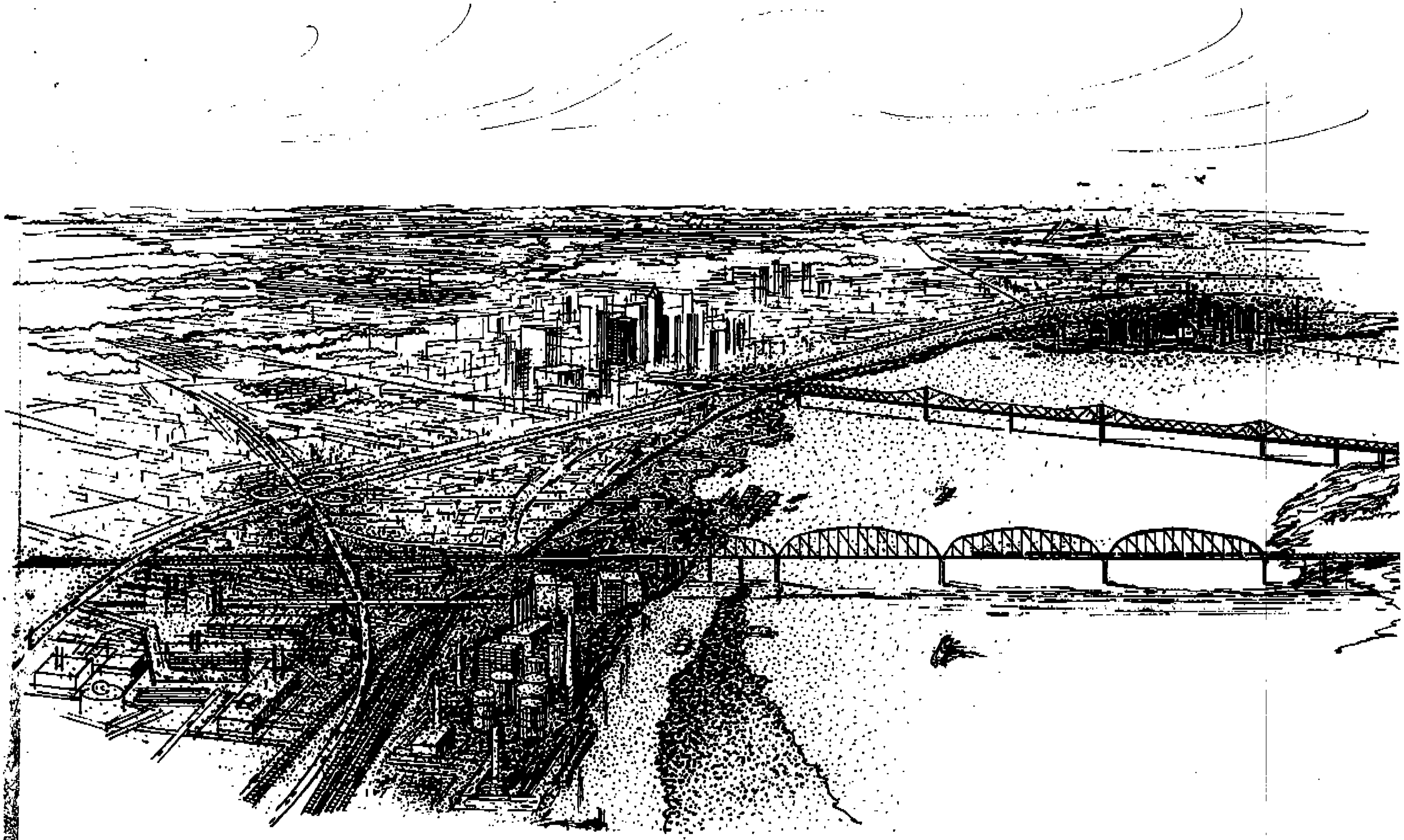
Preliminary Document

AIR POLLUTANT EMISSION FACTORS

April 1971



U.S. ENVIRONMENTAL PROTECTION AGENCY

COMPILATION OF AIR POLLUTANT EMISSION FACTORS

Preliminary Document

by
M. J. McGraw
and
R. L. Duprey

ENVIRONMENTAL PROTECTION AGENCY
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PREFACE

This report represent the latest available atmospheric emission data for which sufficient information exists to establish emission factors. Although based on Public Health Service Publication 999-AP-42, Compilation of Air Pollutant Emission Factors, by R. L. Duprey, this document has been altered considerably. Information on approximately three-fourths of the processes discussed in this edition has been updated or refined in some way. The scope of the document has been broadened to reflect the expanding knowledge about emissions. This report is about one-fourth larger than the previously published document, and some of the emission factors herein are being published for the first time anywhere.

As data are refined and additional information becomes available, this document will be reissued to reflect more accurate, refined emission factors and will contain emission factors for processes not yet studied at the time of publication of this document.

