

1970 ESTIMATE OF BOILERS IN THE IRON AND STEEL INDUSTRY

State	No.	Capacity (10^3 pph)
Alabama	140	9,800
California	53	3,900
Colorado	22	1,500
Connecticut	53	860
Delaware	4	200
Georgia	2	50
Illinois	75	5,750
Indiana	105	9,580
Kentucky	13	5
Maryland	425	5,000
Massachusetts	60	500
Michigan	52	5,000
Minnesota	51	850
Missouri	8	300
New Jersey	15	1,000
New York	48	3,600
Ohio	256	18,400
Pennsylvania	700	30,000
Texas	21	2,600
Utah	28	1,600
West Virginia	21	3,000
	2,269	103,495

actual installment, the boilers sold between 1965 and 1968 should have been installed between 1967 and 1970. Furthermore, the assumption was made that the age profile of the sample is representative of the national age profile of the boilers sold by the ABMA members to the primary metals industry. Using these assumptions, the capacity installed between 1911 and 1970 was found to be 7.09 times as large as the capacity installed in the four-year period of 1967 to 1970. Multiplying the 1965 to 1969 ABMA sales by this factor should give an approximation of the boilers sold to the primary metals industry between 1911 and 1970. This calculation results in a total capacity of 120,885,000 lb/hr. Assuming that 90% of this capacity was sold to the iron and steel industry reduces the figure to 108,796,000 lb/hr. Subtracting about 5% for retired boilers [A-4] results in the final figure of 103,356,000 lb/hr of installed boiler capacity in the iron and steel industry. This compares very favorably with the total capacity obtained from the state-by-state approach, which was 103,495,000 lb/hr. The two approaches differ by less than 1%, giving us confidence in the methodology and the results.

Ranking the states according to installed capacity, we find Pennsylvania to be far ahead of all other states, with Ohio, Indiana, and Alabama in the second, third, and fourth places (see Table A-3).

The boiler inventory is summarized in Table A-4. It was decided to leave out the small cast iron and firetube boilers used in some iron and steel plants. This reduced the number of boilers significantly, but did not affect the total boiler capacities when reported in thousand pounds of steam per hour (see Table A-5).

The age distribution of the boilers in the iron and steel industry available from the Walden sample shows that the Southeastern region of the U.S. has the largest proportion of boilers older than 20 years (see Table A-6). This region has had iron and steel plants since the end of the 19th century and, contrary to the Atlantic states, it has not expanded its iron and steel plants by putting in a larger number of small

TABLE A-3

1970 STATE RANKING BY BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY

Rank		Capacity (10^3 pph)
1	Pennsylvania	30,000
2	Ohio	18,400
3	Alabama	9,800
4	Indiana	9,580
5	Illinois	5,750
6/7	Maryland	5,000
6/7	Michigan	5,000
8	California	3,900
9	New York	3,600

TABLE A-4

1970 REGIONAL ESTIMATES OF BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY

Region	No. of Boilers	Capacity (10^3 pph)
Atlantic	1,305	41,160
Great Lakes	547	39,880
West and South	124	9,600
South East	176	12,855
	2,152	103,495

TABLE A-5

1970 REGIONAL ESTIMATES OF WATERTUBE BOILERS IN THE IRON AND STEEL INDUSTRY

Region	No. of Boilers	Capacity (10^3 pph)	Average (pph)
Atlantic	783	41,160	53,000
Great Lakes	514	39,880	77,600
West and South	123	9,600	78,000
South East	172	12,855	74,700
	1,592	103,495	(65,000)

TABLE A-6

1970 AGE DISTRIBUTION OF WATERTUBE BOILERS IN THE IRON AND STEEL INDUSTRY

Region	Less Than or Equal to 20 Years	Older Than 20 Years
Atlantic	49%	51%
Great Lakes	49%	51%
West and South	31%	69%
South East	10%	90%

boilers. In some cases, larger boilers were ordered to replace the older ones, and it is assumed that the 10% new boilers are mostly those greater than 250,000 pph. In very many cases, however, the iron and steel industry has turned to purchasing steam and electricity, instead of generating steam for process heating and power purposes. The TVA complex in this region has facilitated this process. Summarizing, it may be said that the percentage of new boilers is quite small in iron and steel plants in the Southeast, because this is an old industry for the region, and because many expanding and new plants have eliminated their own boiler plants by buying outside steam and electricity.

From the Walden sample of boilers in the iron and steel industry, the following fuel distributions were obtained: (Table A-7)

TABLE A-7

1970 FUEL DISTRIBUTION OF BOILERS IN THE IRON AND STEEL INDUSTRY (percentages)

Region	Coal	Residual Oil	Natural Gas	Blast Furnace Gas	Coke Oven Gas
Atlantic	10	13	29	34	14
Great Lakes	31	9	19	30	11
West and South	2	5	35	31	27
South East	32	3	26	28	11

From all the above distribution tables, we arrive at the boiler inventory summarized in Table A-8.

From the sample a weighted average was calculated for the load factor of the boilers in the iron and steel industry. This average was about 77%. Boiler efficiencies were not requested on the questionnaire form, but were requested in the telephone interviews. From this smaller sample, the range of efficiencies was found to be from 60% to 92% with an average of about 78%. The larger boilers usually had a higher

TABLE A-8

1970 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY
(10^3 pph)

Boiler Size	Fuel	AT	GL	WS	SE	Total
$WT_{<100}$	CL	1,729	3,956	73	1,439	7,197
	RO	2,247	1,148	182	135	3,712
	GS	5,013	2,425	1,277	1,170	9,885
	BFG	5,878	3,829	1,131	1,260	12,098
	COG	2,420	1,404	985	495	5,304
$WT_{100-250}$	CL	1,317	4,698	42	864	6,921
	RO	1,712	1,364	106	81	3,263
	GS	3,820	2,879	739	702	8,140
	BFG	4,478	4,546	655	756	10,435
	COG	1,844	1,667	570	297	4,378
$WT_{>250}$	CL	1,070	3,709	77	1,810	6,666
	RO	1,391	1,077	192	170	2,830
	GS	3,104	2,273	1,344	1,470	8,191
	BFG	3,639	3,589	1,190	1,584	10,002
	COG	1,498	1,316	1,037	622	4,473
TOTAL		41,160	39,880	9,600	12,855	103,495

efficiency than the smaller ones. It was decided to use the following average boiler efficiencies by size group:

Watertube	<100,001 lbs/hr	- 73%
Watertube	101,001-250,000 lbs/hr	- 78%
Watertube	>250,000 lbs/hr	- 84%

Since no specific data on firing methods were collected for the study, it was decided to use the coal firing method distribution characteristic of intermediate size watertube boilers in general [A-4]. This distribution is shown in Table A-9.

TABLE A-9

PERCENTAGE OF WATERTUBE BOILERS USING VARIOUS FIRING METHODS FOR COAL COMBUSTION

Boiler Size	Pulverized Coal	Cyclone	Overfired	Stokers Spreader Stoker	Stokers Under Fired
$WT_{<100}$	20	0	47	20	13
$WT_{100-250}$	59	2	29	8	2
$WT_{>250}$	92	5	0	2	1

Stokers are used mostly for the smaller watertube boilers; the large boilers tend to utilize pulverized coal.

In order to check the 1970 fuel use results, Walden used the AISI statistical reports. The data only showed coal used for steam raising, so that this is the only direct comparison that could initially be made. It also breaks down the consumption of the other fuels into the following use categories:

Blast Furnace Area { Blast Furnace
Other Uses
(including coke over underfiring) }

Steel Melting Furnaces
Heating and Annealing Furnaces
Heating Ovens for Wire Rods
Other

Discussions with AISI (Mr. Eckel) indicates that the category "other" could be considered to refer to fuel usage for steam raising. Consequently, fuel oil, natural gas, coke oven gas, and blast furnace gas consumption in steam raising were each estimated by summing the fuel quantities listed under "other" (subtracting out in each case the fuel used for coke oven underfiring). Tar and pitch consumption which are also tabulated by AISI were added to the fuel oil figures for this estimated.

REFERENCES TO APPENDIX A

A-1. Dun & Bradstreet Metalworking Directory, 1971, Dun & Bradstreet, Inc., New York.

A-2. County Business Patterns, U.S. Bureau of Labor Statistics, 1969.

A-3. American Boiler Manufacturers Association, Yearly Reports on Boiler Sales.

A-4. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, March 1971.

APPENDIX B

PROJECTIONS OF BOILERS TO THE YEAR 1980

It was found that about 550 kwh of energy is needed to produce a ton of steel in electric furnaces [B-1]. Using this figure and the production figures published by the AISI, we arrived at the actual energy needed for steel production in electric furnaces, shown in the left-hand column of Table B-1.

TABLE B-1

POWER UTILIZATION IN IRON AND STEEL PLANTS

	Energy Used for Production of Raw Steel in Electric Furnaces (10^6 kwh)	Total Electric Power Consumed by the Iron and Steel Industry (10^6 kwh)*		Column Ratio $\frac{A}{B+C}$
		Generated	Purchased	
	A	B	C	D
1964	6,973	12,816	26,049	.179
1965	7,592	12,151	28,006	.189
1966	8,179	12,096	29,891	.195
1967	8,299	11,954	30,557	.195
1968	9,248	12,685	33,470	.200
1969	11,073	11,702	36,691	.229
1970	11,089	11,749	37,833	.224

*Source: AISI - 1970 Annual Statistical Report

The Battelle Systems Study of the integrated iron and steel industry reports projections of raw steel production by type of furnace, see Table B-2.

TABLE B-2

PROJECTIONS OF RAW STEEL PRODUCTION BY TYPE OF FURNACE
(1000 net tons)

Year	Open Hearth	Bessimer	Basic-Oxygen Furnace	Electric Furnace	Total
1975	44,000	--	80,000	33,000	157,000
1980	36,000	--	99,000	45,000	180,000

*Source: Battelle Memorial Institute

Corresponding to the production of steel in electric furnaces, using the factor of 550 kwh/ton of steel, are the figures of respectively 18.150 x 10^6 kwh and 24.750 x 10^6 kwh for energy used for this production in 1975 and 1980 respectively. A linear projection of the ratio in column D of Table B-1 results in the ratio of .275 for 1975 and .320 for 1980. Using these ratios we arrive at the projected figures for total energy required shown in the lefthand column of Table B-3. Purchased energy as a percentage of the total has been increasing significantly [B-3]. In 1970 this percentage was about 76%. Our projections for 1975 and 1980 show that 85% and 93% respectively of the total required energy will be purchased as opposed to generated in-house. The boiler capacity needed for this in-house generation was calculated based on a load factor of 77% and assuming 1 kilowatt to be approximately equivalent to 10 lbs of steam per hour. The results are shown in Table B-3.

Boilers in the iron and steel industry are used to raise steam for power generation, process heating and space heating. The assumption is made below that the amount of steam generated for non-power purposes will remain the same per ton of steel produced during the coming decade. This boiler capacity required for process and space-heating in 1975 and 1980 was arrived at by using the Battelle projections of total steel production shown in Table B-2. The 1970 total

TABLE B-3

PROJECTIONS OF POWER REQUIREMENTS IN THE IRON AND STEEL INDUSTRY (10^6 kwh)

Year	Total Energy	Purchased	Generated	Boiler Capacity in Use for Power Generation
	A	B	C	D
1975	66,000	56,000	9,900	14.7×10^6 pph
1980	77,340	71,926	5,414	8.0×10^6 pph

production of raw steel was $131{,}514 \times 10^3$ tons, corresponding to a boiler capacity of $103{,}495 \times 10^3$ pph. Table B-1 shows that $11{,}749 \times 10^6$ kwh of energy were generated in iron and steel plants in 1970. The boiler capacity required for this would be 17.4×10^6 pph, which is about 17% of the total boiler capacity installed in the iron and steel industry in 1970. The remaining 86.1×10^6 pph are used for space and process heating. The 1970 ratio between the capacity used for non-power purposes and the total tons of raw steel is .65 pph/ton. The assumption is made that this ratio will remain fairly constant through the following decade, since no drastic decreases in steam generated for process and space heating use per ton of steel produced is expected, as opposed to the expected decrease in in-house power generation. Consequently the 1975 boiler capacity required for process and space heating is expected to be $.65 \times 157 \times 10^6 = 102 \times 10^6$ pph, and the corresponding 1980 figure is projected to be 117×10^6 pph. These results are summarized in Table B-4.

It was decided to use the industrial fuel projections obtained in the Intermediate-Size Boiler Study as guidelines for the respective decreases and increases in relative use of the conventional fossil fuels in the iron and steel industry in each region [B-4]. These projections are shown in Table B-5. The 1970 fuel use distribution in the iron and steel industry is shown in Table B-6.

TABLE B-4

PROJECTIONS OF BOILER CAPACITIES IN THE IRON AND STEEL INDUSTRY (10^6 pph)

Year	Boiler Capacity Used for Power Generation	Boiler Capacity Used for Process and Space Heating	Total Boiler Capacity
1970	17.4	86.1	103.5
1975	14.7	102.1	116.8
1980	8.0	117.0	125.0

The growth and decline rates derived from Table B-5 are shown in Table B-7. These ratios are applied to the 1970 fuel distribution for the iron and steel industry, and the distribution in Table B-8 is obtained for the three conventional fossil fuels. The total projected percentage made up by these three fossil fuels is calculated as follows:

(1) Total projected capacities for 1975 and 1980 are respectively 116.8×10^6 pph and 125.0×10^6 pph (see Table B-4).

(2) Total projected consumption in 1975 and 1980 of blast furnace and coke-oven gas are:*

In 1975: blast furnace gas 2.8×10^{12} cu. ft., coke-oven gas 2.46×10^{11} cu. ft.
In 1980: blast furnace gas 2.34×10^{12} cu. ft., coke-oven gas 2.51×10^{11} cu. ft.

(3) The approximate Btu values corresponding to the total capacities are:

In 1975: 985×10^{12} Btu/yr
In 1980: 1.062×10^{12} Btu/yr

*These estimates are discussed in Appendix C, pages C-

TABLE B-5

PROJECTIONS OF INDUSTRUAL FUEL DISTRIBUTION

	1967 (%)				1975 (%)				1980 (%)			
	CL	RO	DO	GS	CL	RO	DO	GS	CL	RO	DO	GS
AT	38.9	42.0	12.8	6.3	28.2	53.8	2.9	15.1	23.9	56.8	2.7	16.6
GL	59.5	10.1	5.3	25.1	58.8	8.7	1.6	30.9	56.5	7.6	1.5	34.3
WS	1.8	19.3	1.2	77.7	1.8	10.7	1.4	86.2	1.6	9.7	1.4	87.3
SE	59.5	10.4	2.3	27.8	46.3	12.0	1.0	40.7	44.2	12.4	1.0	42.4

TABLE B-6

1970 FUEL DISTRIBUTION IN THE IRON AND STEEL INDUSTRY
(percentages)

	CL	RO	GS	BFG	COG
AT	10	13	29	34	14
GL	31	9	19	30	11
WS	2	5	35	31	27
SE	32	3	26	28	11

TABLE B-7

PROJECTED FUEL GROWTH RATES - 1967-1980
(percentages)

	%Δ/yr 1967 - 1975				%Δ/5 years 1975 - 1980			
	CL	RO	DO	GS	CL	RO	DO	GS
AT	-3.4	+3.5	-9.7	+17.5	-15.2	+5.6	-6.9	+9.9
GL	-0.1	-1.7	-8.7	+2.9	-3.9	-12.6	-6.3	+11.0
WS	0	-5.6	+2.1	+1.4	-11.1	-9.3	0	1.3
SE	-2.8	+1.9	-7.1	+5.8	-4.5	+3.3	0	+4.2

TABLE B-8

PROJECTED FUEL RATIOS IN THE IRON AND STEEL INDUSTRY
(percentages)

	1975			1980		
	CL	RO	GS	CL	RO	GS
AT	8.3	15.3	54.4	7.9	16.2	59.8
GL	29.5	8.2	21.8	28.3	7.2	24.2
WS	2.0	3.6	37.5	1.8	3.3	38.0
SE	27.5	3.3	33.5	26.3	3.4	34.9

(4) The approximate Btu values corresponding to the projected use of blast furnace gas and coke-oven gas are:

In 1975: blast furnace gas 266 x 10^{12} Btu/yr, coke-oven gas 123 x 10^{12} Btu/yr
In 1980: blast furnace gas 222 x 10^{12} Btu/yr, coke oven gas 126 x 10^{12} Btu/yr

(5) The percentages of the total Btu value taken up by blast furnace gas and coke oven gas are:

In 1975: 27% blast furnace gas and 12% coke oven gas
In 1980: 21% blast furnace gas and 12% coke oven gas

(6) The remaining 61% in 1975 and 67% in 1980 are taken up by the fossil fuels.

(7) By reducing the ratios on the previous page to add up to these percentages, we obtain the final fuel distribution for the projected years as indicated in Table B-9.

TABLE B-9

PROJECTED FUEL DISTRIBUTION IN THE IRON AND STEEL INDUSTRY
(percentages)

	1975					1980				
	CL	RO	GS	BFG*	COG*	CL	RO	GS	BFG*	COG*
AT	6	12	43	27	12	6	13	48	21	12
GL	30	9	22	27	12	32	8	27	21	12
WS	3	5	53	27	12	3	5	59	21	12
SE	26	3	32	27	12	27	4	26	21	12

*Insufficient data are available to vary these percentages regionally.