BECAUSE OF THE URGENT NEED FOR EMISSION FACTOR DATA, THE AIR POLLUTION CONTROL OFFICE IS ISSUING "PRELIMINARY COPIES" OF THIS DOCUMENT FOR USE BY LOCAL, STATE, AND FEDERAL AGENCIES. THIS MATERIAL WILL BE PUBLISHED IN THE NEAR FUTURE AS THE SECOND EDITION OF REPORT NUMBER AP-42. ALL DATA IN THE NEW EDITION WILL BE EXPRESSED IN BOTH ENGLISH AND METRIC UNITS.

ACKNOWLEDGMENTS

Sincere gratitude is extended to the many individuals and companies who contributed emissions data for this report. Special thanks are due to Richard Gerstle and other members of the staff of Resources Research Incorporated who provided the write-ups and emission factor data for approximately one third of this report.

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INTRODUCTION

In the assessment of community air pollution, there is a critical need for accurate data on the quantity and characteristics of emissions from the numerous sources which contribute to the problem. The large numbers of these individual sources and the diversity of source types makes it impractical to conduct field measurements of emissions on a source-by-source basis at the point of release. Therefore, the only feasible method of determining pollutant emissions for a given community is to make generalized estimates of typical emissions from each of the source types (emission factors).

The emission factor is a statistical average of the rate at which a pollutant is released to the atmosphere as a result of some activity, such as combustion or industrial production, divided by the level of that activity. For example, assume that in the production of 260,000 tons/year of ammonia, 26,000 tons of carbon monoxide was emitted to the atmosphere. The emission factor for the production of ammonia would therefore be: 200 pounds CO released per ton of ammonia produced. The emission factor thus relates the quantity of pollutants emitted to some indicator such as production capacity, quantity of fuel burned, vehicle miles traveled by autos, etc.

The emission factors presented in this report were estimated by the whole spectrum of techniques available for determining such factors. These techniques include: detailed source testing involving many measurements related to a variety of process variables, single measurements not clearly defined as to their relationship to process operating conditions, process material balances and engineering appraisals of a given process.

The limitations and applicability of emission factors must be understood. To give some idea of how good the factors presented for a specific process are, each process has been ranked as either "A," "B," "C," "D," or "E." For a process with an "A" ranking the emission factor should be considered excellent, i.e. based on field measurements of a large number of sources. A process ranked "B" should be considered above average, i.e., based on a limited amount of field measurements. A ranking of "C" is considered average, "D" below average and "E" poor. These rankings are presented above the table numbers throughout the report.

In general, the emission factors presented are not precise indicators of emissions for a single process. They are more valid when applied to a large number of processes. With this in mind, emission factors are extremely useful when intelligently applied in conducting source inventories as part of air pollution community or nationwide air pollution studies.

STATIONARY COMBUSTION SOURCES

Stationary combustion sources include steam-electric generating plants, industrial establishments, commercial and institutional buildings, and domestic combustion units. Coal, fuel oil, and natural gas are the major fossil fuels used by these sources. Other fuels such as liquified petroleum gas, wood, lignite, coke, refinery gas, blast furnace gas or other waste or by-product type fuels are also used, but the quantities consumed are relatively small. Coal, oil, and natural gas currently supply about 95 percent of the total BTU's consumed in the United States. In 1968 over 500 million tons of coal, 580 million barrels of residual fuel oil, 590 million barrels of distillate fuel oil and 20 trillion cubic feet of natural gas were consumed in the United States.[1]

The burning of these fuels for both space heating and process heating is one of the largest sources of sulfur oxides, nitrogen oxides, and particulate emissions. Controls for particulate emissions are presently being used, but for sulfur oxides and nitrogen oxides no wide spread control techniques are practiced. The following sections present detailed emission data for the major fossil fuels coal, fuel oil, and natural gas, as well as for liquified petroleum gas, and wood waste combustion in boilers. Detailed information on the particle size distribution from the combustion of each of these fuels is presented in Appendix C.

BITUMINOUS COAL COMBUSTION

General Information

Coal is the most plentiful fuel in the United States, and is burned in a wide variety of furnaces to produce heat and steam. Coal fired furnaces range in size from small handfired units with capacities of 10-20 pounds of coal per hour to large pulverized coal fired units which burn 300-400 tons of coal per hour.

Although predominantly carbon, coal contains many compounds in varying amounts. The exact nature and quantity of these compounds is determined by the source of the coal and will usually affect the final use of the coal.

Emissions and Controls

Particulates: Particulates emitted from coal combustion consists primarily of carbon, silica, alumina, and iron oxide in the fly ash. The quantity of particulate emissions is dependent upon the ash content of the coal, the type of combustion unit, and the control equipment used. Table 1 gives the range of collection efficiencies for common types of fly ash control equipment. Particulate emission factors are presented in Table 2 for the various types of furnaces based on the quantity of coal burned.

Sulfur Oxides: Increased attention has been given to the control of sulfur oxide emissions from the combustion of coal. Low sulfur coal has been recommended in many areas, but where this is not possible other methods, in which the focus is on the removal of sulfur oxide emissions from the flue gas before it enters the atmosphere must be considered. No flue gas desulfurization processes are presently in widespread use, but several methods are presented in Table 3 with the expected efficiencies obtainable from the various types of control. Uncontrolled emissions of sulfur oxides are shown in Table 2 along with the other gaseous emissions.