The growth of the installed capacity of the various watertube boiler sizes is obtained from the Systems Study of Intermediate-Size Boilers. (See Table B-10) [B-4].

In 1970 the capacity distribution by size and region was as shown in Table B-11. Applying the relative growth of the various size groups for intermediate boilers as a whole [B-4] to the iron and steel boilers on a total basis results in Table B-12. The proportions for each region within a size group are assumed to remain the same as in 1970.

From the distribution tables developed above, the boiler inventories for 1975 and 1980 in the iron and steel industry are derived and summarized below in Tables B-13 and B-14.

TABLE B-10

PROJECTED BOILER CAPACITIES BY SIZE - INTERMEDIATE BOILERS
(10^6 pph)

	1970	1975	1980
Watertube ≤100,000 pph	921	1.045	1.123
Watertube 100,001-250,000 pph	658	700	745
Watertube >250,001-500,000 pph	259	286	282

TABLE B-11

1970 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY BY SIZE
(10^6 pph)

	AT	GL	WS	SE	Total
Watertube ≤100,000 pph	17,287	12,762	3,648	4,499	38,196
Watertube 100,001-250,000 pph	13,171	15,154	2,112	2,700	33,137
Watertube >250,000 pph	10,702	11,964	3,840	5,656	32,162
	41,160	39,880	9,600	12,855	103,495

TABLE B-12

PROJECTED BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY BY SIZE
(10^6 pph)

	1975	1980	1975	1980	1975	1980	1975	1980	1975	1980
WT ≤100,000 pph	21.1	23.5	15.6	17.0	4.5	4.7	5.5	5.8	46.7	51.0
WT 100,001-250,000 pph	14.4	15.6	16.5	17.9	2.3	3.7	2.9	3.1	36.1	40.3
WT >250,000 pph	11.3	11.2	12.7	12.6	4.0	4.0	6.0	5.9	34.0	33.7
	46.8	50.3	44.8	47.5	10.8	12.4	14.4	14.8	116.8	125.0

TABLE B-13

1975 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY
(10^6 pph)

		AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	1.3	4.7	.1	1.4	7.5
	RO	2.5	1.4	.2	.2	4.3
	GS	9.1	3.4	2.4	1.7	16.6
	BFG	5.7	4.2	1.2	1.5	12.6
	COG	2.5	1.9	.6	.7	5.7
$WT_{100-250}$	CL	.9	5.0	.1	.8	6.8
	RO	1.7	1.5	.1	.1	3.4
	GS	6.2	3.6	1.2	.9	11.9
	BFG	3.9	4.4	.6	.8	9.7
	COG	1.7	2.0	.3	.3	4.3
$WT_{>250}$	CL	.6	3.8	.1	1.6	6.1
	RO	1.4	1.2	.2	.2	3.0
	GS	4.9	2.8	2.1	1.9	11.7
	BFG	3.0	3.4	1.1	1.6	9.1
	COG	1.4	1.5	.5	.7	4.1
TOTAL		46.8	44.8	10.8	14.4	116.8

TABLE B-14

1980 BOILER CAPACITY IN THE IRON AND STEEL INDUSTRY
(10^6 pph)

		AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	1.4	5.4	.1	1.6	8.5
	RO	3.0	1.4	.2	.2	4.8
	GS	11.3	4.6	2.8	2.1	20.8
	BFG	4.9	3.6	1.0	1.2	10.7
	COG	2.8	2.0	.6	.7	6.1
$WT_{100-250}$	CL	.9	5.7	.1	.8	7.5
	RO	2.0	1.4	.2	.1	3.7
	GS	7.5	4.8	2.2	1.1	15.6
	BFG	3.3	3.8	.8	.7	8.6
	COG	1.9	2.2	.4	.4	4.9
$WT_{>250}$	CL	.7	4.0	.1	1.6	6.4
	RO	1.5	1.0	.2	.2	2.9
	GS	5.4	3.4	2.4	2.1	13.3
	BFG	2.4	2.7	.8	1.3	7.2
	COG	1.3	1.5	.5	.7	4.0
TOTAL		50.3	47.5	12.4	14.8	125.0

REFERENCES TO APPENDIX B

B-1. The Making, Shaping, and Treating of Steel, 8th Edition, U.S. Steel Corporation, Pittsburgh, Pa., 1964.

B-2. A Systems Analysis Study of the Integrated Iron and Steel Industry, Battelle Memorial Institute, Columbus, Ohio, 1964.

B-3. Statistical Report, American Iron and Steel Institute, 1970.

B-4. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, Cambridge, Mass., 1971.

APPENDIX C

PROCESS EMISSIONS

INTRODUCTION

Process emissions in the iron and steel industry emanate from two distinct types of sources. First, emissions are produced during the handling of raw materials and the subsequent processing of these materials to produce steel. These emissions fall within the conventional definition of process emissions. However, in order to meet its energy demands during the manufacturing steps, the iron and steel industry combusts significant quantities of fuel. This non-boiler combustion forms the second source of process emissions.

Estimation of the emission loadings from the two types of sources will be considered separately. Estimates, both for the base year of 1970 and projections to 1980 will be dealt with together since it is felt that in that manner the underlying logic will be most easily understood.

Section I of this appendix discusses the conventional process emissions from iron and steel plants in detail by pollutant. For the various potential sources of process emissions, uncontrolled emission factors were determined, a brief look was taken at controls, and finally, emission estimates were made for 1970, 1975, and 1980. Section II discusses the emissions from fuels.

I. CONVENTIONAL PROCESS EMISSIONS

A. PARTICULATES

Each of the following separate processing operations encountered in the iron and steel industry are potential sources of particulate emissions:

(1) Sinter Plants
(2) Pellet Plants
(3) Coke Manufacture
(4) Blast Furnaces
(5) Steel Furnaces
    Open Hearth
    Basic Oxygen Furnace (BOF)
    Electric Arc Furnace
(6) Scarfing
(7) Materials Handling

In estimating emissions from the above operations, only a very brief description of the actual process will be given (sufficient for understanding any subsequent comments). For a more detailed description of the operations, the reader is directed to "The Making, Shaping and Treating of Steel" [C-1], and Battelle's Systems Study of the Integrated Iron and Steel Industry [C-2].

1. Sinter Plants

Sintering plants produce from iron ore fines and blast furnace dust larger sized materials that can be easily charged to the blast furnace. The technique used is to slowly burn on a slow moving grate a mixture of fines plus fuel (coal dust or coke) so that a sticky mass is formed. This material is then cooled producing sinter.

Emissions from sinter plant operation are produced mainly during the combustion and firing and the cooling and screening stages, although minor amounts of dusts result from handling of raw materials.

a. Uncontrolled Emission Factors

Nationwide Emission Factor Compilation (NEFC) [C-3] quote the following emission factors:

Windbox (i.e., combustion gases from ignition and firing)	20 lb part/ton of sinter
Discharge end (cooling and screening)	22 lb part/ton of sinter

These figures are in substantial agreement with average values quoted by Schueneman, et al. [C-4] although there have been reports of large variations in dust emissions (windbox and discharge each 5-100 lb/ton of sinter) [C-5].

b. Controls

Cyclones and electrostatic precipitators are the generally used techniques for control of particulate emissions from sinter plants. NEFC [C-3] report the following collection efficiencies for sinter plant control techniques.

Windbox:

Dry cyclone collection eff. = 90%
Electrostatic precipitator eff. = 95%
(in series with dry cyclone collection)

Discharge:

Dry cyclone collection eff. = 93%

Private conversations with steel industry representatives [C-6] indicate that all current sinter plants are controlled. This is confirmed by the Midwest Research Institute report on particulate emissions [C-7].

c. Estimation of Emissions

(1) Base Year - 1970. American Iron and Steel (AISI) Statistical Report for 1970 [C-8] indicate that sinter production in 1970

(Table 47 in Reference 8) was 45.6×10^6 tons/yr. Thus, assuming conservatively that collection efficiencies in sinter plants were 90%, the following emissions (after controls) are produced:

$$45.6 \times 10^6 \frac{42}{2000} \times (1-0.9) = 9.6 \times 10^4 \text{ tons/yr}$$

(2) Projections to 1975 and 1980. Estimation of emissions for 1975 and 1980 requires estimates of sinter production for these years.

Battelle [C-2] reports, as shown in Table C-1 below, the physical form of iron ore consumed in the U.S. and estimates to 1980. These data can be used to project sinter production to 1975 and 1980 provided a procedure for estimating the total sinter production (as opposed to the sinter produced only from iron ore as quoted in Table C-1) can be determined.

Of course, by far the largest fraction of agglomerated products (sinter and pellets) is produced from ore fines and this is shown below in Table C-2 taken from the AISI Statistical Reports [C-8].

Using the data of Table C-2, the following fraction was determined:

$$F_s = \frac{\sum \text{other materials (i.e., flue dust and sludge and scale)}}{\text{ore fines and concentrates}}$$

F_s is plotted against time in Figure C-1, from which it appears that F_s has been fairly constant over the past few years. It will be assumed that this value of 0.075 will hold constant to 1975 and 1980.

It should be noted that F_s is based on AISI figures for the total amount of material used to produce both sinter and pellets. (However, it is assumed that since pellet plants are generally away from the steel mills, that all the additional material goes to producing

TABLE C-1

PHYSICAL FORM OF IRON ORE CONSUMED IN THE U.S. AND ESTIMATES TO 1980

	Lump Ore		Sinter[a]		Pellets		Total	
Year	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%
1960	62.0	54.1	41.5	36.3	11.0	9.6	114.5	100.0
1967	46.7	35.3	42.2	31.9	43.4	32.8	132.3	100.0
1975	31.7	20.0	46.0	29.0	80.8	51.0	158.5	100.0
1980	34.9	19.5	48.3	27.0	95.8	53.5	179.0	100.0

[a]Includes only iron ore used for making sinter

TABLE C-2

MATERIALS USED IN PRODUCING AGGLOMERATED PRODUCTS (SINTER AND PELLETS)
(Net tons)

	1970	1969	1968	1967	1966	1965	1964
Materials Used:							
Ore fines and concentrates	92,734,970	94,349,152	92,396,601	88,560,907	89,542,769	79,289,827	79,928,246
Flue dust and sludge	3,228,350	3,452,802	3,455,426	4,131,686	4,661,915	4,965,958	5,136,601
Scale	3,695,427	3,720,456	3,544,342	3,431,559	3,287,503	2,938,674	2,510,242
Coke breeze	2,266,675	2,290,189	2,247,994	2,309,236	2,486,341	2,439,288	2,709,256
Coal	464,359	622,660	747,819	819,052	896,969	966,014	1,014,343
Cinder and slag	625,231	768,477	466,682	329,502	332,889	406,995	445,453
Limestone and dolomite	8,430,560	8,799,262	8,512,911	7,929,735	7,903,032	6,661,494	6,623,558
Other	1,645,015	1,755,295	1,979,162	1,976,898	1,591,862	1,274,071	933,560
Total Materials Used	113,090,587	115,758,293	113,350,937	109,488,575	110,703,280	98,942,321	99,301,259

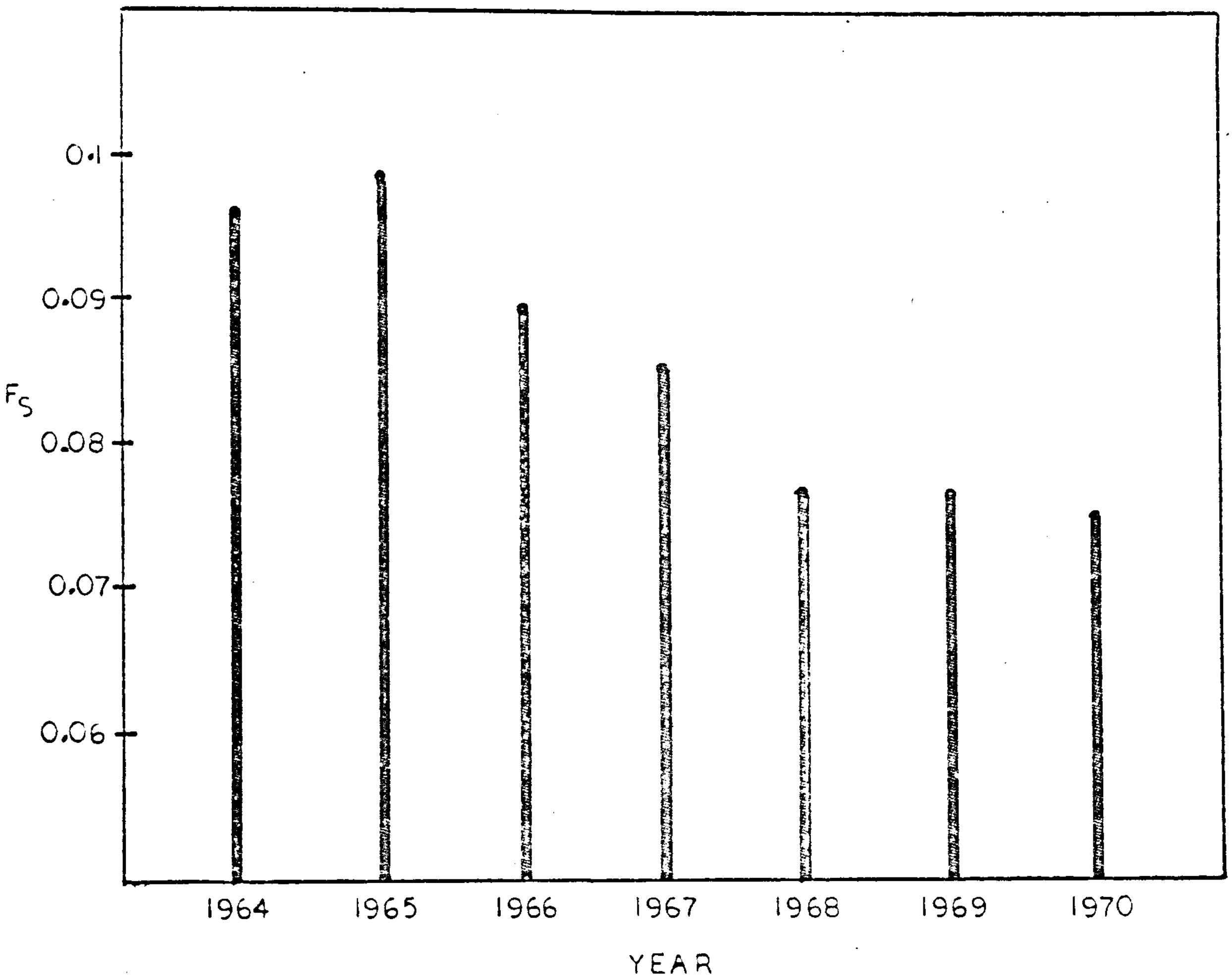

FIGURE C-1. PLOT OF F_S VERSUS YEAR

sinter.) Thus, using the figures of Table C-1, the total sinter production for 1975 and 1980 is:

<u>1975</u>

$$[46.0 + (46.0 + 80.8) \times 0.075] \times 10^6 \text{ T/yr} = 55.5 \times 10^6 \text{ T/yr}$$

<u>1980</u>

$$[48.3 + (48.3 + 95.8) \times 0.075] \times 10^6 \text{ T/yr} = 59.1 \times 10^6 \text{ T/yr}$$

Controlled emissions are, therefore:

<u>1975</u>

$$55.5 \times 10^6 \times \frac{42}{2000} \times (1 - 0.9) \text{ T/yr} = 1.17 \times 10^5 \text{ T/yr}$$

<u>1980</u>

$$59.1 \times 10^6 \times \frac{42}{2000} \times (1 - 0.9) \text{ T/yr} = 1.24 \times 10^5 \text{ T/yr}$$

2. Pellet Manufacture

In contrast to sintering plants that are usually located near the blast furnace plant (because sinter does not withstand shipment without degrading), pellet plants are usually located near the ore mine (or within several hundred miles of the mine). The pellets which are strong, are often shipped hundreds or thousands of miles to blast furnace plants.

Battelle [C-2] indicates that only very low emissions result from pellet production and that these emissions are effectively knocked out by simple cyclones.

3. Coke Manufacture

Metallurgical coke is the major fuel and reducing agent used in the production of pig iron. Coke is produced from coal by distillation of the volatile matter. Two types of coke ovens are employed for producing coke: (1) the beehive oven and (2) the by-product oven. By far the largest amount of coke is produced via the by-product oven process.

In the by-product oven process, coal is heated in the absence of air. The gaseous products that are evolved are removed from the oven and stripped of any condensible or absorbable product (tar, ammonia liquor, light oil) in a by-product plant. The remaining gas is then utilized in the plant as a high heating value fuel. The process is batch, and necessitates coal charging to the ovens and subsequent quenching of the hot coke after a 16 to 20 hr carbonizing period.

The coke plants emit both particulate materials and offensive gases in the normal course of operation. The particulates are mainly coal and coke dust that become airborne during handling, discharging and quenching of the coke. The gases are mainly mixtures of ammonia and aromatic vapors that escape from the ovens and the by-product system.

a. Uncontrolled Emission Factors

Table C-3 below is reproduced from NEFC [C-5] and summarizes the uncontrolled emission factors for metallurgical coke manufacture.

b. Control

Control of coke plant emissions generated in a coke plant is difficult because of the nature of the process and the great amount of material handling that is required.