Other Gases: Gaseous emissions from coal combustion include sulfur oxides, aldehydes, carbon monoxide, hydrocarbons and nitrogen oxides. In the section, attention will be focused on hydrocarbons, carbon monoxide and nitrogen oxides.

The carbon monoxide and hydrocarbon content of the gases emitted from bituminous coal combustion depend mainly on the efficiency of combustion. Successful combustion and a low level of gaseous carbon and organic emissions involve a high degree of turbulence, high temperatures, and sufficient time for the combustion reaction to take place. Thus, careful control of excess air rates, high combustion temperature, and intimate fuel air contract will minimize these emissions.

Emissions of nitrogen oxide result from the high temperature reaction of atmospheric nitrogen and oxygen in the combustion zone. This pollutant is thus emitted at a greater rate from more efficient combustion sources which generally have lower excess air rates, higher combustion temperature, and greater furnace release rates.

Factors for gaseous emissions are presented in Table 2. The size range in BTU per hour for the various categories is only shown as a guide in applying these factors and is not meant to clearly distinguish between furnace applications.

TABLE 1 RANGE OF COLLECTION EFFICIENCIES FOR COMMON TYPES OF FLY ASH CONTROL EQUIPMENT[a]

Type of Furnace	Range of Collection Efficiencies, %			
	Electrostatic Precipitator	High Efficiency Cyclone	Low-Resistance Cyclone	Settling Chamber expanded Chimney Bases
Cyclone Furnace	65-99[b]	30-40	20-30	--
Pulverized Unit	80-99.9[b]	65-75	40-60	--
Spreader Stoker	--	85-90	70-80	20-30
Other Stokers	--	90-95	75-85	25-50

[a] - Reference 2

[b] - High values attained with high-efficiency cyclones in series with electrostatic precipitators.

TABLE 2[A] UNCONTROLLED EMISSION FACTORS FOR BITUMINOUS COAL COMBUSTION (lbs/ton of coal burned)

Furnace Size 10^6 BTU/hr heat input	Partic-[d] ulates	Sulfur[e] Oxides	Carbon Monoxide	Hydro-[f] carbons	Nitrogen Oxides	Aldehydes (HCHO)
Greater than 100[a] (Utility and large industrial boilers)						
Pulverized						
General	16A	38S	1	0.3	18	0.005
Wet Bottom	13A[g]	38S	1	0.3	30	0.005
Dry Bottom	17A	38S	1	0.3	18	0.005
Cyclone	2A	38S	1	0.3	55	0.005
10 - 100[b]						
(Large Commercial and general industrial boilers)						
Stoker[h]	13A[g]	38S	2	1	15	0.005
Less than 10[c] (Commercial and domestic furnaces)						
Stoker	2A	38S	10	3	6	0.005
Handfired Units	20	38S	90	20	3	0.005

a - References 2,3,4,5,6,7, and 11

b - References 2,4,5,8,9, and 11

c - References 9,10,11

d - The letter A on all units other than hand-fired equipment indicates that the weight percent ash in the coal should be multiplied by the value given.
Example: If the factor is 16 and the ash content is 10 percent, the particulate emission before the control equipment would be 10 times 16 or 160 pounds of particulate per ton of coal.

e - S equals the sulfur content (see footnote d above).

f - Expressed as methane.

g - Without fly ash reinjection

h - For all other stokers use 5A for particulate emission factor.

TABLE 3 PERCENT SO_2 REMOVAL FROM VARIOUS TYPES OF PROCESSES[a]

Type Process	Percent SO_2 Removal
Limestone-dolomite injection, dry process	40-60
Limestone-dolomite injection, wet process	80-90
Catalytic Oxidation	90

a = Reference 12

ANTHRACITE COAL COMBUSTION

General[13]

Due to its low volatile content, and the non-clinking characteristics of the ash, anthracite coal is largely used in medium sized industrial and institutional boilers using stationary or traveling grates. Anthracite coal is not used in spreader stokers because of its low volatile content and relatively high ignition temperature. This fuel may be burned in pulverized coal fired units, but due to ignition difficulties, this practice is limited to only a few plants in Eastern Pennsylvania. This fuel has also been widely used in hand fired furnaces.

Emissions and Controls[13]

Particulate emissions from anthracite coal combustion are greatly affected by the rate of firing and by the ash content of the fuel. Due to the low volatile content of this coal, smoke emissions are rarely a problem. High grate heat release loadings result in excessive emissions since greater quantities of underfire air are required to burn the fuel. Hand fired and some small natural draft units have lower particulate emissions since underfire air rates cannot be increased very much. However, larger units equiped with force draft fans may produce high rates of particulate emissions.

As is the case with other fuels, sulfur dioxide emissions are directly related to the sulfur content of the coal. Nitrogen oxides and carbon monoxide emissions are similar to those found in bituminous coal fired units since excess air rates and combustion temperatures are similar. Due to the lower volatile matter content of anthracite, hydrocarbon emissions are somewhat lower than those from bituminous coal combustion.