At present, no effective controls are utilized in coke plants [C-7], although new installations are utilizing techniques such as underground reclaiming to reduce handling emissions. Furthermore, some success has been demonstrated with the use of baffles to reduce quench emissions to one quarter of their original value [C-2].

Many of the above types of improvements, however, can only be installed in new plants and, as such, will be slow in being implemented.

c. Estimation of Emissions

(1) <u>Base Year - 1970</u>. AISI [C-8] statistics indicate the following tons of coal used in production of coke = 87.2×10^6

TABLE C-3

UNCONTROLLED EMISSION FACTORS FOR METALLURGICAL COKE MANUFACTURE[d]

	Particulates	Sulfur[a] Dioxide	Carbon Monoxide	Hydrocarbons[b]	Nitrogen[c] Oxides	Ammonia
By-Product Coking[d]						
Unloading	0.4	---	---	---	---	---
Charging	1.5	0.02	0.6	2.5	0.03	0.02
Coking Cycle	0.1	---	0.6	1.5	0.01	0.06
Discharging	0.6	---	0.07	0.2	---	0.1
Quenching	0.9	---	---	---	---	---
Underfiring	---	10	---	---	---	---
Beehive Ovens	200		1	8	---	2

[a] SO_2
[b] Expressed as methane
[c] NO_2
[d] Reference 3

$\therefore$ Particulate emissions = $87.2 \times 10^6 \times \frac{3.5}{2000}$ T/yr

$= 1.52 \times 10^5$ T/yr

(2) Estimation of Emissions to 1975 and 1980. Coke oven particulate emissions are determined by the coke production rate, which, in turn, is controlled by pig iron requirements and changes in blast furnace technology. Consequently, several factors must be considered in estimating future coke oven emissions.

The average coke rate, defined as pounds of coke/ ton of pig iron, has been continually decreasing as is shown in Figure C-2 (calculated from AISI [C-8,C-9] data). Indeed, Ramm [C-10] and Nakatani, et al. [C-11] have shown that it should be possible to reduce the coke rate to about 840 lb (ideally) per net ton of hot metal by the use of improved burden materials, injection of auxiliary fuels (such as oil and natural gas) and the use of very high blast temperatures.

Based on extrapolations of the average coke rate (Figure C-2), the following coke rates were obtained:

1975

Coke rate: 1175 lb coke/T pig iron

1980

Coke rate: 1100 lb coke/T pig iron

However, the actual data in Figure C-2 only covers the years 1958 to 1970 during which time little auxiliary fuel injection was employed. It will be shown in Section II of this appendix that by 1975 about 30 lb of fuel oil and natural gas/T pig iron and by 1980 about 80 lb of fuel and natural/T pig iron will be used in the blast furnace. Since, to a first approximation (see Figure A-5 in Ref. C-2], a lb of oil injected will result in a lb reduction in the coke rate, this means that the actual coke rates should be adjusted to:

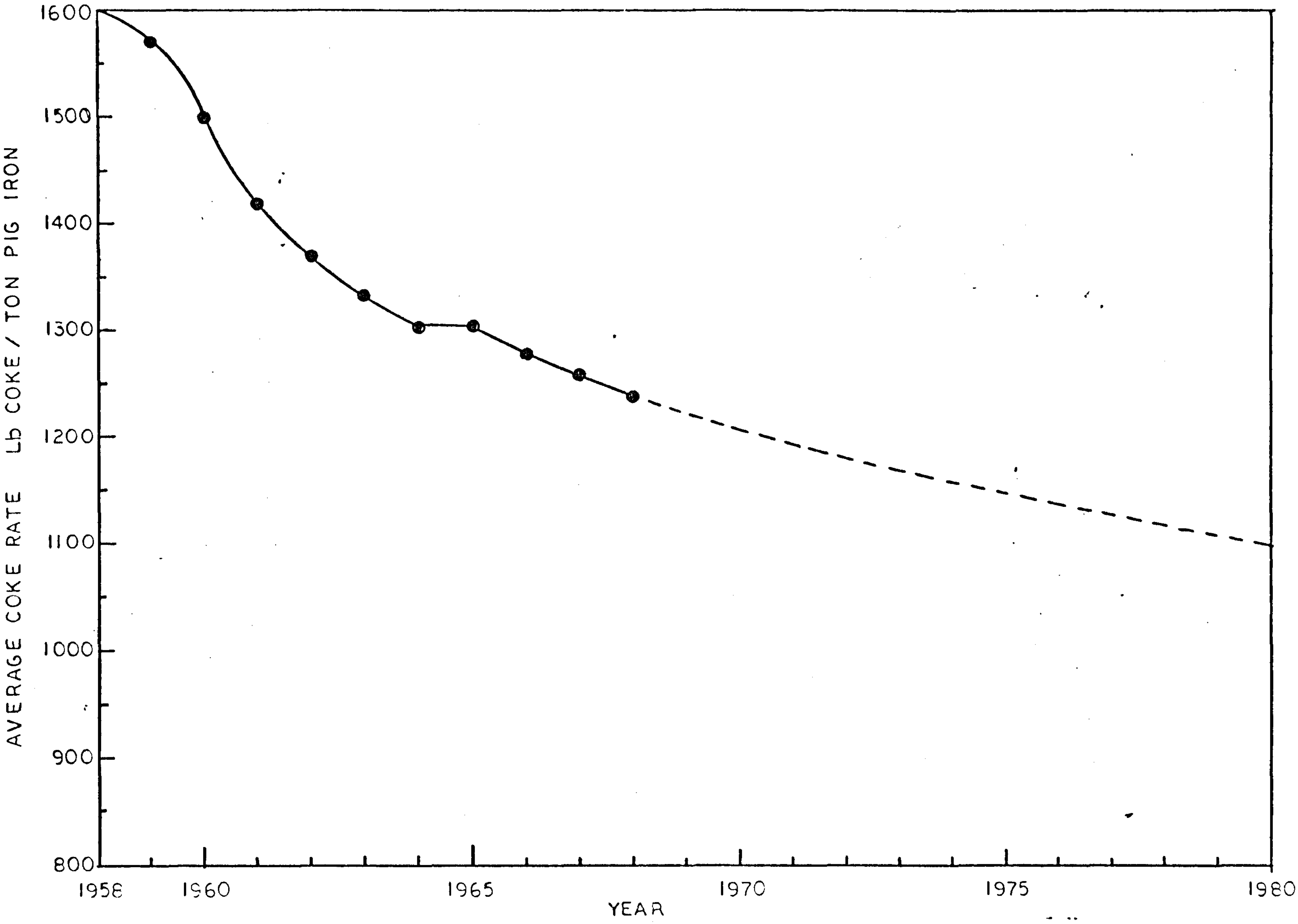

FIGURE C-2

TRENDS IN THE COKE RATE USED FOR THE PRODUCTION OF HOT METAL

1975

1145 lb coke/T pig iron

1980

1020 lb coke/T pig iron

Finally, before estimating emissions, it is necessary to determine the tons of coal used per ton of coke produced. (Emission factors in Table C-3 are based on tons of coal charged.) Table C-4 summarizes data extracted from the AISI statistical report [C-8,C-9].

No obvious trend is discernable and, consequently, an average of 1.45 tons coal/ton coke will be utilized in any further calculations.

Table C-5 presents projected pig iron requirements for the U.S. to 1980 [C-2].

∴ Uncontrolled emissions are:

1975

$$106.8 \times 10^6 \times \frac{1145}{2000} \times 1.45 \times \frac{3.5}{2000} = 155{,}000 \text{ T/yr}$$

1980

$$122.4 \times 10^6 \times \frac{1020}{2000} \times 1.45 \times \frac{3.5}{2000} = 159{,}000 \text{ T/yr}$$

As indicated earlier, it is difficult to estimate the amount of controls likely to be installed by 1980 and, as such, any estimates of the controlled emissions would at present be speculative.

4. Blast Furnaces

Pig iron is produced by reducing iron ores in a blast furnace. Iron ore, fluxes and coke are charged into the top of the furnace through two or three seals that serve to limit leakage of gas at this

TABLE C-4

CALCULATION OF TONS OF COAL REQUIRED PER TON OF COKE

	Pig Iron 10^6 T	Coke Rate T/T Pig Iron	Coal Used For Coke Production	Tons Coal Ton Coke
1970	91.43	.63	87.21	1.52
1969	95.02	.626	84.06	1.42
1968	88.78	.624	81.24	1.47
1967	86.98	.631	82.70	1.50
1966	91.50	.641	85.52	1.46
1965	88.18	.656	83.93	1.45
1964	85.60	.655	78.70	1.40
1963	71.84	.669	67.93	1.42
1962	65.64	.690	66.00	1.46
1961	64.63	.708	65.03	1.43

TABLE C-5

PIG IRON REQUIREMENTS FOR THE U.S. IN 1960 AND 1967 AND PROJECTIONS TO 1980

Year	Raw Steel Production (10^6 tons)	Apparent Pig Iron Consumption (10^6 tons)
1960	99.3	66.5
1967	127.2	87.0
1975	157.0	106.8
1980	180.0	122.4

point; preheated air (sometimes with oil, gas, oxygen or steam) is forced through ports near the bottom of the furnace. The incoming air reacts with the hot coke to produce a reducing gas mixture rich in H_2 and CO which reacts with the iron ore producing pig iron.

a. Uncontrolled Emission Factors

Emissions from the blast furnace occur during charging of the reactants and removal of the products and blast furnace gas.

Estimates of the emissions resulting from raw material handling and fume and kish particles evolved during product removal are not known. Similarly, the emissions produced during the occasional "slips" have not been reported. However, it is generally conceded that these emissions are relatively minor compared to the dust evolved with the blast furnace gas.

The particulate loadings in blast furnace gas is dependent on the type of charge used in the blast furnace. NEFC [C-3] quote the following uncontrolled emission factors:

Ore charge: 110 lb dust/ton of pig iron

Agglomerates charge: 40 lb dust/ton of pig iron

These numbers are in substantial agreement with those quoted by Battelle [C-2].

b. Control

Blast furnace gas is cleaned so that it can be used as a fuel in the blast furnace stoves and elsewhere. Since the blast furnace stoves are of the regenerative checker type, dust loadings of about 0.01 grains/SCF are presently required [C-12] for efficient thermal utilization, and future high temperature blast furnace operations will require dust loadings of not greater than 0.001 grains/SCF. Consequently, the majority of blast furnaces have preliminary, primary and secondary cleaning equipment with the following typical collection efficiencies (from NEFC [C-3]):

Type	Efficiency
1. Preliminary cleaning - settling chambers or dry cyclones	60%
2. Primary cleaning - gas washers and wet scrubbing	90%
3. Secondary cleaning - electrostatic precipitator or high energy washers	90%

Because the blast furnace gas produced, even after cleaning, is not emitted directly to the atmosphere (but is burnt), there is, except for losses of the gas, little actual particulate emissions from the blast furnace "process". However, since upon combustion, blast furnace gas emits the particulates it obtained during the blast furnace operation, these particulate loadings will be estimated here.

c. Estimation of "Emissions"

(1) Base Year - 1970. Both ore and agglomerates are presently charged to blast furnaces. In order to estimate emissions factors for mixed charges, the following linear relationship will be used:

$$F = a X + b$$

where F = emission factor lb dust/ton pig iron

X = fraction of charge that is ore $\frac{\text{ore}}{\text{ore + agglomerates}}$

Based on earlier quoted emission factors then

$$b = 40, \quad a = 70$$

$\therefore F = 70X + 40$

It should be pointed out that this assumption of linearity is verified approximately by data quoted by Battelle (Figure C-25 in Ref. C-2).

From the AISI Statistical Report [C-8], the following materials were used by blast furnaces in the manufacture of pig iron in 1970:

Iron ore: 38.19×10^6 tons

Agglomerates: 109.00×10^6 tons

$$\therefore X = \frac{38.19}{109.00 + 38.19} = 0.26$$

$$\therefore F = 70 \times 0.26 + 40 = 68.2 \text{ lb dust/ton pig iron}$$

$\therefore$ Uncontrolled dust loadings in blast furnace gas:

$$= \frac{68.2}{2000} \times 91.43 \times 10^6 = 3.14 \times 10^6 \text{ T/yr}$$

pig iron production 1970 [C-8]

$\therefore$ Controlled dust loadings in blast furnace gas:

$$3.14 \times 10^6 \times \underset{\text{Preliminary}}{(1 - 0.6)} \; \underset{\text{Primary}}{(1 - 0.9)} \; \underset{\text{Secondary}}{(1 - 0.9)}$$

$$= 1.26 \times 10^4 \text{ T/yr}$$

(2) Estimation of "Emissions" for 1975 and 1980. The following sinter productions for 1975 and 1980 were estimated earlier on page C-3).

<u>1975</u>

$$55.5 \times 10^6 \text{ T/yr}$$

<u>1980</u>

$$59.1 \times 10^6 \text{ T/yr}$$

Then using the data from Table C-1:

<u>1975</u>

$$X = \frac{31.7}{31.7 + 55.5 + 80.8} = 0.188$$

$$\therefore F = 53.2 \text{ lb dust/ton pig iron}$$

1980

$$X = \frac{34.9}{34.9 + 59.1 + 95.8} = 0.184$$

$\therefore$ F = 52.9 lb dust/ton pig iron

Thus, using the pig iron estimates quoted in Table C-5, the following uncontrolled and controlled dust loadings in the blast furnace g s can be calculated:

1975

Uncontrolled: $\frac{53.2}{2000} \times 106.8 \times 10^6$ T/yr

$= 2.85 \times 10^6$ T/yr

Controlled: $2.85 \times 10^6 \times (1\text{-}0.6)(1\text{-}0.9)(1\text{-}0.9)$

$= 1.14 \times 10^4$ T/yr

1980

Uncontrolled: $\frac{52.9}{2000} \times 122.4 \times 10^6$ T/yr

$= 3.24 \times 10^6$ T/yr

Controlled: $3.24 \times 10^6 \times (1\text{-}0.6)(1\text{-}0.9)(1\text{-}0.9)$

$= 1.3 \times 10^4$ T/yr

5. Steelmaking

a. Open Hearth Furnaces

Open hearth steel is made usually from a mixture of scrap and pig iron. The objective of the operation is to lower the impurities present in the scrap and pig iron, which consist of carbon, manganese, silicon, sulfur, and phosphorous. The refining operation is carried out by means of slag that forms a continuous layer on the surface of the liquid metal. The operation is a batch one and is comprised of several phases, namely, charging, melt down, hot metal addition, ore and lime boil, refining and tapping. The entire process takes about 100 hours from start to finish.

Particulate and gaseous emissions from the open hearth process originates from (1) the physical action of the flame on charged materials and the resulting pickup of fines, (2) the chemical reactions in the bath, (3) the agitation of the bath, and (4) the combustion of fuel. The emissions include SO_2, CO_2, CO, fly ash from fuels and iron oxide and other metallurgical fumes. The amount of emissions vary according to the stage of the process and according to practice. Recent use of oxygen lancing in open hearth furnaces has resulted in more particulate emissions than previous practice without lancing.

(1) Uncontrolled Emissions Factors. NEFC [C-3] quote the following particulate emission factors:

Open hearth furnace with oxygen lancing	22 lb dust/ton pig iron
Open hearth furnace with no oxygen lancing	12 lb dust/ton pig iron

(2) Controls. The open hearth furnace is one of the more significant polluters in the iron and steel industry. This is the result of lack of effective controls on many installations and the advent of oxygen lancing. The open hearth furnaces operated without the use of oxygen lances are themselves fairly efficient dust collectors because of the auxiliary units needed to achieve efficient operation. But even so, significant emissions result.

Electrostatic precipitators have been the principle choice for emission control although venturi scrubbers and bag houses have also been used. The NEFC [C-3] quote the following collection efficiencies for the above control techniques when applied to open hearth furnaces:

Type	Efficiency
Electrostatic precipitator	98%
Venturi scrubber	85-98%
Bag house	99%

However, the fraction of open hearths under control is a major unanswered question in estimating emissions. Schueneman [C-4] indicated that in March 1961 only 7.8% of the annual open hearth steel producing capacity of 9.9 x 10^6 tons/yr which were controlled (98% of this capacity used electrostatic precipitators; the rest, venturi scrubbing). However, control equipment for a further 9.1 x 10^6 tons/yr of open hearth steel capacity was under construction or to be installed, as of March 1961 (all using electrostatic precipitators).

Table C-6 extracted from Battelle [C-2] shows production of raw steel in the U.S. by type of furnace and projections of production to 1980.

Based on the figures presented in Table C-6, it is possible to estimate limits on the fraction of open hearth furnaces that have emission controls.

TABLE C-6

PRODUCTION OF RAW STEEL IN THE U.S. BY TYPE OF FURNACE AND PROJECTIONS TO 1980

Year	Open Hearth (10^3 tons)	Bessimer (10^3 tons)	Basic Oxygen Furnace (10^3 tons)	Electric Furnace (10^3 tons)	Total (10^3 tons)
1960	86,368	1,189	3,346	8,379	99,282
1967	70,690	---	41,434	15,089	127,213
1975	44,000	---	80,000	33,000	157,000
1980	36,000	---	99,000	45,000	180,000

In making these estimates, it will be assumed that by 1980 all open hearth furnaces operating will have emission controls.