The uncontrolled emissions from anthracite coal combustion are presented in Table 4.

B

TABLE 4 UNCONTROLLED EMISSIONS FROM ANTHRACITE COAL COMBUSTION
(pounds per ton coal burned)

Type of Furnace	Particulate[a]	SO_2	SO_3[b]	HC[c,h]	CO[d]	NO_x[d]
Pulverized (dry bottom) No fly ash reinjection	17A[f]	38S[g]	0.5S[g]	0.03	1	18
Overfeed Stokers[e] No fly ash reinjection	2	38S[g]	0.5S[g]	0.2	(2-10)[j]	(6-15)[k]
Handfired Units	10	36S[g]	0.8S[g]	2.5	90	3

a - References 8,14,15,16,17, 18

b - References 16,18,19,20

c - Based on reference 8 and bituminous coal combustion.

d - Based on bituminous coal combustion

e - Based on data obtained from traveling grate stokers in the 12 to 180 BTU/hr heat input range. Anthracite is not burned in spreader stokers.

f - A is the ash content expressed as weight %.

g - S is the sulfur content expressed as weight %.

h - Expressed as methane.

i - Emitted as NO.

j - Use high side of range for smaller sized units (less than 10×10^6 BTU/hr. heat input.

k - Use low side of range for smaller sized units (less than 10×10^6 $\frac{\text{BTU}}{\text{hr}}$ heat input).

Note: Efficiencies of control devices used for anthracite are approximately, cyclone 75 - 85%, electrostatic precipitator 85%.

FUEL OIL COMBUSTION

General Information

Fuel oil is one of the major fossil fuels used in this country for power production, industrial process heating, and space heating. It is classified into two major types--residual or distillate. Distillate fuel oil is primarily a domestic fuel, but is used in some commercial and industrial applications where a high quality oil is required. Residual fuel is used in power plants, commercial establishments and by industries. The primary difference between residual oil and distillate oil is the higher ash and sulfur content of residual oil and the fact that it is harder to burn properly. Residual fuel oils have a heating value of approximately 150,000 BTU/gallon, whereas for distillate oils the heating value is around 140,000 BTU/gallon.

Emissions

Emissions from oil combustion are dependent on type of equipment, size, method of firing and maintenance. Table 5 presents emission factors for fuel oil combustion. Note that the industrial and commercial category is split into residual and distillate since there is a significant difference in particulate emissions from the same equipment depending on the fuel oil used. It should also be noted that power plants emit less particulate per quantity of oil consumed, reportedly because of better design and more precise operation of equipment.

In general large sources produce more nitrogen oxides than small sources.[2] This is due primarily to the higher flame and boiler temperatures characteristic of large sources. Large sources, however, emit less aldehydes than smaller sources as a result of more complete combustion and higher flame temperatures. It may be expected that small sources would emit relatively larger amounts of hydrocarbons than large sources because of the small flame volume, the large proportion of relatively cool gases near the furnace walls, and frequently because of improper operating practices. However, this was not reflected in the data.

TABLE 5[A] EMISSION FACTORS FOR FUEL OIL COMBUSTION
(pounds per 1,000 gallons of oil burned)

	Type of Unit			
		Industrial and Commercial		
Pollutant	Power Plant	Residual	Distillate	Domestic
Particulate[a]	8	23	15	10
Sulfur Dioxide[b]	157S	157S	142S	142S
Sulfur Trioxide[b,h]	2S	2S	2S	2S
Carbon Monoxide[c]	0.04	0.2	0.2	5
Hydrocarbons[d]	5	3	3	3
Nitrogen Oxides (NO_2)[e]	105	(40-80)[f]	(40-80)[f]	12
Aldehydes (HCHO)[g]	1	1	2	2

a - References 21 through 25

b - Reference 21

c - References 21,26,27,32,33

d - References 21,25,28,32,33

e - References 21 through 25,29,32,33

f - Use 40 for tangentially fired units and 80 for horizontally fired units.

g - References 21,28,30,31

h - S equals weight percent sulfur in oil.

NATURAL GAS COMBUSTION

General Information

Natural gas is rapidly becoming one of the major fuels used throughout the country. It is used mainly in power plants, industrial heating, domestic and commercial space heating and gas turbines. The primary component of natural gas is methane, but it does contain smaller quantities of inorganics, particularly nitrogen and carbon dioxide. However, Pennsylvania natural gas has been reported to contain as much as one-third ethane.[34] The heating value of natural gas is approximately 1,050 BTU per standard cubic foot.

Emissions and Controls

Even though natural gas is considered to be a relatively clean fuel, emissions may still occur from the combustion reaction.

When insufficient air is supplied large amounts of carbon monoxide and hydrocarbons may be produced.[35] Emissions of sulfur oxides are dependent on the amount of sulfur in the fuel. The sulfur content of natural gas is usually low, around 2,000 grains/million cubic feet.

Nitrogen oxide emissions are a function of the temperature in the combustion chamber and the rate of cooling of the combustion products. This varies considerably with the type and size of unit. Emissions of aldehydes are increased when there is an insufficient amount of combustion air or incomplete mixing of the fuel and the combustion air.

Emission factors for natural gas combustion are presented in Table 6. Control equipment has not been utilized to control emissions from natural gas combustion equipment.

TABLE 6[B] EMISSION FACTORS FOR NATURAL GAS COMBUSTION

(pounds per million cubic feet of natural gas burned)

Pollutant	Type of Unit				
	Power Plant	Industrial Process Boilers	Domestic and Commercial Heating Units	Gas Turbines	Gas Engines
Particulates[a]	15	18	19	--	
Oxides of Sulfur[b] (SO_2)	0.6	0.6	0.6	--	
Carbon Monoxide[c]	0.4	0.4	20	--	
Hydrocarbons[d] (CH_4)	40	40	8	--	
Oxides of Nitrogen[e] (NO_2)	390	(120-230)[h]	(50-100)[i]	200	770-7,300[j]
Aldehydes[f] (HCHO)	3	3	10	--	
Organics[g]	4	7	1	--	

a - Reference 22
b - Reference 36 (Based on average sulfur content of natural gas of 2,000 grains/million cubic feet)
c - Reference 37,38,39
d - References 23,37,38,39
e - References 22,29,35,44
f - References 23,28,29,35,38,40,41,42,43
g - Reference 44
h - Use 120 for smaller industrials boilers <500 h. p. and 230 for larger industrial boilers >7,500 h. p.
i - Use 50 for domestic heating units and 100 for commercial units.
j - Use 770 for oil and gas production
Use 4,300 for gas plants
Use 7,300 for pipelines
Use 4,400 for refineries

LIQUIFIED PETROLEUM GAS CONSUMPTION

General Information[13]

Liquified petroleum gas, commonly referred to as LPG, consists mainly of butane, propane, or a mixture of the two; and trace amounts of propylene and butylene. This gas, obtained from oil or gas wells, or as a by-product of gasoline refining is sold as a liquid in metal cylinders under pressure. It is therefore often called bottled gas. LP gases are graded according to maximum vapor pressure with Grade A being predominantly butane, Grade F being predominantly propane, and Grades B through E consisting of varying mixtures of butane and propane. The heating value of LPG ranges from 337,000 BTU/gallon for Grade A to 308,000 BTU/gallon for Grade F. The largest market for LPG is presently the domestic-commercial heating market followed by the chemical industry and internal combustion engines.

Emissions[13]

LPG is considered a "clean" fuel because of the lack of visible emissions. Gaseous pollutants such as carbon monoxide hydrocarbons, and nitrogen oxides, however, do occur. The most significant factor affecting these emissions is the burner design, adjustment, and venting.[45] Improper design, blocking and clogging of the flue vent and lack of combustion air will result in improper combustion causing the emission of aldehydes, carbon monoxide, hydrocarbons, and other organics. Nitrogen oxide emissions are a function of a number of variables including temperature, excess air, and residence time in the combustion zone. The amount of SO_2 emitted is directly proportional to the amount of sulfur in the fuel.

Emission factors for LPG combustion are presented in Table 7.

TABLE 7[c] EMISSION FACTORS FOR LPG COMBUSTION[a]

(pounds per 1,000 gallons)

Pollutant	Industrial Process Furnaces Butane	Industrial Process Furnaces Propane	Domestic and Commercial Furnaces Butane	Domestic and Commercial Furnaces Propane
Particulate	6.3	5.8	6.7	6.1
Sulfur Oxides[b]	0.3S	0.3S	0.3S	0.3S
Carbon Monoxide	0.1	0.1	7.0	6.4
Hydrocarbons	14	13	2.7	2.5
Nitrogen Oxides[c]	42	38	20-35[d]	20-35[d]
Aldehydes (HCHO)	3.5	3.2	3.5	3.2
Other Organics	2.4	2.2	0.4	0.3

a - Factors based on an analysis of the similarities between LPG combustion and natural gas and fuel oil combustion, and data in reference 22.

b - S equals sulfur content expressed in grains per 100 CF gas vapor, eg., if the sulfur content is 0.16 grains per 100 CF vapor, the SO_2 emission factor would be 0.30 x 0.16 or 0.048 lb. SO_2 per 1,000 gallons butane burned.

c - Expressed as NO_2

d - Use 20 for domestic units and 35 for commercial units.

WOOD WASTE COMBUSTION IN BOILERS

General Information

Wood is no longer a primary source of heat energy, however, for certain industries such as lumber, furniture, plywood etc., where wood is as a by-product readily available, it is a desirable fuel. The wood is used in the form of hogged chips, shavings, and sawdust.

Firing Practices

In general, furnaces designed for the burning of wood waste fall into three types: (1) pile, (2) thin-bed, and (3) cyclonic. All three of these furnaces are usually watercooled and can be modified to burn supplemental fuel with the wood.