Thus, assuming that at least controls will be operating on 19 x 10^6 T/yr of open hearth capacity [9.1 x 10^6 + 9.9 x 10^6 T/yr from Ref. C-4] by 1967, the following limits can be calculated:

1967

$$\text{Minimum fraction controlled} = \frac{19}{71} = 0.26$$

$$\text{Maximum fraction controlled} = \frac{36}{71} = 0.51$$

1975

$$\text{Minimum fraction controlled} = \frac{19}{44} = 0.43$$

$$\text{Maximum fraction controlled} = \frac{36}{44} = 0.82$$

1980

$$\text{Fraction controlled} = \frac{36}{36} = 1.00$$

Conversations with iron and steel industry representatives [C-14] indicates that at present (1971), probably about 50% of the open hearths have emission control equipment. Furthermore, the data of the Midwest Research Institute [C-7] indicate that in 1970, 41% of the open hearth furnaces were controlled. Both of these data verify the limit calculations presented earlier.

Thus, in estimation of emissions, the following averages of the previously calculated limits will be used:

1967

Fraction controlled: 0.38

1970

Fraction controlled: 0.41 (from Ref. C-7)

1975

Fraction controlled: 0.62

1980

Fraction controlled: 1.00

(3) Estimation of Emissions

(a) Base Year - 1970. From AISI Statistical Report [C-8], the open hearth raw steel production for 1970 was 48.0×10^6 tons/yr.

Estimation of emissions necessitates knowledge of the fraction of the open hearth furnaces using oxygen lancing. Since no data on this number could be found, two emission limits will be calculated: the first will consider all the furnaces have no oxygen lancing and the second will be calculated for the case where all the furnaces have oxygen lancing.

In all cases, it will be assumed that furnaces with control use electrostatic precipitators with collection efficiencies of 98%.

Minimum Emissions

$$48.0 \times 10^6 \times \frac{12}{2000} \; [0.41 \times (1-0.98)] + (1-0.41)$$

$$= 1.70 \times 10^5 \text{ tons/yr}$$

Maximum Emissions

$$1.70 \times 10^5 \times \frac{22}{12} \text{ tons/yr}$$

$$= 3.12 \times 10^5 \text{ tons/yr}$$

(b) Estimation of Emissions for 1975 and 1980

1975

Minimum Emissions

$$44.0 \times 10^6 \times \frac{12}{2000} [0.62 \times (1-0.98) + (1-0.62)]$$

$$= 1.03 \times 10^5 \text{ tons/yr}$$

Maximum Emissions

$$= 1.03 \times 10^5 \times \frac{22}{12} \text{ tons/yr}$$

$$= 1.89 \times 10^5 \text{ tons/yr}$$

1980

Minimum Emissions

$$36.0 \times 10^6 \times \frac{12}{2000} \times (1-0.98)$$

$$= 4.32 \times 10^3 \text{ tons/yr}$$

Maximum Emissions

$$4.32 \times 10^3 \times \frac{22}{12} \text{ tons/yr}$$

$$= 7.9 \times 10^3 \text{ tons/yr}$$

b. Basic Oxygen Furnace (BOF)

More and more open hearth furnaces are being replaced by basic oxygen furnaces. These furnaces have the considerable advantage in that they require much less time to refine the steel and no external heat has to be supplied as in the open hearth furnace. The BOF is pear shaped and a water cooled lance is used to supply high purity oxygen at high velocity to the surface of the metal bath. The high velocity oxygen impinging on the metal surface produces violent agitation and results in rapid oxidation of the dissolved carbon silicon and manganese thus producing steel. The rapid oxidation reactions supply a considerable quantity of the heat required for refining.

The predominant particulate emission is brown iron oxide and the only gas of concern is CO. A predominance of submicron sizes in the oxide dust makes it especially difficult to trap and collect.

(1) Uncontrolled Emission Factors. The NEFC [C-3] quote uncontrolled emission factors for the BOF as 46 lb dust/ton steel produced. These figures are in substantial agreement with data of Massobrio and Santini [C-16] in Europe (19.6 to 46.6 lb dust/ton steel) and the data of Battelle [C-2] for emissions from U.S. furnaces (40 lb dust/ton steel).

(2) Controls. Since the BOF has only been in use in the iron and steel industry since 1952, most of the furnaces are controlled by either venturi scrubbers or electrostatic precipitators (of collection efficiency ∿98%). The data of the Midwest Research Institute [C-7] confirm that all BOF's have controls.

(3) Estimation of Emissions

(a) Base Year - 1970. From the AISI Statistical Report [C-8] 63.3×10^6 tons/year of steel were produced via basic oxygen furnaces.

Controlled Emissions

$$= 63.3 \times 10^6 \times \frac{46}{2000} \times (1-0.98) \text{ tons/yr}$$

$$= 2.82 \times 10^4 \text{ tons/yr}$$

(b) Estimation of Emissions for 1975 and 1980. From Table C-6, the steel produced in the BOF for 1975 and 1980 are:

1975

$$80.0 \times 10^6 \text{ tons/yr}$$

1980

$$99.0 \times 10^6 \text{ tons/yr}$$

∴ Emissions are:

1975

$$80.0 \times 10^6 \times \frac{46}{2000} \times (1-0.98)$$

$$= 3.56 \times 10^4 \text{ tons/yr}$$

1980

$$4.60 \times 10^4 \text{ tons/yr}$$

c. Electric Arc Furnaces

Electric furnaces utilize electrical energy for heating. Thus, they are extremely versatile and can produce steel from charges consisting of only cold metal. Oxygen lancing is also frequently used in electric furnaces.

Emissions generated during electric furnace steel making originate from the type of scrap used, the nature of the melting operation and oxygen lancing.

(1) Uncontrolled Emission Factors. Figure C-3 below, reproduced from Battelle (Figure C-62 in Ref. C-2), shows reported dust emissions for 22 operations using various combinations of normal scrap (scrap with little to moderate rust), dirty scrap (scrap with heavy rust), and oxygen lancing. The effect of type of scrap, nature of the melting operation and oxygen lancing are clearly evident.

The emission factors quoted in NEFC [C-3] for electric furnaces are:

Electric furnaces with oxygen lancing	11 lb dust/ton of steel
Electric furnaces with no oxygen lancing	7 lb dust/ton of steel

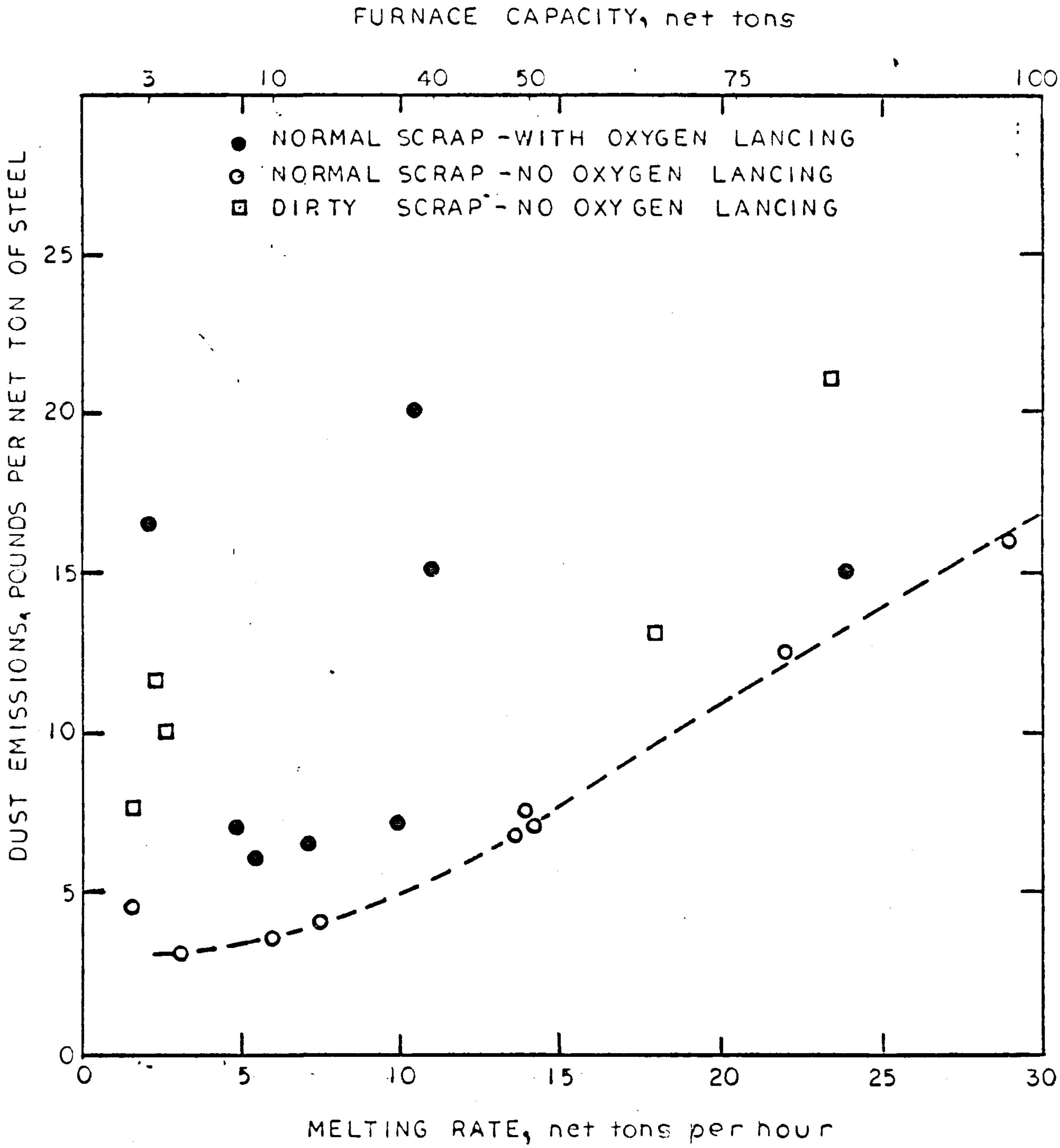

FIGURE C-3 DUST EMISSIONS DURING ELECTRIC FURNACE MELTING OF STEEL

Comparison with Figure C-3 indicates that these emission factors are for furnaces of about 50 to 75 tons capacity. Since the trend in new electric furnaces is towards larger and larger furnaces (the largest installations to date are a 200 ton direct arc electric at Laclede Steel Co., Alton, Ill.; four 200 ton furnaces at the Republic Steel Corp., Canton, Ohio, and a 250 ton furnace at Northwestern Steel and Wire Co. which was placed in operation in early 1969), the quoted emission factors in NEFC [C-3] may be in error for estimating emissions from future installations.

(2) Control. Control of emissions from electric steelmaking furnaces are affected by whether the furnace is a movable roof top charging furnace or a fixed roof door charging furnace.

Emissions from the electric furnaces are controlled and collected by three main types of systems: (1) collection of emissions by the use of hoods over and around the furnace at points of emission, (2) direct extraction from the furnace interior, and (3) shop roof extraction and collection.

The particulates are removed by the use of high efficiency scrubbers, electrostatic precipitators and bag houses. NEFC [C-3] quote the following collection efficiencies when these systems are used on electric furnaces:

Type	Efficiency
High efficiency scrubber	up to 98%
Electrostatic precipitators	92-97%
Bag houses	98-99%

Midwest Research Institute [C-7] indicates that at present 79% of all electric arc furnaces have controls.

However, no data could be found on the fraction of electric arc furnaces that use oxygen lancing.

(3) Estimation of Emissions

(a) Base Year - 1970. 20.16×10^6 tons of steel were produced via the electric arc process in 1970 [C-8].

In calculating emissions it will be assumed that all the furnaces were oxygen lanced (i.e., a conservative answer will be obtained); and that the average collection efficiency of the control method is 95%.

$$\therefore \text{ Emissions} = 20.16 \times 10^6 \times \frac{11}{2000} [0.79\ (1-0.95) + (1-0.79)]$$

$$= 2.76 \times 10^4 \text{ tons/yr}$$

(b) Estimation of Emissions in 1975 and 1980. From Table C-6, the steel produced in the electric arc furnace in 1975 and 1980 is:

1975

33.0×10^6 tons

1980

45.0×10^6 tons

Assuming that all furnaces are controlled by 1975 and that the average furnace capacity has increased to about 100 tons by 1975 (so that the emission factor is 18 lb dust/ton product), the following emissions can be determined:

1975

$$\text{Emissions: } 33.0 \times 10^6 \times \frac{18}{2000} (1-0.95)$$

$$= 1.49 \times 10^4 \text{ tons/yr}$$

1980

$$\text{Emissions: } 45.0 \times 10^6 \times \frac{18}{2000} (1-0.95)$$

$$= 2.04 \times 10^4 \text{ tons/yr}$$

6. Scarfing

Scarfing is the term applied to the process of removing blemishes from the solid shapes (billets, blooms, slabs) into which molten steel is formed.

Fairly extensive particulate emissions result during the processing although a significant fraction of this emission is now controlled.

a. Uncontrolled Emission Factors

Little data are available on scarfing particulate emission factors. However, both Schueneman, et al. [C-4] and NEFC [C-3] indicate that about 3 lb of dust is produced per ton of steel processed.

b. Control

Only the data of the Midwest Research Institute [C-7] could be found on controls used for the prevention of particulate emissions from scarfing operations. They indicate that presently 75% of all scarfing machines are controlled with precipitators of about 90% average collection efficiency.

c. Estimation of Emissions

It will be assumed for estimating emissions that all steel produced is scarfed.

(1) Base Year 1970 - From AISI Statistical Report [C-8] the total steel production for 1970 was 131.0×10^6 tons.

∴ Controlled emissions

$$= 131.0 \times 10^6 \times \frac{3}{2000} \times [(1-0.9) \times 0.75 - (1-0.75)]$$

$$= 63{,}000 \text{ tons}$$

(2) Estimation of Emissions for 1975 and 1980. Table C-5 indicates projected raw steel production for 1975 and 1980. Using

these figures and assuming that the fraction of scarfing machines controlled remains the same as in 1970, the following emissions can be calculated:

<u>1975</u>

$$\frac{157}{131} \times 63{,}000 = 73{,}600 \text{ tons}$$

<u>1980</u>

$$\frac{180}{131} \times 63{,}000 = 86{,}500 \text{ tons}$$

B. <u>SULFUR OXIDE EMISSIONS</u>

Fuels required to carry out the various processes in the making of iron and steel constitute the major source of sulfur. By far, most of this sulfur originates in the coal used to make the coke that is a vital requirement for operation of the blast furnace. However, fuel oil and iron ore also contain sulfur and, as such, contribute to sulfur oxide emissions.

Fortunately, however, most of present day steel technology calls for operations under basic conditions (these result from the addition of lime and limestone, etc., as fluxes). Consequently, a significant fraction of the sulfur which enters a steel mill via the raw materials is removed with the slag and thus does not form an air pollutant. Battelle [C-2] has produced a comprehensive and thorough description of the fate of sulfur during the iron and steel plant processing, and it from their calculations that a significant fraction of the following material is taken.

At this point, <u>only air pollution sulfur emissions</u> that are produced as a result of the actual process operation (as opposed to sulfur emissions that result from fuel combustion associated with the particular process under consideration) will be considered. Thus, in many cases processes which result in no process sulfur air pollution emissions will be glossed over lightly.

1. Process Sulfur Air Pollution Emission Factors

a. Sinter Plants

Sulfur enters sinter plants via the iron bearing materials, coke, oil, and limestone and leaves in the sinter fines and combustion gases.

Table C-7 shows a sulfur balance for sintering machine operation [C-2].

It should be pointed out, however, that Schueneman [C-4] indicates that 71% of the sulfur in the raw materials is carried up the stack in sintering operations (as opposed to the 36% shown above from Ref. C-2).

Thus, process sulfur air pollution emission factor = 0.71 lb sulfur/ton sinter.

b. Coke Manufacture

Sulfur enters coke ovens via the coal and leaves with the coke breeze, by-products and coke oven gas. Thus, effectively, no air pollution sulfur emissions are produced during the coke manufacture.

c. Blast Furnaces

Sulfur enters the blast furnace from practically all of the raw materials used for making iron; the major source being the sulfur in the coke. Because of the reducing and basic conditions in the blast furnace no sulfur leaves the furnace as sulfur dioxide, instead it is carried out as reduced compounds in the slag.

d. Steelmaking

(1) Open Hearth Furnaces. Sulfur enters the open hearth furnace with most of the added raw materials and leaves in the steel and scrap, slag and combustion gases. About 47% of the sulfur entering the open hearth system leaves in the metal and slag; the remainder leaves as

TABLE C-7

SULFUR BALANCE FOR SINTERING MACHINE OPERATION
(Based on production of one net ton of sinter)

Item	Amount Pounds	Sulfur Content %		Amount of Sulfur Pounds
		Input		
Iron bearing material	2,200	0.041		0.90
Coke	100	0.70		0.70
Oil	50	0.55		0.27
Limestone	200	0.049		0.10
			TOTAL	1.97
		Output		
Sinter	2,000	0.055		1.10
Sinter fines	289	0.055		0.16
Sulfur in combustion gases				0.71
			TOTAL	1.97

SO_2. A sulfur balance for an open hearth furnace using 60% hot metal and 40% steel scrap is given in Table C-8.

∴ Process sulfur air pollution emission factor = 0.70 lb sulfur/ton of steel.