In pile burning, the wood is fed through the furnace roof and burned in a cone shaped pile on the grate. Thin-bed burning is accomplished on a moving grate similar to a spreader stoker. In a cyclone furnace, wood (especially bark) is usually burned with coal.

Emissions[13]

Excessive smoking will result from improper grate maintenance of wood burning furnaces, especially where coal is burned simultaneously with the wood. Another major factor affecting emissions is the water content of the wood refuse. This is not only a function of the absorptive property of the wood, but also a function of the process which produces the waste. Thus, wet bark will generally produce more emissions than kiln dried lumber. Of minor importance, except as it reflects on the factor noted above, is the species of wood. For example, bark contains less carbon and nitrogen, but more sulfur than wood. This difference coupled with a high moisture content is thought to account for more severe dust and smoke problems when burning bark. Emission factors for the combustion of wood and bark in boilers are shown in Table 8.

TABLE 8[C] EMISSION FACTORS FOR WOOD AND BARK COMBUSTION IN BOILERS[a]

(pounds per ton of fuel fired, approximately 50% moisture content)

Pollutant	Conditions of Operation		
	No Reinjection	50% Reinjection[b]	100% Reinjection[b]
Particulate	25-30	30-35	40-45
Sulfur Oxides (SO_2)[c]	0-3		
Carbon Monoxide	2		
Hydrocarbons[d]	2		
Nitrogen Oxides (NO_2)	10		
Carbonyls[e]	0.5[f]		

a - References 46,47,48,49

b - This is not an emission factor. Value represents the loading reaching the control equipment usually used on this type of furnace, and is based on the percentage of fly ash reinjection indicated.

c - Use 0 for most wood and higher values for bark.

d - Expressed as methane

e - Emitted as formaldehyde

f - Based on trench incinerator emission

SOLID WASTE DISPOSAL

As defined in the Solid Waste Disposal Act of 1965, the term "solid waste" means garbage, refuse, and other discarded solid materials, including solid-waste materials resulting from industrial, commercial, and agricultural operations, and from community activities. It includes both combustibles and non-combustibles such as garbage, rubbish, ashes, street refuse, dead animals and abandoned automobiles.

An average of 5.5 pounds of refuse and garbage are collected per capita per day in the United States.[50] This does not include some of the uncollected waste such as industrial waste, commercial and apartment house incinerators, and backyard burning which contribute at least 4.5 pounds per capita per day. Together this gives a conservative per capita generation rate of 10 pounds per day. Approximately 50% of all the generated waste in the United States is burned by a wide variety of combustion methods including both enclosed and open burning.[1] Atmospheric emissions, both gaseous and particulate, result from refuse disposal operations which utilize combustion to reduce the quantity of refuse. Emissions from these combustion processes cover a wide range because of their dependence on the refuse burned, the method of combustion or incineration plus many other factors. Because of the large number of variables involved it was impossible in most cases to establish useable ranges in emission factors and conditions when the upper or lower limit should be used. For this reason, in most cases, only a single factor has been presented.

REFUSE INCINERATION

Process Description[13,51,52,53]

The most common types of incinerators consist of a refractory lined chamber with a grate upon which refuse is burned. Combustion products are formed by contact between underfire air and waste on the grates in the primary chamber. Additional air (overfire air) is admitted above the burning waste to promote gas phase combustion. In the multiple chamber type incinerator, gases from the primary chamber flow to a small mixing chamber where more air is admitted, and then to a larger, secondary chamber where more complete oxidation occurs. As much as 150 percent excess air may be supplied in order to promote oxidation of combustibles. Also auxillary burners are sometimes installed in the mixing chamber to increase combustion temperature. Many small size incinerators are single chamber units which vent gases from the primary combustion chamber directly into the exhaust stack.

Definitions of Incinerator Categories[13]

No exact definitions of incinerator size categories exist, but for this report the following general categories and descriptions have been selected:

1) Municipal incinerators--a multiple chamber unit with capacities greater than 50 tons per day usually equipped with automatic charging mechanisms and temperature controls. Municipal incinerators are also usually equipped with some type of particulate control device such as a spray chamber.
2) Industrial/Commercial incinerators--These units cover a wide size range, generally between 50 and 4,000 lbs per hour. They are frequently manually charged, operate intermittently, and may be either single or multiple chamber designs. Emission control systems among the better designs include gas-fired afterburners and/or scrubbers.
3) Domestic incinerators--This category includes incinerators marketed for residential use. They are fairly simple in design (with single or multiple chamber) and usually are equipped with an auxillary burner to air combustion.
4) Flue-fed incinerators--These units, commonly found in large apartment houses, are characterized by the charging method which consists of dropping refuse down the incinerator flue and into the combustion chamber. Modified flue-fed incinerators utilize afterburners and draft controls to improve combustion efficiency and reduce emissions.
5) Pathological incinerators--These are incinerators used to dispose of animal remains and other high moisture content organic material. Generally, these units are in a size range of 50-100 pounds per hour. They are equipped with combustion controls and afterburners to insure good combustion and minimum emissions.
6) Control Air incinerators--These units operate on the controlled combustion principle where a small percentage of theoretical air required to burn the waste is supplied to the main chamber. These units are usually equipped with automatic charging mechanisms and are characterized by the high exit temperatures reached.