(2) Basic Oxygen Furnaces. A sulfur balance for a BOF practice using 70% hot metal and 30% steel scrap is given in Table C-9. Almost all the sulfur leaves the system in the metal and slag with only about 4% of the sulfur leaving as SO_2 in the off gas. Battelle [C-2] indicates that there is no detailed information available in the literature on the sulfur content of BOF off gases.

(3) Electric Furnace. Like the BOF process, the electric furnace steelmaking process does not depend on a sulfur bearing fuel as the major source of energy. However, sulfur enters the system via the steelmaking raw materials but a considerable fraction of this sulfur is removed in the slag. A sulfur balance for an electric furnace is given in Table C-10.

e. Controls

At present, no controls exist for sulfur air pollution emissions.

2. Estimation of SO_2 Emissions

In all cases (i.e., both for the base year and the projections to 1975 and 1980) only the uncontrolled SO_2 emissions will be estimated. Whereas this is correct for the present, it may be in error in the calculations for future years.

(1) Base Year - 1970. From the AISI Statistical Report [C-8] the following 1970 productions can be obtained:

Sinter production	45.61×10^6 tons
Open hearth production	48.02×10^6 tons
BOF production	63.33×10^6 tons
Electric furnace production	20.16×10^6 tons

TABLE C-8

SULFUR BALANCE FOR OPEN HEARTH FURNACE WITH 60% HOT METAL AND 40% STEEL SCRAP WITH OXYGEN LANCING
(Based on production of one ton of raw steel)

Item	Amount Pounds	Sulfur Content %		Amount of Sulfur Pounds
		Input		
Hot metal	,361	0.030		0.41
Steel scrap	907	0.020		0.18
Iron ore	70	0.040		0.03
Flux	150	0.049		0.07
Fuel oil	111	0.55		0.61
Ferro alloys	14	0.07		0.01
			TOTAL	1.31
		Output		
Steel and scrap	2,060	0.02		0.41
Slag	200	0.10		0.20
Combustion gases				0.70
			TOTAL	1.31

TABLE C-9

SULFUR BALANCE FOR BOF STEELMAKING WITH
70% HOT METAL AND 30% SCRAP
(Based on the production of one net ton of steel)

Item	Amount Pounds	Sulfur Content %		Amount of Sulfur Pounds
		Input		
Hot metal	1,581	0.030		0.47
Steel scrap	678	0.020		0.14
Burnt lime	142	0.060		0.08
Ferro alloys	14	0.070		0.01
			TOTAL	0.70
		Output		
Steel and scrap	2,077	0.020		0.41
Slag	263	0.100		0.26
Sulfur in off gases				0.03
			TOTAL	0.70

TABLE C-10

SULFUR BALANCE FOR AN ELECTRIC FURNACE USING A CHARGE OF COLD STEEL SCRAP AND OXYGEN LANCING
(Based on the production of one ton of steel)

Item	Amount Pounds	Sulfur Content %		Amount of Sulfur Pounds
		Input		
Steel scrap	2,136	0.020		0.43
Coke breeze	6	0.700		0.04
Burnt lime	99	0.060		0.06
Ferro alloys	14	0.070	TOTAL	0.54
		Output		
Steel and scrap	2,060	0.020		0.42
Slag	140	0.080		0.11
Off gas				0.01
			TOTAL	0.54

$\therefore$ SO_2 emissions are:

$$10^3\ [45.61 \times 0.71 + 48.02 \times 0.70 + 63.33 \times 0.03 + 20.16 \times 0.01]\ \text{tons/yr}$$

$$= 68.1 \times 10^3\ \text{tons/yr}$$

(2) <u>Projected SO_2 Process Emissions for 1975 and 1980</u>. From previous calculations on sinter plant (Section A.1) and Table C-6, the following data are obtained:

<u>1975</u>

Sinter production	55.5×10^6 tons
Open hearth production	44.0×10^6 tons
BOF production	80.0×10^6 tons
Electric furnace production	33.0×10^6 tons

<u>1980</u>

Sinter production	59.1×10^6 tons
Open hearth production	36.0×10^6 tons
BOF production	99.0×10^6 tons
Electric furnace production	45.0×10^6 tons

$\therefore$ 1975 SO_2 emissions:

$$10^3\ [55.5 \times 0.71 + 44.0 \times 0.70 + 80.0 \times 0.03 + 33.0 \times 0.01]$$

$$= 73.0 \times 10^3\ \text{tons/yr}$$

1980 SO_2 emissions:

$$10^3\ [59.1 \times 0.71 + 36.0 \times 0.7 + 99 \times 0.03 + 45.0 \times 0.01]$$

$$= 80.0 \times 10^3\ \text{tons/yr}$$

C. NITROGEN OXIDE EMISSIONS

Once again, as was done in estimating sulfur oxide emissions, only nitrogen oxide emissions that result from the actual process under consideration will be considered in this section. Thus, for example, the NO_x produced from combustion of blast furnace gas in the blast furnace stoves is a fuel combustion source (even though it is associated with the blast furnace) and, as such, will not be considered here.

The literature is sparse in NO_x emission data taken on processes in the iron and steel industry. Most of the data quoted in this section have been extracted from Esso's System Study on NO_x emissions [C-16] (Section 3.1.3.4 - Metallurgical Processes). Perusal of NO_x emission data indicate that only the open hearth furnace and sintering plants produce "process" NO_x air pollution emissions.

1. Uncontrolled Emission Factors

a. Open Hearth Furnace

1970 fuel figures indicate that 3.x 10^6 Btu of fuel are required/T of steel produced in an open hearth. This agrees with Esso's estimate [C-16]. Furthermore, the average open hearth furnace steel batch is 200 tons in size and the batch is heated over a period averaging 10 hours [C- 2]. It will be assumed these averages apply also in the years 1975 and 1980.

$$\therefore \text{Average combustion rate} = \frac{3.2 \times 10^6 \times 200}{10} \text{ Btu/hr}$$

$$= 64 \times 10^6 \text{ Btu/hr}$$

Using emissions of oxides of nitrogen from stationary sources in Los Angeles County [C-17], the following lbs NO_x are emitted in the production of a 200 ton batch of steel:

Fuel	lbs NO_x/200 Tons Steel
Fuel oil and tar	250
Natural gas and coke oven gas	150

b. Sinter Plants

1.04 lb NO_x/ton sinter [C-16]

2. Controls

No controls are currently employed to reduce NO_x emissions. It will further be assumed that no controls are available even in 1980.

3. Estimation of NO_x Emissions

a. Base Year - 1970

Open hearth production [C-8]: 48×10^6 tons

Sinter production [C-8]: 45.6×10^6 tons

Fractional fuel consumption in open hearths:

Fuel oil and tar and pitch: 0.57
Natural gas and coke oven gas: 0.43

$\therefore$ Open hearth emissions:

$$24 \times 10^4 [0.125 \times 0.57 + 0.075 \times .43] = 24{,}800 \text{ tons } NO_x$$

No. of 200 ton batches

Sinter emissions:

$$45.6 \times \frac{1.04}{2} \times 10^3 \text{ tons} = 23{,}700 \text{ tons } NO_x$$

b. Estimation of Emissions for 1975 and 1980

From previous calculations on sinter plants (Section A.1 of this Appendix) and Table C-6, the following data are obtained:

1975

Open hearth production:	44.0×10^6 tons
Sinter production:	55.5×10^6 tons

Fractional fuel consumption in open hearths:

Fuel oil and tar and pitch	0.55
Natural gas and coke oven gas	0.45

1980

Open hearth production:	36.0×10^6 tons
Sinter production:	59.1×10^6 tons

Fractional fuel consumption in open hearths:

Fuel oil and tar and pitch	0.55
Natural gas and coke oven gas	0.45

$\therefore$ 1975 NO_x emissions are:

Open hearths:	22,500 tons NO_x
Sinter production:	28,600 tons NO_x

1980 NO_x emissions are:

Open hearths:	18,400 tons NO_x
Sinter production:	31,000 tons NO_x

II. EMISSIONS FROM FUELS

Five fuels are extensively used in the Iron and Steel Industry to supply process energy. These are fuel oil, natural gas, tar and pitch, coke oven gas and blast furnace gas. The latter three fuels are produced within the steel mill as by-products and their production is dependent on the coke rate and ultimately on pig iron requirements. Fuel oil and natural gas, on the other hand, are purchased fuels whose usage is tied into the process in a fairly complex fashion as will be discussed later.

In estimating emissions from fuels used in process areas, it is necessary first to determine fuel consumption and then to apply emission factors. Fuel consumptions for 1970 are available [C-8] but extrapolation to 1975 and 1980 will have to be made based on understanding of how fuel usage is connected to process requirements.

The AISI Statistical Reports [C-8,C-9] break down fuel consumption into the following use categories:

(1) Blast Furnace Area — Blast Furnaces; Other Uses
(2) Steel Melting Furnaces
(3) Heating and Annealing Furnaces
(4) Heating Ovens for Wire Rods
(5) Other

In addition, included under other uses in the blast furnace area, are reported the quantity of fuel used for coke oven underfiring.

Discussions with AISI officials [C-15] indicate that:

(1) The category of "other" (i.e., 5) could be considered to refer mainly to the use of the particular fuel in steam raising boilers, and

(2) Steel melting furnaces refers to fuel usage in open hearth furnaces.

A. FUEL CONSUMPTIONS

1. Base Year - 1970

Table C-11 summarizes the fuel consumption data for 1970 extracted from the AISI Statistical Report [C-8].

2. Estimation of Fuel Consumptions for 1975 and 1980

Estimation of fuel consumption for future years must be based on an understanding of how the particular fuels are utilized in the overall process. Fuel oil and natural gas will be considered first:

a. Fuel Oil and Natural Gas

The following underlying logic will be used to estimate future fuel usage.

(1) Fuel oil and natural gas used in the blast furnace are injected through the tuyeres [C-2]. As such these fuels reduce the blast furnace coke burden and lead to more efficient performance of the furnace [C-2]. Since these fuels ultimately produce blast furnace gas, estimation of their consumption for future years is necessary in order to determine blast furnace gas production.

The fuels used in the blast furnace area are dependent on pig iron production and thus their consumption will be correlated with pig iron production.

(2) As indicated earlier, steel melting furnaces refer to open hearth furnaces. Thus fuel oil and natural gas consumption used in steel melting furnaces will be correlated with open hearth production.

(3) Heating and annealing furnaces are mainly utilized in steel production and therefore fuel oil and natural gas consumption in these areas will be correlated with raw steel production.

(4) Finally it will be assumed that fuel consumption used for steam raising will correlated with raw steel production.

TABLE C-11

1970 FUEL CONSUMPTION IN THE IRON AND STEEL INDUSTRY

Fuel	Purpose								
	Blast Furnace Area								
	Furnaces	Other[a] Uses	Coke Oven Underfiring	Steel Melting Furnaces	Heating & Annealing Furnaces	Heating Ovens for Wire Rods	Other	Steam[b] Raising	Total
Fuel Oil 10^3 gals	146,031	19,801	5,000	416,822	377,593	1,648	273,558	288,359	1,235,453
Tar & Pitch 10^3 gals	42,500	--	--	176,902	--	--	41,503	41,503	260,905
Natural Gas 10^6 scf	44,474	10,262	4,000	57,797	306,097	4,403	170,483	176,745	593,516
Coke Oven Gas 10^6 scf	9,177	319,628	274,603	22,056	363,899	4,217	208,959	253,984	927,936
Blast Furnace Gas 10^6 scf	1,592,038	1,246,894	286,402	--	164,693	--	1,519,250	2,479,742	4,522,875
Liquid Pet. Gas 10^3 gals	--	--	--	--	6,555	--	12,220	12,220	18,775

[a]Includes coke oven underfiring

[b]Steam raising = Σ other - coke oven underfiring

Table C-12 shows time series data extracted from the AISI Statistical Reports [C-8,C-9] that were used in the above correlations. Based on extrapolations of the data, ratios of fuel oil and natural gas consumptions relative to production were obtained for 1975 and 1980. These ratios are listed below:

Fuel Oil:

1. Blast furnace area:	1975:	3.7 gal/ton pig iron
	1980:	10 gal/ton pig iron
2. Steel melting furnaces: (open hearth)	1975:	8.3 gal/ton open hearth steel
	1980:	8.3 gal/ton open hearth steel
3. Heating and annealing furnaces:	1975:	2.2 gal/ton raw steel
	1980:	2.2 gal/ton raw steel
4. Steam raising	1975:	2.1 gal/ton raw steel
	1980:	2.1 gal/ton raw steel

Natural Gas:

1. Blast furnace area:	1975:	0.5×10^3 ft^3/T pig iron
	1980:	0.5×10^3 ft^3/T pig iron
2. Steel melting furnaces: (open hearth) no obvious trend use avg. of 1969-1964	1975:	1.1×10^3 ft^3/T open hearth
	1980:	1.1×10^3 ft^3/T open hearth
3. Heating and annealing furnaces:	1975:	2.7×10^3 ft^3/T raw steel
	1980:	3.05×10^3 ft^3/T raw steel
4. Steam raising	1975:	1.34×10^3 ft^3/T raw steel
	1980:	1.55×10^3 ft^3/T raw steel

Battelle [C-2] quote the following projected production rates:

TABLE C-12

TIME SERIES OF FUEL OIL AND NATURAL GAS CONSUMPTION IN THE IRON AND STEEL INDUSTRY

Year	Pig Iron Production 10^3 tons	Raw Steel Production 10^3 tons	Open Hearth Production 10^3 tons	Fuel Oil in Blast Furnaces 10^3 gal	Fuel Oil in Steel Melting Furnaces 10^3 gal	Fuel Oil In Heating & Annealing 10^3 gal	Fuel Oil In Steam Raising 10^3 gal	Nat. Gas In Blast Furnaces 10^6 scf	Nat. Gas In Steel Melting 10^6 scf	Nat. Gas In Heating & Annealing 10^6 scf
1970	91,435	131,514	48,000	146,031	416,822	377,593	287,558	44,474	57,797	310,500
1969	95,017	141,262	61,000	116,770	504,673	314,064	298,541	44,355	92,446	342,112
1968	88,780	131,462	66,000	80,778	549,585	368,253	282,097	46,507	102,159	303,982
1967	86,984	127,213	71,000	67,223	567,663	403,426	215,663	44,255	85,932	283,004
1966	91,500	134,101	85,000	53,247	721,661	461,939	206,071	51,510	96,002	264,228
1965	88,185	131,462	94,000	53,131	889,580	448,649	219,144	46,636	105,571	277,317
1964	85,601	127,076	98,000	46,189	1,008,296	392,300	228,344	38,796	108,540	256,250

[a] Open hearth production obtained from data of Battelle [C-2], as shown in Figure C-7.

TABLE C-12 (Cont.)

Year	Nat. Gas in Steam Raising 10^6 scf	Fuel Oil in Blast Furnace / Pig Iron gal/ton	Fuel Oil in Heating & Annealing / Raw Steel gal/ton	Fuel Oil in Steel Melting / Open Hearth gal/ton	Fuel Oil in Steam Raising / Raw Steel gal/ton	Nat. Gas in Blast Furnace / Pig Iron 10^3 scf/ton	Nat. Gas in Heating & Annealing / Raw Steel 10^3 scf/ton	Nat. Gas in Steel Melting / Open Hearth 10^3 scf/ton	Nat. Gas in Steam Raising / Raw Steel 10^3 scf/ton
1970	180,747	1.597	2.87	8.7	2.19	0.486	2.36	1.2	1.374
1969	155,607	1.229	2.22	8.3	2.11	0.467	2.42	1.5	1.101
1968	134,212	0.910	2.80	8.3	2.15	0.524	2.31	1.54	1.02
1967	121,270	0.773	3.17	8.0	1.69	0.510	2.22	1.21	0.953
1966	105,385	0.582	3.44	8.5	1.54	0.563	1.97	1.13	0.786
1965	117,552	0.602	3.41	9.4	1.67	0.530	2.11	1.12	0.894
1964	109,513	0.540	3.09	10.2	1.80	0.453	2.01	1.10	0.862

1975

Pig iron: 106.8×10^6 tons
Open hearth production: 44.0×10^6 tons
Raw steel production: 157.0×10^6 tons

1980

Pig iron: 122.4×10^6 tons
Open hearth production: 36.0×10^6 tons
Raw steel production: 180.0×10^6 tons

Using the above production figures, together with the extrapolated ratios, fuel oil and natural gas consumption can be calculated and the results are shown in Table C-13.

TABLE C-13

PROJECTED FUEL OIL AND NATURAL GAS CONSUMPTIONS FOR 1975 AND 1980

Fuel	Year	Purpose			
		Blast Furnace	Steel Melting	Heating & Annealing	Steam Raising
Fuel Oil 10^3 gals	1975	396,000	366,000	395,000	377,000
Fuel Oil 10^3 gals	1980	1,224,000	300,000	396,000	377,000
Nat. Gas 10^6 scf	1975	53,400	49,500	424,000	210,000
Nat. Gas 10^6 scf	1980	61,400	39,400	549,000	278,000

b. Coke Based Fuels, i.e., Coke Oven Gas, Blast Furnace Gas and Tar and Pitch

Production rates of coke oven gas, tar and pitch and blast furnace gas are closely correlated with the coke rate and ultimately the projected pig iron requirements. The coke rate has been discussed in Section I of this appendix, where it was shown, based on extrapolations, that the coke rate for 1975 and 1980 would be 1175 and 1110 lb/coke/T pig iron. However, previous estimates based on extrapolation of historical data indicated that the following quantities of fuel oil and natural gas would be injected into the tuyeres of the blast furnace.