Emissions and Controls[13]

Operating conditions, refuse composition, and basic incinerator design have a great effect on emissions. The manner in which air is supplied to the combustion chamber or chambers has the greastest effect on the quantity of particulate emissions. Air may be introduced from beneath the chamber, from the side or from the top of the combustion area. As underfire air is increased, and increase in fly ash emissions have been noted. The way in which refuse is charged has a great effect on the particulate emissions. Improper charging causes a disruption of the combustion bed with the subsequent release of large quantities of particulates. Emissions of oxides of sulfur are dependent on the sulfur content of the refuse. Nitrogen oxide emissions depend on the temperature of the combustion gases, residence time in the combustion zone, and the excess air rate. Carbon monoxide and hydrocarbon emissions also depend on the quantity of air supplied to the combustion chamber and efficiency of combustion.

Table 9 lists the relative collection efficiencies of particulate control equipment used for municipal incinerators. This control equipment has little effect on gaseous emissions. Table 10 summarizes the uncontrolled emissions factors for the various types of incinerators previously discussed.

TABLE 9 COLLECTION EFFICIENCIES FOR VARIOUS TYPES OF MUNICIPAL INCINERATION PARTICULATE CONTROL SYSTEMS[a]

Type System	Efficiency %
Settling Chamber	0-30
Settling Chamber and Water Spray	30-60
Wetted Baffles	60
Mechanical Collector	30-80
Scrubber	80-95
Electrostatic Precipitator	90-96
Fabric Filter	97-99

a - References 52, 56, 63-68

TABLE 10^{A} EMISSION FACTORS FOR REFUSE INCINERATORS WITHOUT CONTROL (pounds per ton of waste as fired)[a]

Incinerator Type	Particulates	Sulfur Oxides[b]	Carbon Monoxide	Hydrocarbons[c]	Nitrogen Oxides[d]
Municipal[e]					
Multiple Chamber Uncontrolled	30(8-70)	1.5	1(0.3-4)	1.5	2
With Settling Chamber and Water Spray System[f]	14(3-35)	1.5	1(0.3-4)	1.5	2
Industrial/Commercial					
Multiple Chamber[g]	7(4-8)	1.5[j]	10(1-25)	3(0.3-20)	3
Single Chamber[h]	15(4-31)	1.5[j]	20(4-200)	15(0.5-50)	2
Controlled-Air[i]	1.4(0.7-2)	1.5	Neg.	Neg.	10
Flue Fed[k]	30(7-70)	0.5	20	15(2-40)	3
Flue Fed (Modified)[l,m]	6(1-10)	0.5	10	3(0.3-20)	10
Domestic Single Chamber					
Without Primary Burner[n]	35	0.5	300	100	1
With Primary Burner[o]	7	0.5	Neg.	2	2
Pathological[p]	8(2-10)	Neg.	Neg.	Neg.	3

a - Average factors given based on NAPCA procedures for Incinerator Stack Testing. Use high side of particulates, HC and CO emission range when operation is intermittent, and combustion conditions are poor.
b - Expressed as SO_2
c - Expressed as Methane
d - Expressed as NO_2
e - References 54-60
f - Most municipal incinerators are equipped with at least this much control, see Table 9 for appropriate efficiencies for other controls.
g - References 52,56,57,60,61
h - References 52,56,57,61
i - Reference 55
j - Based on Municipal Incinerator data
k - References 52,57,58,60,61,62
l - With afterburners and draft controls
m - References 52,58,61
n - References 56,57
o - Reference 56
p - References 52,55

AUTO BODY INCINERATION

Process Description[13]

Auto incinerators consist of a primary combustion chamber into which a partially stripped car(s) is placed. The car is then ignited, and the incinerator doors are closed. Approximately 30-40 minutes are required to burn two bodies simultaneously.[69] Up to 50 cars per day can be burned in this batch type operation depending on the size of the incinerator, that is, the number of cars that can be burned simultaneously. Continuous operations in which cars are placed on a conveyor belt and passed through a tunnel type incinerator have capacities of more than 50 cars per 8 hour day.

Emissions and Controls[13]

Both the degree of combustion as determined by the incinerator design, and the amount of combustible material left on the car greatly affect emissions. Temperatures on the order of 1200°F. are reached during auto body incineration.[69] This relatively low combustion temperature is a result of the large incinerator volume needed to contain the bodies as compared to the small quantity of combustible material. The use of overfire air jets in the primary combustion chamber will increase combustion efficiency by providing air and increased turbulence.

In an attempt to reduce the various air pollutants produced by this burning, some auto incinerators are equipped with emission control devices. Both afterburners and/or low voltage electrostatic precipitators have been used to reduce particulate emissions, with the former also reducing some of the gaseous emissions.[70,71] When afterburners are used to control emissions, the temperature in the secondary combustion chamber should be at least 1500°F. Lower temperatures will result in higher emissions. Emission factors for auto body incinerators are presented in Table 11.