Fuel Oil:	1975:	3.5 gal/T pig iron
	1980:	10.0 gal/T pig iron
Natural Gas:	1975:	500 ft^3/T pig iron
	1980:	500 ft^3/T pig iron

These fuel quantities translate to about 30 and 80 lb/T pig iron respectively, for 1975 and 1980. Thus assuming approximately that one pound of fuel will result in an equivalent pound reduction in the coke rate. The actual coke rates of 1975 and 1980 were projected to be 1145 and 1020 lb coke/T pig iron. However, before total production rates can be calculated, it is necessary to determine how the production rates are related to the coke rate.

(1) Total Production Rates - Coke Oven Gas. Volumetric production rates of coke oven gas/T coke are not easily predicted and as such the historical data presented in Table C-14 and taken from AISI [C-8, C-9] will be used.

There is no obvious trend in the data and as such a mean of 15,000 scf/T coke will be used in subsequent computations.

Thus total coke oven gas production rates for 1975 and 1980 are readily computed:

TABLE C-14

COKE OVEN GAS PRODUCTION/T COKE

Year	SCF/T Coke
1958	14,200
1959	15,200
1960	17,200
1961	15,000
1962	14,800
1963	12,400
1964	17,300
1965	17,640
1966	15,300
1967	15,700
1968	15,600
1969	15,100
1970	15,900

1975

$$15{,}000 \times \frac{1145}{2000} \times 106.8 \times 10^6 \text{ SCF}$$

$$= 9.2 \times 10^{11} \text{ SCF}$$

1980

$$15{,}000 \times \frac{1020}{2000} \times 122.4 \times 10^6 \text{ SCF}$$

$$= 9.35 \times 10^{11} \text{ SCF}$$

(2) Blast Furnace Gas. A similar procedure based on historical data, can be used to estimate blast furnace gas production rates. Table C-15 presents such data extracted from AISI statistics [C-8, C-9].

TABLE C-15

BLAST FURNACE GAS PRODUCTION/T COKE USED IN BLAST FURNACE

	10^6 SCF Blast Furnace Gas Production	Coke Used in Blast Furnace (tons)	Pig Iron Production (tons)	SCF/T Coke
1966	4,076,149	59.6×10^6	91.5×10^6	68,500
1967	4,131,003	56.2×10^6	87.0×10^6	73,400
1968	4,453,712	56.2×10^6	88.8×10^6	79,100
1969	4,757,049	60.2×10^6	95.0×10^6	79,100
1970	4,522,875	59.4×10^6	91.4×10^6	76,000

Esso [C-16] reports that four to five tons of blast furnace gas are generated/ton of pig iron produced, i.e., approximately 96,000 SCF to 120,000 SCF of blast furnace gas is produced/T of pig iron. It would be expected that the blast furnace gas production rate should depend on the coke rate and this is bourne out by the data presented in Figure C-12 below [C-18]. However, it is readily seen from Figure C-12 that at a coke rate of 1260-1300 lb coke/T pig iron (i.e., the data from Table C-15), total blast furnace production rate is about 118,000 SCF/T coke.

Both the results of Esso [C-16] and Heynert [C-18] indicate considerably higher production rates than are shown by the data in Table C-15 (even if a fraction of the blast furnace gas is lost as shown in Figure C-12. Discussion with personnal at AISI concerning this problem, revealed that measurements of the volumetric blast furnace gas production rates as reported in the AISI statistics may be in error due to the difficulties in determining such large volumetric rates.

If it is assumed that 20% of the blast furnace gas produced is lost through leaks etc., then the data of Heynert [C-18] would only be 20% above the measured data shown in Table C-15. It is clear that without further information this disparity cannot be resolved, although after considering a reasonable loss rate, the data are not that far apart. Thus in estimating blast furnace gas production rates for 1975 and 1980, it will be assumed that the production rate is a function of the coke rate as predicted by Figure C- 4, but that this value of the rate obtained at a given coke rate will be reduced by 40%.

An equivalent coke rate of the actual coke rate plus fuel oil and natural gas injection rate into the tuyeres was used to calculate the SCF blast furnace gas/T pig iron from Figure C-4.

∴ For 1975

$$\text{Effective coke rate} = 1175 \frac{\text{lb coke}}{\text{T pig iron}}$$

∴ Blast furnace gas production rate

$$= 79{,}000 \times 0.6 \times 106.8 \times 10^6 \text{ SCF}$$

$$= 5.07 \times 10^{12} \text{ SCF}$$

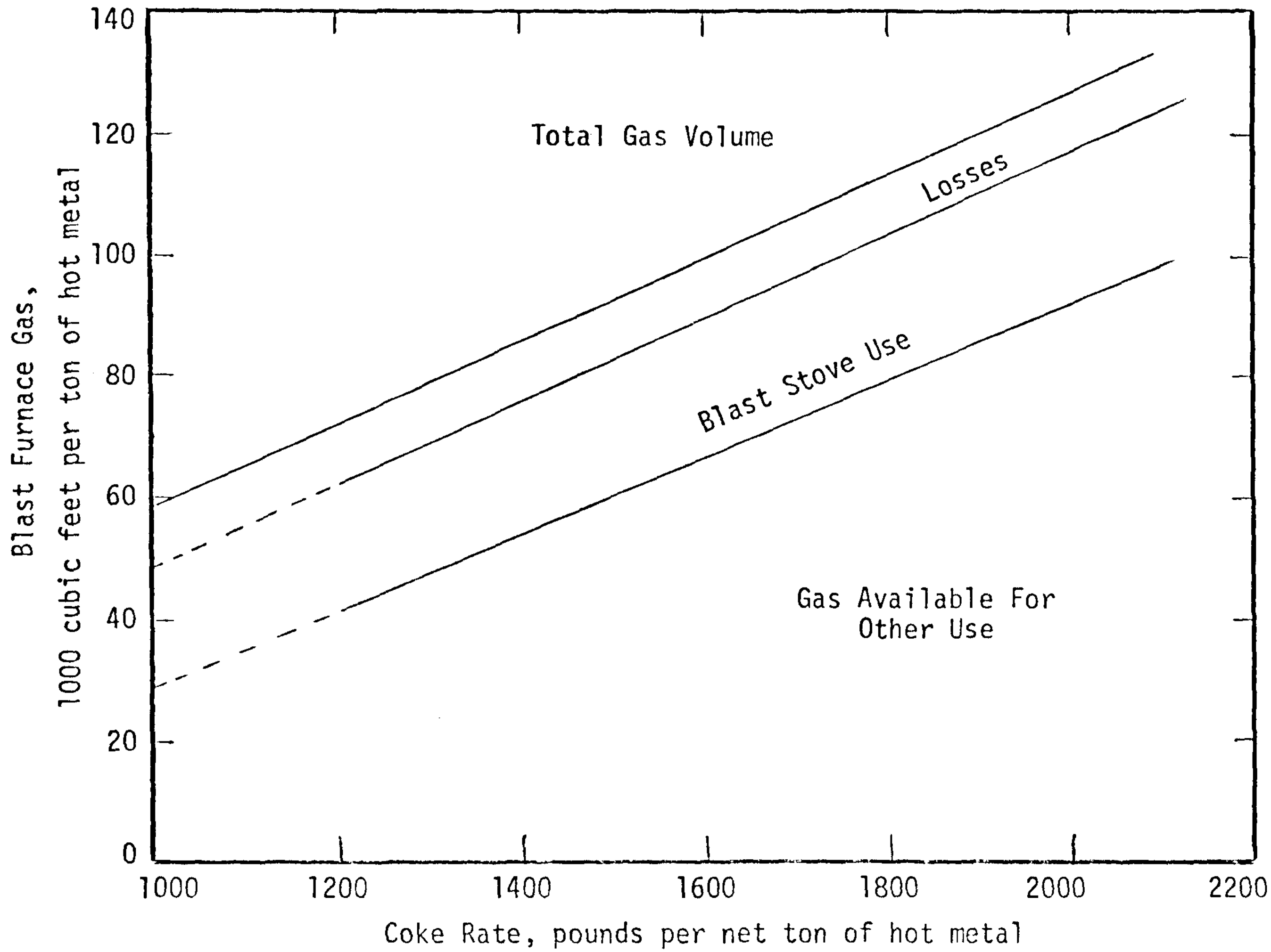

Figure C-4. Effect of Coke Rate on Volume of Blast Furnace Gas Produced.

and for 1980

$$\text{Effective coke rate} = 1100 \frac{\text{lb coke}}{\text{T pig iron}}$$

∴ Blast furnace gas production rate

$$= 62{,}000 \times 0.6 \times 122.4 \times 10^6 \text{ SCF}$$

$$= 4.56 \times 10^{12} \text{ SCF}$$

(3) Tar and Pitch. Production rate of tar and pitch/T coke are presented in Figure C-5. Extrapolations to 1975 and 1980 indicate productions of 3.5 and 2.6 gals/T coke.

∴ Tar and pitch production rates for 1975 and 1980 are respectively:

1975

$$3.5 \times \frac{1145}{2000} \times 106.8 \times 10^6 \text{ gals}$$

$$= 2.14 \times 10^8 \text{ gals}$$

1980

$$2.6 \times \frac{1020}{2000} \times 122.4 \times 10^6 \text{ gals}$$

$$= 1.62 \times 10^8 \text{ gals}$$

3. Fractional Usage of Fuels

Calculation of emissions necessitates an estimation of fractional usage of the total fuel production amongst the different process units. This fractional allocation of the coke based fuels is a complex economic problem which will be circumvented by assuming that the fractional allocations for 1975 and 1980 can be estimated from extrapolation of historical data.

Tables C-16 and C-17 present historical data taken from AISI statistics together with fractional fuel consumption in the different process areas.

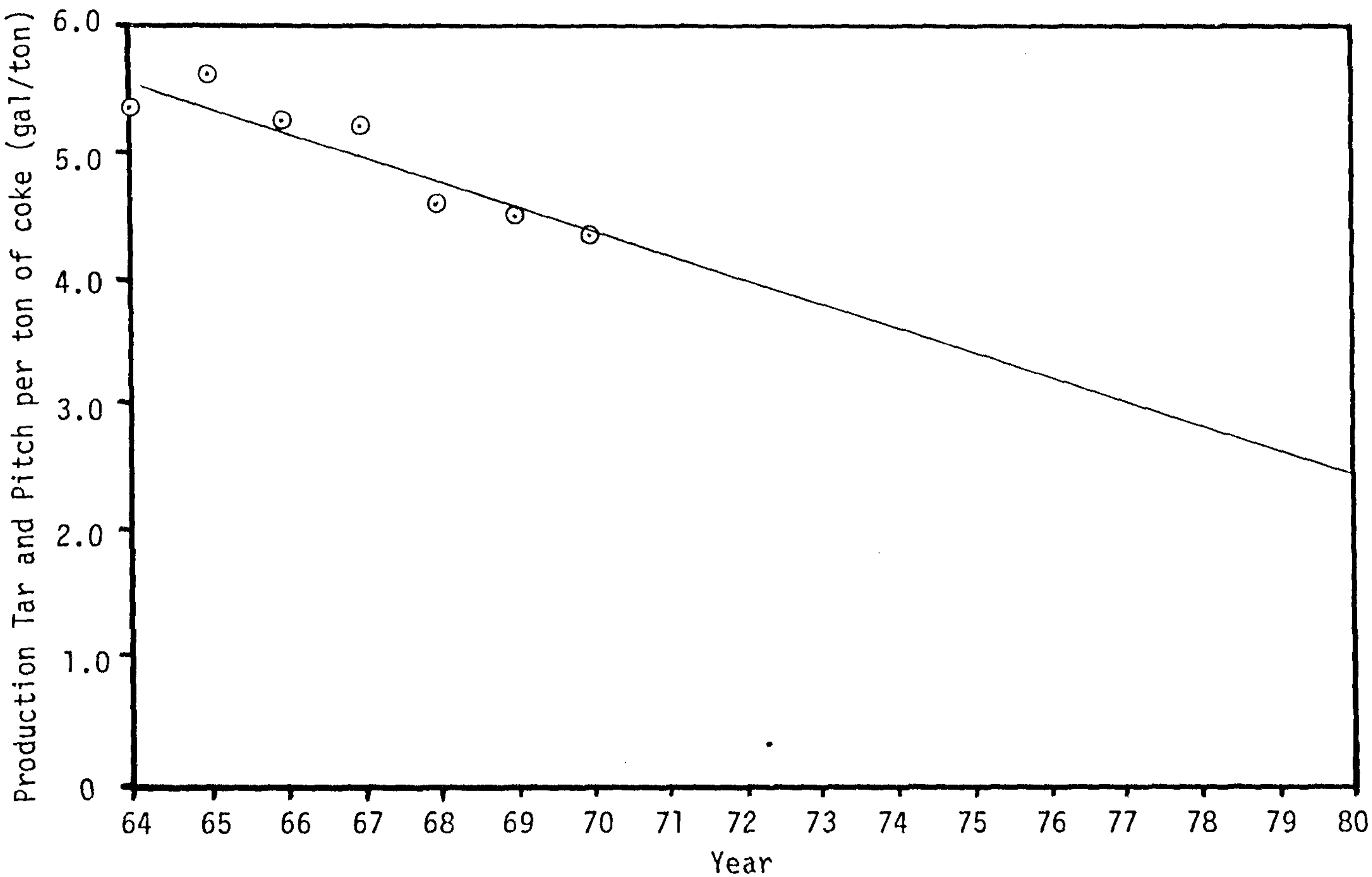

Figure C-5. Relative Production Rate of Tar and Pitch.

TABLE C-16

BLAST FURNACE GAS HISTORICAL DATA

Year	Blast Furnaces	Fraction B.F.G. Used in Blast Furnaces	Coke Oven Underfiring	Fraction B.F.G. Used in Coke Oven Underfiring	Steel Melting Furnaces	Fraction B.F.G. Used in Steel Melting Furnaces	Heating & Annealing Furnaces	Fraction B.F.G. Used in Heating Furnaces
1970	1,592,038	.352	286,402	.063			164,693	.036
1969	1,733,763	.364	345,270	.072			185,223	.039
1968	1,542,082	.346	340,771	.076			165,451	.037
1967	1,400,147	.339	334,068	.081			162,898	.039
1966	1,329,672	.326	358,288	.088	11,571	.002	156,010	.038

TABLE C-16 (Cont.)

Year	Steam Raising	Fraction B.F.G. Used in Steam Raising	Total
1970	2,479,742	.548	4,522,875
1969	2,492,793	.524	4,757,049
1968	2,405,408	.540	4,453,712
1967	2,233,890	.540	4,731,003
1966	2,220,608	.544	4,076,149

TABLE C-17

COKE OVEN GAS HISTORICAL DATA

Year	Blast Furnaces	Fraction C.O.G. Used in Blast Furnaces	Coke Oven Underfiring	Fraction C.O.G. Used in Coke Oven Underfiring	Steel Melting Furnaces	Fraction C.O.G. Used in Steel Melting Furnaces	Heating & Annealing Furnaces	Fraction C.O.G. Used in Heating Furnaces
1970	9,177	.01	274,603	.295	22,056	.02	363,899	.392
1969	11,021	.01	254,991	.277	29,946	.03	378,028	.413
1968	12,118	.013	231,922	.262	32,800	.04	359,368	.407
1967	13,433	.014	237,541	.267	32,762	.04	352,236	.397
1966	7,529	.01	225,119	.245	55,042	.06	359,949	.393
1965	11,233	.01	n.a.	--	71,864	.09	350,029	.444
1964	8,458	.01	n.a.	--	76,335	.10	334,310	.466
Average 1966-1970		.01		.269		.03		.400

TABLE C-17 (Cont.)

Year	Heating Ovens For Wire Rods	Fraction C.O.G. Used in Heating Ovens For Wire Rods	Steam Raising		Total
1970	4,217	.004	253,984	.273	927,436
1969	12,606	.013	229,049	.250	915,641
1968	12,705	.014	232,161	.263	881,074
1967	9,681	.010	240,575	.270	886,228
1966	5,378	.006	261,874	.285	914,891
1965	4,471	.005	350,495	.444	788,095
1964	5,257	.007	291,874	.406	716,234
Aver.					
1966-1970		.01		.268	

Perusal of the fractional usage of coke oven gas and blast furnace gas indicate little variation of time since 1966 and as such the average values presented in the tables will be used in subsequent computations where necessary.

4. Estimation of Emissions

a. Emission Factors

The following emission factors were used in estimation of emissions:

Sulfur Oxides

Fuel Oil (see Appendix D, Table D-1):

$$0.68 \times 10^4 \times (\%\ \text{sulfur}) \frac{\text{lb } SO_x}{1000 \text{ barrels oil}}$$

Natural Gas (see Appendix D, Table D-1): 0.0

Blast Furnace Gas (see Appendix D, Section 2): 0.0

Coke Oven Gas (see Appendix D, Section 2):

$$\frac{0.77 \text{ lb } SO_x}{1000 \text{ SCF C.O.G.}}$$

Particulates

Fuel Oil (see Appendix D, Table D-1):

$$0.42 \times 10^3 \frac{\text{lb particulates}}{1000 \text{ barrels oil}}$$

Natural Gas (see Appendix D, Table D-1):

$$0.15 \times 10^2 \frac{\text{lb particulates}}{10^6 \text{ SCF}}$$

Blast Furnace Gas (see Appendix D, Section 2):

$$\frac{2.4 \text{ lb particulates}}{10^6 \text{ SCF}}$$

Coke Oven Gas (see Appendix D, Section 2):

$$0.15 \times 10^2 \frac{\text{lb particulates}}{10^6 \text{ SCF}}$$

Nitrogen Oxides

Whereas the emission factors for sulfur oxides and particulates are essentially independent of the process unit size and firing rate, emissions of NO_x are strongly dependent on the firing rate and fuel. As such emission factors for the different process units have to be discussed separately. Some of the following information was obtained from NO_x Systems Study [C-16].

(1) Blast Furnace. Fuel is used to heat the three blast furnace stoves which are usually associated with each blast furnace. Two are generally on heat while the third is on blast.

The Battelle Systems Study [C-2] indicated the following average pig iron productions per day.

TABLE C-18

AVERAGE PRODUCTION OF PIG IRON PER U.S. BLAST FURNACE PER DAY

Year	Net Tons/Day
1960	1181
1967	1570
1975	1920
1980	2200

Fuel oil and natural gas used in the blast furnace area are injected into the blast furnace, so that effectively the only major fuel used for heating is blast furnace gas. Thus the following estimates can be computed of the average Btu/hr firing rate of blast furnace gas in an averaged size blast furnace.

TABLE C-19

DETERMINATION OF THE AVERAGE FIRING RATE OF BLAST FURNACE GAS IN AN AVERAGE SIZED BLAST FURNACE

Year	Total Usage in Blast Furnace Area Btu/Yr	Total Usage in Blast Furnace Area How Obtained	Pig Iron Production	Fuel Usage Per Ton Pig Iron Btu/T	Average Fuel Usage Per Blast Furnace Btu/Hr
1970	$1.51x10^{14}$	Table C-11	$91.4x10^{6}$	$1.67x10^{6}$	$1.19x10^{8}$
1975	$1.66x10^{14}$	Use of Total Production &	$106.8x10^{6}$	$1.56x10^{6}$	$1.24x10^{8}$
1980	$1.50x10^{14}$	Fract. B.F.G. Used in Blast Furnaces	$122.4x10^{6}$	$1.22x10^{6}$	$1.12x10^{8}$

NO_x emission rates from combustion of blast furnace gas is not well established. However, it is suggested in Appendix D, Section 2, that emission rates be estimated as if the blast furnace gas was natural gas and then more realistically adjusted by multiplying by 0.022.

Table C-20 summarizes these NO_x emission factors.

(2) Coking Ovens. The estimations of Esso [C-16] indicate that 2.7 lbs NO_x is produced in the carbonization of 20 tons of coal

$\therefore$ Emission factor = 0.135 lbs NO_x/T coal fed

(3) Heating and Annealing Furnaces. Esso [C-16] indicates that NO_x emissions from heating and annealing furnaces are best estimated on the basis of steel production. It is estimated that 0.086 lb NO_x produced/ton steel.

TABLE C-20

NO_x EMISSION FACTORS FOR BLAST FURNACE GAS COMBUSTION

Year	Production Rate T/Hr	Average Fuel Usage/Blast Furnace Stove Btu/Hr	Conservative NO_x Emissions lb/hr
1970	70.7	5.9×10^7	11.4
1975	80	6.2×10^7	11.5
1980	91.6	5.6×10^7	11.0

5. Estimation of Fuel Based Process Emissions

Tables C-21, C-22 and C-23 summarize the fuel based process emissions calculated from the previously estimated fuel consumption data and emission factors for 1970, 1975 and 1980, respectively.

Based on the data of Battelle [C-2], the following average sulfur contents were used in the above calculations.

Fuel Oil: 1.8% sulfur
Tar and Pitch: 0.6% sulfur

6. Summary

Tables C-24, C-25 and C-26 summarize the results of Sections I and II of this Appendix.

TABLE C-21

1970 EMISSIONS IN PROCESS FROM FUEL COMBUSTION (tons)

	Blast Furnace Area			Coke Oven Underfiring			Heating & Annealing Furnaces & Heating Ovens for Wire Rods		
Fuel	SO_x	Particulate	NO_x	SO_x tons	Particulate	NO_x	SO_x	Particulate	NO_x
Fuel Oil				725	25		54,000	1,890	
Tar & Pitch				-	-		-	-	
Natural Gas				-	30		-	2,330	
Coke Oven Gas				106,000	2,060		140,000	2,720	
Blast Furnace Gas	-	2,220		-	400		-	230	
TOTAL		2,220	160	106,725	2,515	5,900	194,000	7,170	5,600

TABLE C-22

1975 EMISSIONS IN PROCESS FROM FUEL COMBUSTION
(tons)

	Blast Furnace Area			Coke Oven Underfiring			Heating & Annealing Furnaces & Heating Ovens for Wire Rods		
Fuel	SO_x	Particulate	NO_x	SO_x	Particulate	NO_x	SO_x	Particulate	NO_x
Fuel Oil							57,500	2,000	
Tar & Pitch									
Natural Gas				-	-		-	3,000	
Coke Oven Gas				95,000	1,800		145,000	3,000	
Blast Furnace Gas		2,400		-	500		-	300	
TOTAL		2,400	170	95,000	2,300	6,000	196,500	8,300	6,700

TABLE C-23

1980 EMISSIONS IN PROCESS FROM FUEL COMBUSTION
(tons)

	Blast Furnace Area			Coke Oven Underfiring			Heating & Annealing Furances & Heating Ovens for Wire Rods		
Fuel	SO_x	Particulate	NO_x	SO_x	Particulate	NO_x	SO_x	Particulate	NO_x
Fuel Oil							57,500	2,000	
Tar & Pitch									
Natural Gas				-	-		-	4,000	
Coke Oven Gas				97,000	2,000		148,000	3,000	
Blast Furnace Gas	-	2,200		-	500			300	
TOTAL		2,200	170	97,000	2,500	6,000	205,500	9,300	7,700

TABLE C-24

SUMMARY OF 1970 PROCESS EMISSIONS
(tons)*

	Process			Fuel Combusted in Process			Total		
	SO_x	Part.	NO_x	SO_x	Part.	NO_x	SO_x	Part.	NO_x
Sinter Plants	32,000	96,000	24,000				32,000	96,000	24,000
Coke Manufacture		152,000		107,000	3,000	6,000	107,000	155,000	6,000
Blast Furnaces					2,000	negl.		2,000	negl.
Steel Furnaces (Open Hearth)	35,000	312,000	25,000				35,000	312,000	25,000
B.O.F.	2,000	28,000					2,000	28,000	
Electric Arc	negl.	28,000					negl.	28,000	
Heating & Annealing Furnaces				194,000	7,000	6,000	194,000	7,000	6,000
Scarfing		63,000						63,000	
Material Handling		446,000						446,000	
TOTAL	69,000	1,125,000	49,000	301,000	12,000	12,000	370,000	1,137,000	61,000

*Tons rounded to the nearest thousand

TABLE C-25

SUMMARY OF 1975 PROCESS EMISSIONS
(tons)*

	Process			Process - From Fuel Combustion			Total		
	SO_x	Part.	NO_x	SO_x	Part.	NO_x	SO_x	Part.	NO_x
Sinter Plants	39,000	117,000	29,000				39,000	117,000	29,000
Coke Manufacture		155,000		95,000	2,000	6,000	95,000	157,000	6,000
Blast Furnaces					2,000	negl.		2,000	negl.
Steel Furnaces (Open Hearth)	31,000	189,000	22,000				31,000	189,000	22,000
B.O.F.	2,000	36,000					2,000	36,000	
Electric Arc	negl.	15,000					negl.	15,000	
Heating & Annealing Furnaces				196,000	8,000	7,000	196,000	8,000	7,000
Scarfing		73,000						73,000	
Material Handling		533,000						533,000	
TOTAL	72,000	1,118,000	51,000	291,000	12,000	13,000	363,000	1,130,000	64,000

*Tons rounded to the nearest thousand

TABLE C-26

SUMMARY OF 1980 PROCESS EMISSIONS
(tons)*

	Process Emissions			Process - From Fuel Combustion			Total		
	SO_x	Part.	NO_x	SO_x	Part.	NO_x	SO_x	Part.	NO_x
Sinter Plants	42,000	124,000	31,000				42,000	124,000	31,000
Coke Manufacture		159,000		97,000	2,000	6,000	97,000	161,000	6,000
Blast Furnaces					2,000	negl.		2,000	negl.
Steel Furnaces (Open Hearth)	25,000	8,000	18,000				25,000	8,000	18,000
B.O.F.	3,000	46,000					3,000	4,600	
Electric Arc	negl.	20,000					negl.	20,000	
Heating & Annealing Furnaces				205,000	9,000	8,000	205,000	9,000	8,000
Scarfing		86,000						86,000	
Material Handling		612,000						612,000	
TOTAL	70,000	955,000	49,000	302,000	13,000	14,000	372,000	968,000	63,000

*Tons rounded to the nearest thousand

REFERENCES TO APPENDIX C

C-1. The Making, Shaping, and Treating of Steel, 8th Edition, U.S. Steel Corporation, Pittsburgh, Pa. (1964).

C-2. A Systems Analysis Study of the Integrated Iron and Steel Industry Battelle Memorial Institute, Columbus, Ohio (1964).

C-3. McGraw, M.J. and R.L. Duprey, Compilation of Air Pollution Emission Factors, Preliminary Document E.P.A., Research Triangle Park, N.C. (April 1971).

C-4. Schueneman, J.J., et al., Air Pollution Aspects of the Iron and Steel Industry, Public Health Service, Cincinnati, Ohio.

C-5. O'Mara, R.F., Dust and Fume Problems in the Steel Industry, Air Pollution Symposium, Iron Steel Engr., 30, 100 (1953).

C-6. Private communication with R. Devorek, U.S. Steel Corp., U.S. Steel Bldg., Pittsburgh, Pa.

C-7. Systems Study on Particulate Emissions, Midwest Research Institute, Information obtained from R.C. Lorentz, E.P.A., 411 W. Chapel Hill Street Annex, Durham, N.C. 27701.

C-8. Statistical Report American Iron and Steel Institute (1970).

C-9. Statistical Report American Iron and Steel Institute (1968).

C-10. Ramm, A.N., Minimum Theoretical Possible Coke Oven Consumption for Pig Iron Production under Modern Conditions, Stal No. 10, 860 (1964).

C-11. Nakatani, F., et al., Theoretical Considerations on Blast Furnace Coke Rate, Trans. of the Iron and Steel Dist. Japan 6, 263 (1966).

C-12. Weise, W.H., Blast Furnace Dust Treatment Facilities, Sewage and Industrial Wastes 28, 1398 (1956).

C-13. Hipp, N.E. and J.R. Westerholm, Developments in Gas Cleaning - Great Lakes Steel Corp., Iron and Steel Engineer 44 (8), 101 (1967).

C-14. Private communication with Dr. Smith, Jones & Laughlin Steel Corp., 3 Gateway Center, Pittsburgh, Pa.

C-15. Private communication with Mr. Eckel, American Iron and Steel Institute, 150 E. 42nd Street, New York, N.Y. 10017.

C-16. Bartok, W., et al., Systems Study of Nitrogen Oxide Control Methods for Stationary Sources, Esso Research and Engineering Co., Government Research Laboratory.

REFERENCES TO APPENDIX C (Cont.)

C-17. Massobrio, G. and F. Santini, Some Starting and Operating Experiences with the 300 Ton Oxygen Furnaces at the Toronto Works, AIME Open Hearth Proceedings 48, 115 (1965).

C-18. Heynert, Von G., et al, Charge Preparation and Its Effect on Operating Results of the Blast Furnace, Stahl und Eisle 81, 1 (1961).

APPENDIX D

EMISSION FACTORS AND BOILER EMISSIONS

1. DISCUSSION OF EMISSION FACTORS FOR COAL, RESIDUAL OIL, AND NATURAL GAS

The emissions resulting from combustion of coal, residual oil, and natural gas under boilers were based on the emission factors and sulfur and ash contents used for industrial intermediate-size boilers in the Systems Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, and are shown below in Tables D-1 and D-2 [D-1].

TABLE D-1

EMISSION FACTORS

Pollutant	Size	Fuel	Firing Type	Factor*
SO_2	all	GS		0
SO_2	all	RO		$.6804 \times 10^4$
SO_2	all	CL	all	$.3800 \times 10^5$
NO_x	WT_1	GS		$.1676 \times 10^3$
	WT_2	GS		$.2280 \times 10^3$
	WT_3	GS		$.2489 \times 10^3$
NO_x	WT_1	RO		$.2218 \times 10^4$
	WT_2	RO		$.3072 \times 10^4$
	WT_3	RO		$.3372 \times 10^4$
NO_x	all	CL	PV	$.2000 \times 10^5$
			CY	$.6000 \times 10^5$
			OF	$.1500 \times 10^5$
			SS	$.1000 \times 10^5$
			UF	$.1000 \times 10^5$
Particulates	WT_1	GS		$.1800 \times 10^2$
	WT_2	GS		$.1500 \times 10^2$
	WT_3	GS		$.1500 \times 10^2$
	WT_1	RO		$.9660 \times 10^3$
	WT_2	RO		$.4200 \times 10^3$
	WT_3	RO		$.4200 \times 10^3$
	all	CL	PV	$.1600 \times 10^5$
Particulates	all	CL	CY	$.2000 \times 10^4$
			OF	$.1300 \times 10^5$
			SS	$.5000 \times 10^4$
			UF	$.5000 \times 10^4$

*Emission factors: GS - pounds pollutants per million cubic feet
RO - pounds pollutants per thousand barrels
CL - pounds pollutants per thousand tons

TABLE D-2

SULFUR AND ASH CONTENTS

		% Sulfur	% Ash
AT	RO	1.34	0
AT	CL	1.83	8.07
GL	RO	1.52	0
GL	CL	2.38	8.57
WS	RO	1.44	0
WS	CL	2.06	7.89
SE	RO	1.81	0
SE	CL	1.67	7.72

2. EMISSION FACTORS FOR BLAST FURNACE GAS AND COKE OVEN GAS

A. PARTICULATE EMISSIONS

(1) Blast Furnace Gas

The particulate emissions resulting from the combustion of B.F.G. come primarily from particles entering with the gas, i.e., the particulate emissions are determined by the efficiency with which the B.F.G. gas is cleaned upon leaving the blast furnace.

The incentive for cleaning the gas is high, since if B.F.G. were not cleaned the particulate matter would clog the holes in the regenerative brickwork of the blast furnace stoves, slagging reactions would be accelerated and might lead to catastrophic failure of the large amount of brickwork in the stoves.

Weise [D-4] reported in 1956 that cleaned gas had dust contents of order 0.01 grains/SCF while Hipp and Westerholm [D-5] indicate that future use of higher blast temperatures (which result in improvements in furnace efficiency) will create the need for gas cleanliness in the 0.001 grains/SCF range. 0.01 grains/SCF translates to 1.4 $lb/10^6$ SCF. However, based on emission factors from the blast furnace and quoted cleaning efficiencies estimates show that the blast furnace gas contains about 3.4 $lb/10^6$ SCF. Thus as a compromise a mean of 2.4 $lb/10^6$ SCF were used for the particulate emission factor for blast furnace gas.

(2) Coke Oven Gas

No information on particulate loadings of coke oven gas could be found. However, since almost all C.O.G. is produced via the "by-product" coking process which involves a significant number of scrubbers and condensers, it will be assumed that C.O.G. is as clean as natural gas when it is finally used.

B. NITROGEN OXIDE EMISSIONS

(1) Blast Furnace Gas

The only reported data that could be found on NO_x production from B.F.G. combustion are in the Esso Study [D-6]. They state that unpublished data on stack gas samples from the blast furnace stoves had NO_x concentrations varying from 1.7 to 6.6 ppm. No mention of the stove size is indicated but if it is assumed that it is an average sized blast furnace stove (67 x 10^6 Btu/hr) then it can be shown that

$$\frac{\text{(NO) observed with burning of B.F.G.}}{\text{(NO) from natural gas burning}} = 0.022$$

Although this ratio is dependent on the firing rate it will be assumed that it holds constant for all sizes.

(2) Coke Oven Gas

NO_x emissions from coke oven gas combustion will be calculated as if the fuel was natural gas. This conclusion was based on good comparisons obtained between measured NO_x concentrations from coke oven gas combustion (from Esso) and values predicted from natural gas combustion at similar burning rates.

C. SULFUR OXIDE EMISSIONS

(1) Blast Furnace Gas

Battelle [D-7] indicates that because of the reducing conditions in the blast furnace, it is not possible for any of the sulfur present in the charge material to be oxidized and leave the blast furnace as SO_2. This is confirmed by Bureau of Mines tests [D-3].

(2) Coke Oven Gas

The sulfur in C.O.G. is determined by the sulfur content of the coal used to produce the coke. The sulfur content of bituminous coals shipped to American coke plants varied between 0.5 and 2.1% [D-2] with an average of 0.8% S. Battelle indicates a linear relationship between sulfur in C.O.G. and % S in coal.

From Battelle [D-7], for 0.8% S coal, ∿ 4.25 lb S in C.O.G. results from the coking of 1 ton of coal. Now, 1.4 T coal required/T coke and 15,500 ft^3 C.O.G. produced/T coke (see AISI statistics).

$$\therefore \text{ lb } SO_2/1000 \text{ ft}^3 \text{ C.O.G.}$$

$$= \frac{4.25 \times 1.4 \times 2}{15.5}$$

$$= 0.77 \text{ lb } SO_2/1000 \text{ ft}^3 \text{ C.O.G.}$$

Of course, if the iron and steel industry is forced to use higher S coal in the future, this will affect the SO_2 content of C.O.G.

Table D-3 shows a summary of the emission factors for blast furnace gas and coke oven gas.

TABLE D-3

SUMMARY OF EMISSION FACTORS FOR BLAST FURNACE GAS AND COKE OVEN GAS

Pollutant	Size	Fuel	Factor (lb/million cu ft)
SO_2	all	BFG	0
SO_2	all	COG	$.77 \times 10^3$
NO_x	WT_1	BFG	$3.69\ (.022 \times .1676 \times 10^3)$
	WT_2	BFG	$5.02\ (.022 \times .2280 \times 10^3)$
	WT_3	BFG	$5.48\ (.022 \times .2489 \times 10^3)$
NO_x	WT_1	COG	$.1676 \times 10^3$
	WT_2	COG	$.2280 \times 10^3$
	WT_3	COG	$.2489 \times 10^3$
Particulates	all	BFG	2.4
	WT_1	COG	18
	WT_2	COG	15
	WT_3	COG	15

3. EMISSIONS

The calculated emissions are shown in detail in Tables D-4 through D-12.

Uncontrolled boiler emissions were calculated according to the equations shown below:

$$SO_2 \text{ (tons)} = \frac{\text{fuel consumption x emission factor x \% sulfur}^{*}}{2000}$$

$$NO_x \text{ (tons)} = \frac{\text{fuel consumption x emission factor}}{2000}$$

$$\text{Particulates (tons)} = \frac{\text{fuel consumption x emission factor x \% ash}^{**}}{2000}$$

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*Only in the case of coal- or oil-fired boilers

**Only in the case of coal-fired boilers

TABLE D-4

SO_2 EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1970
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	4.2	12.4	.3	3.2	20.1
		CY	0	0	0	0	0
		OF	9.8	29.2	.5	7.4	46.9
		SS	4.2	12.4	.2	3.2	20.0
		UF	2.8	8.0	.2	5.2	16.2
	RO		15.1	8.7	1.3	1.8	26.9
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		16.8	9.7	6.9	3.5	36.9
$WT_{100-250}$	CL	PV	8.8	40.5	.3	5.2	54.8
		CY	.3	1.4	0	.1	1.8
		OF	4.3	20.0	.2	2.6	27.1
		SS	1.2	5.6	.2	.7	7.7
		UF	.3	1.4	0	.2	1.9
	RO		10.8	9.8	.7	.7	22.0
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		11.9	10.9	3.7	1.9	28.4
$WT_{>250}$	CL	PV	10.3	46.5	.9	16.0	73.7
		CY	.5	2.4	0	.9	3.8
		OF	0	0	0	0	0
		SS	.3	1.0	0	.4	1.7
		UF	.1	.5	0	.1	.7
	RO		8.2	7.1	1.2	1.3	17.8
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		9.0	7.9	6.2	3.8	26.9
TOTAL			118.9	235.4	22.8	58.2	435.3

TABLE D-5

PARTICULATES EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1970
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	7.7	18.7	.5	6.2	33.1
		CY	0	0	0	0	0
		OF	14.7	36.0	.6	11.8	63.1
		SS	2.4	5.9	.1	1.9	10.3
		UF	1.6	3.8	.1	1.3	6.8
	RO		1.6	.8	.1	.1	2.6
	GS		.4	.2	.1	.1	.8
	BFG		.7	.4	.1	.1	1.3
	COG		.4	.2	.2	.1	.9
$WT_{100-250}$	CL	PV	16.4	61.4	.5	10.2	88.5
		CY	.1	.3	0	0	.4
		OF	6.5	24.6	.2	4.1	35.4
		SS	.7	2.6	.1	.4	3.8
		UF	.2	.7	0	.1	1.0
	RO		.5	.4	0	0	.9
	GS		.2	.2	0	0	.4
	BFG		.5	.5	.1	.1	1.2
	COG		.2	.2	.1	0	.5
$WT_{>250}$	CL	PV	19.2	70.4	1.5	31.1	122.2
		CY	.1	.5	0	.2	.8
		OF	0	0	0	0	0
		SS	.2	.5	0	.2	.9
		UF	.1	.2	0	.1	.4
	RO		.4	.3	.1	0	.8
	GS		.2	.1	.1	.1	.5
	BFG		.4	.4	.1	.2	1.1
	COG		.2	.2	.1	.1	.6
TOTAL			75.6	229.5	4.7	68.5	378.3

TABLE D-6

NO_x EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1970
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	1.2	2.7	.1	1.0	5.0
		CY	0	0	0	0	0
		OF	2.1	4.8	.1	1.8	8.8
		SS	.6	1.4	0	.5	2.5
		UF	.4	.9	0	.3	1.6
	RO		3.7	1.9	.3	.2	6.1
	GS		3.8	1.8	1.0	.9	7.5
	BFG		1.0	.7	.2	.1	2.0
	COG		3.7	2.1	1.5	.8	8.1
$WT_{100-250}$	CL	PV	2.5	9.0	.1	1.7	13.3
		CY	.2	.9	0	.1	1.2
		OF	.9	3.3	0	.6	4.8
		SS	.2	.6	0	.1	.9
		UF	0	.2	0	0	.2
	RO		3.6	2.9	.2	.2	6.9
	GS		3.7	2.8	.7	.7	7.9
	BFG		1.0	1.0	.1	.2	2.3
	COG		3.5	3.2	1.1	.6	8.4
$WT_{>250}$	CL	PV	3.0	10.3	.2	5.0	18.5
		CY	.5	1.6	0	.8	2.9
		OF	0	0	0	0	0
		SS	0	.1	0	.1	.2
		UF	0	.1	0	0	.1
	RO		3.0	2.3	.4	.4	6.1
	GS		3.0	2.2	1.3	1.4	7.9
	BFG		.8	.8	.3	.4	2.3
	COG		2.9	2.6	2.0	1.2	8.7
TOTAL			45.3	60.2	9.6	19.1	134.2

TABLE D-7

SO_2 EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1975
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	3.1	14.8	.3	3.1	21.3
		CY	0	0	0	0	0
		OF	7.4	34.5	.6	7.2	49.7
		SS	3.1	14.8	.3	3.1	21.3
		UF	2.1	9.6	.2	2.0	13.9
	RO		16.8	10.7	1.4	1.8	30.7
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		17.3	13.2	4.2	4.9	39.6
$WT_{100-250}$	CL	PV	6.0	43.3	.8	4.9	55.0
		CY	.3	1.6	0	.1	2.0
		OF	2.9	21.2	.3	2.3	26.7
		SS	.8	5.9	.2	.6	7.5
		UF	.1	1.4	0	.2	1.7
	RO		10.7	10.7	.6	.8	22.8
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		11.0	13.0	1.9	1.9	27.8
$WT_{>250}$	CL	PV	5.8	47.7	1.1	14.0	68.6
		CY	.3	2.6	.2	.7	3.8
		OF	0	0	0	0	0
		SS	.1	1.0	0	.4	1.5
		UF	.1	.5	0	.1	.7
	RO		8.2	8.0	1.3	1.6	19.1
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		8.5	9.0	3.0	4.2	24.7
TOTAL			104.6	263.5	16.4	53.9	438.4

TABLE D-8

PARTICULATES EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1975
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	5.7	22.4	.5	5.9	34.5
		CY	0	0	0	0	0
		OF	11.1	42.4	.8	11.4	65.7
		SS	1.8	7.0	.2	1.9	10.9
		UF	1.2	4.5	.1	1.2	7.0
	RO		1.8	1.0	.1	.1	3.0
	GS		.7	.3	.1	.1	1.2
	BFG		.6	.5	.1	.2	1.4
	COG		.4	.3	.1	.1	.9
$WT_{100-250}$	CL	PV	11.2	65.7	1.2	9.5	87.6
		CY	.1	.3	0	0	.4
		OF	4.4	26.1	.4	3.7	34.6
		SS	.5	2.8	.1	.4	3.8
		UF	.1	.7	0	.1	.9
	RO		.5	.4	0	0	.9
	GS		.4	.2	.1	.1	.8
	BFG		.4	.5	.1	.1	1.1
	COG		.2	.3	0	0	.5
$WT_{>250}$	CL	PV	10.7	72.3	1.7	27.3	112.0
		CY	.1	.5	0	.2	.8
		OF	0	0	0	0	0
		SS	.1	.5	0	.2	.8
		UF	.1	.2	0	.1	.4
	RO		.4	.3	.1	.1	.9
	GS		.3	.2	.1	.1	.7
	BFG		.3	.3	.1	.2	.9
	COG		.2	.2	.1	.1	.6
TOTAL			53.3	249.9	6.0	63.1	372.3

TABLE D-9

NO_x EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1975
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	.9	3.3	.1	1.0	5.3
		CY	0	0	0	0	0
		OF	1.6	5.7	.1	1.7	9.1
		SS	.4	1.6	0	.5	2.5
		UF	.3	1.1	0	.3	1.7
	RO		4.1	2.3	.3	.3	7.0
	GS		6.9	2.6	1.8	1.3	12.6
	BFG		1.0	.7	.2	.3	2.2
	COG		3.8	2.9	.9	1.1	8.7
$WT_{100-250}$	CL	PV	1.7	9.6	.2	1.5	13.0
		CY	.2	1.0	0	.1	1.3
		OF	.6	3.5	.1	.5	4.7
		SS	.1	.7	0	.1	.9
		UF	0	.2	0	0	.2
	RO		3.6	3.2	.2	.2	7.2
	GS		6.0	3.5	1.2	.9	11.6
	BFG		.9	1.0	.1	.2	2.2
	COG		3.3	3.9	.6	.6	8.4
$WT_{>250}$	CL	PV	1.7	10.5	.3	4.4	16.9
		CY	.2	1.7	.1	.7	2.7
		OF	0	0	0	0	0
		SS	0	.1	0	.1	.2
		UF	0	.1	0	0	.1
	RO		3.0	2.6	.4	.4	6.4
	GS		4.8	2.7	2.0	1.9	11.4
	BFG		.7	.8	.2	.4	2.1
	COG		2.7	2.9	1.0	1.4	8.0
TOTAL			48.5	68.2	9.8	19.9	146.4

TABLE D-10

SO_2 EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1980
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	3.4	16.9	.3	3.5	24.1
		CY	0	0	0	0	0
		OF	7.9	39.7	.6	8.3	56.5
		SS	3.4	16.9	.3	3.5	24.1
		UF	2.3	11.1	.2	2.2	15.8
	RO		20.2	10.7	1.4	1.8	34.1
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		19.4	13.9	4.1	4.9	42.3
$WT_{100-250}$	CL	PV	6.0	49.4	.8	4.9	61.1
		CY	.3	1.7	0	.1	2.1
		OF	2.9	24.2	.3	2.3	29.7
		SS	.8	6.6	.2	.6	8.2
		UF	.1	1.7	0	.2	2.0
	RO		12.7	10.0	1.4	.8	24.9
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		12.3	14.2	2.6	2.6	31.7
$WT_{>250}$	CL	PV	6.8	50.1	1.1	14.0	72.0
		CY	.4	2.8	.2	.7	4.1
		OF	0	0	0	0	0
		SS	.1	1.0	0	.4	1.5
		UF	0	.5	0	.1	.6
	RO		8.8	6.6	1.3	1.6	18.3
	GS		0	0	0	0	0
	BFG		0	0	0	0	0
	COG		7.9	9.0	3.0	4.2	24.1
TOTAL			115.7	287.0	17.8	56.7	477.2

TABLE D-11

PARTICULATES EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1980
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	6.2	25.6	.5	6.9	39.2
		CY	0	0	0	0	0
		OF	11.9	48.9	.8	13.1	74.7
		SS	1.9	8.0	.2	2.2	12.3
		UF	1.3	5.3	.1	1.3	8.0
	RO		2.1	1.0	.1	.1	3.3
	GS		.9	.4	.2	.2	1.7
	BFG		.6	.4	.1	.1	1.2
	COG		.5	.3	.1	.1	1.0
$WT_{100-250}$	CL	PV	11.2	74.9	1.2	9.5	96.8
		CY	.1	.3	.4	0	.8
		OF	4.4	29.8	.4	3.7	38.3
		SS	.5	3.1	.1	.4	4.1
		UF	.1	.8	0	.1	1.0
	RO		.6	.4	.1	0	1.1
	GS		.5	.3	.1	.1	1.0
	BFG		.4	.4	.1	.1	1.0
	COG		.2	.3	.1	.1	.7
$WT_{>250}$	CL	PV	12.7	75.9	1.7	27.3	117.6
		CY	.1	.5	0	.2	.8
		OF	0	0	0	0	0
		SS	.1	.5	0	.2	.8
		UF	0	.2	0	.1	.3
	RO		.4	.3	.1	.1	.9
	GS		.3	.2	.1	.1	.7
	BFG		.2	.3	.1	.1	.7
	COG		.2	.2	.1	.1	.6
TOTAL			57.4	278.3	6.7	66.2	408.6

TABLE D-12

NO_x EMISSIONS FROM BOILERS IN THE IRON AND STEEL INDUSTRY - 1980
(10^3 tons)

Size	Fuel	Firing	AT	GL	WS	SE	Total
$WT_{\leq 100}$	CL	PV	1.0	3.7	.1	1.1	5.9
		CY	0	0	0	0	0
		OF	1.7	6.6	.1	2.0	10.4
		SS	.5	1.9	0	.6	3.0
		UF	.3	1.2	0	.3	1.8
	RO		4.9	2.3	.3	.3	7.8
	GS		8.5	3.5	2.1	1.6	15.7
	BFG		.9	.6	.2	.2	1.9
	COG		4.2	3.0	.9	1.1	9.2
$WT_{100-250}$	CL	PV	1.7	10.9	.2	1.5	14.3
		CY	.2	1.2	0	.1	1.5
		OF	.6	4.0	.1	.5	5.2
		SS	.1	.7	0	.1	.9
		UF	0	.2	0	0	.2
	RO		4.3	3.0	.4	.2	7.9
	GS		7.2	4.6	2.1	1.1	15.0
	BFG		.7	.8	.2	.2	1.9
	COG		3.6	4.2	.8	.8	9.4
$WT_{>250}$	CL	PV	2.0	11.1	.3	4.4	17.8
		CY	.3	1.8	.1	.7	2.9
		OF	0	0	0	0	0
		SS	0	.1	0	.1	.2
		UF	0	.1	0	0	.1
	RO		3.2	2.2	.4	.4	6.2
	GS		5.3	3.3	2.3	2.0	12.9
	BFG		.5	.6	.2	.3	1.6
	COG		2.5	2.9	1.0	1.4	7.8
TOTAL			54.2	74.5	11.8	21.0	161.5

REFERENCES TO APPENDIX D

D-1. Systematic Study of Air Pollution from Intermediate-Size Fossil-Fuel Combustion Equipment, Walden Research Corporation, Cambridge, Mass., 1971.

D-2. DeCarlo, et al., Sulfur Content in U.S. Coals, Bureau of Mines Information Circular 8312, p. 40, 1966.

D-3. Woolf, P.L. and Mahan, W.M., Fuel Oil Injection in an Experimental Blast Furnace, Bureau of Mines Report of Investigations 6150, p. 13, 1963.

D-4. Weise, W.H., Blast Furnace Flue Dust Treatment Facilities, Sewage and Industrial Wastes, 28, 1398, 1956.

D-5. Hipp, N.E. and Westerholm, J.R., Development in Gas Cleaning - Great Lakes Steel Corp., Iron and Steel Engineer 44, (8), 101, 1967.

D-6. Bartok, W., et al., Systems Study of Nitrogen Oxide Content Methods for Stationary Sources, Esso Research and Engineering Co., Government Research Laboratory.

D-7. A Systems Analysis Study of the Integrated Iron and Steel Industry, Battelle Memorial Institute, Columbus, Ohio, 1964.

BIBLIOGRAPHIC DATA SHEET	1. Report No. EPA-R2-73-192	2.	3. Recipient's Accession No.
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9. Performing Organization Name and Address Walden Research Corporation 359 Allston Street Cambridge, Massachusetts 02139			10. Project/Task/Work Unit No.
			11. Contract/Grant No. EHSD 71-21
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			14.

15. Supplementary Notes

16. Abstracts
The report provides an estimated inventory of: conventional boiler capacity; and the pollutant emissions attributable to these boilers. Boiler capacity and emissions are projected to 1980. The report supplements a separate iron and steel industry process systems study report. Significant findings are that the boilers are often fired with process waste gases supplementing conventional fuels, and that the boiler pollutant emissions are significant, compared to process emissions.

17. Key Words and Document Analysis. 17a. Descriptors

*Iron and Steel Industry
Air Pollution
Boilers
Capacity
Emission
Inventories
Forecasting

17b. Identifiers/Open-Ended Terms

Stationary Sources

17c. COSATI Field/Group 13B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
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