TABLE 11[B] EMISSION FACTORS FOR AUTO BODY INCINERATION

(pounds per car burned)[a]

Pollutants	Uncontrolled	With Afterburner
Particulates[b]	2	1.5
Carbon Monoxide[c]	2.5	Neg.
Hydrocarbons[c] (CH_4)	0.5	Neg.
Nitrogen Oxides[d] (NO_2)	0.1	0.02
Aldehydes[d] (HCOH)	0.2	0.06
Organic Acids[d] (Acetic)	0.3	0.4

a - Based on 250 lbs of combustible material on stripped car body (one without tires)

b - References 69,71

c - Based on data for open burning and References 69,72

d - Reference 71

CONICAL BURNERS

Process Description[13]

Conical burners are generally a truncated metal cone with a screened top vent. The charge is placed on a raised grate by conveyor or bulldozer, the former method resulting in more efficient burning. No supplemental fuel is used, but limited control of combustion air is often effected by means of a blower which supplies underfire air below the grate and peripheral openings in the shell which provide overfire air.

Emissions and Controls

The quantities and types of pollutants released from conical burners are dependent on the make-up and moisture content of the charged material, control of combustion air, type of charging system used, and the condition in which the incinerator is maintained. The most critical of these factors seems to be the lack of maintenance on the incinerators. It is not uncommon for conical burners to have missing doors and a multiplicity of holes in the shell, all resulting in excessive combustion air, low temperatures, and therefore high emission rates.[73]

Particulate control systems have been adapted to conical burners with some success. These control systems include water curtains (wet caps) and water scrubbers. Emission factors from conical burners are shown in Table 12.

TABLE 12[B] UNCONTROLLED EMISSION FACTORS FOR WASTE INCINERATION IN CONICAL BURNERS
(pounds per ton of waste as fired)[a]

Type of Waste	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
Municipal Refuse[b]	20(10-60)[c,d]	2	60	20	5
Wood[h]	1[e]	0.1	130	11	1
	7[g]				
	20[g]				

a - Moisture content as-fired is approximately 50% for wood waste

b - Except for particulates, factors based on comparison with other waste disposal practices.

c - Use high side of range for intermittent operations charged with a bulldozer.

d - Based on Reference 23

e - Satisfactory operation: Properly maintained burner with adjustable underfire air supply and adjustable, tangential overfire air inlets, approximately 500% excess air and 700°F exit gas temperature.

f - Unsatisfactory operation: Properly maintained burner with radial overfire air supply near bottom of shell, approximately 1200% excess air and 400°F exit gas temperature.

g - Very unsatisfactory operation: Improperly maintained burner with radial overfire air supply near bottom of shell and many gaping holes in shell, approximately 1500% excess air and 400°F exit gas temperature.

h - References 74-79

OPEN BURNING

General Information[13]

Open burning can be carried out in open drums or baskets and in large scale open dumps or pits. Materials commonly disposed of in this manner are municipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, and bulky industrial refuse. While the open burning of waste is not desirable from an air pollution point of view, exemptions from control are often applied to right-of-way clearing, field burning of agricultural wastes, logging debris and bulky material, since it is frequently the cheapest method for disposing of such refuse.

Emissions

Ground level open burning is affected by many variables including wind, ambient temperature, moisture content of the debris burned, size and shape of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase the emissions of particulate, carbon monoxide and hydrocarbons, while suppressing the emissions of nitrogen oxides and sulfur oxides. Sulfur oxide emissions are also a direct function of the sulfur content of the refuse. Emission factors are presented in Table 13 for the open burning of three broad categories of waste: 1) municipal refuse, 2) automobile components and 3) horticultural refuse.

TABLE 13[B] EMISSION FACTORS FOR OPEN BURNING
(pounds per ton of waste as fired)

Type Waste	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
Municipal Refuse[a]	16	1	85	30	6
Automobile Components[b,d]	100	Neg.	125	30	4
Horticultural Refuse[d]					
Agricultural Field Burning	17	Neg.	100	20	2
Landscape Refuse and Pruning	17	Neg.	60	20	2
Wood	17	Neg.	50	4	2

a - Reference 72,49,81-83

b - Upholstery, belts, hoses, and tires burned in common

c - Reference 72

d - References 72,82,84,85

MOBILE COMBUSTION SOURCES

Transportation in general is a major source of carbon monoxide, hydrocarbons and nitrogen oxides. In 1968 estimated emissions from all transportation sources in the United States were 64 million tons of carbon monoxide, 17 million tons of hydrocarbons and 8 million tons of nitrogen oxides.[1] The primary mobile source of these emissions is the gasoline powered motor vehicle. Other significant sources include aircraft, diesel powered trucks and buses, locomotives and river vessels. Emission factors for these sources are presented in this section. Because of the increasing control technology applied to these sources the effects of controls have been shown whenever possible.

GASOLINE POWERED MOTOR VEHICLES

General

The gasoline powered motor vehicle category consists of three major types of vehicles: passenger cars, light-duty trucks, and gasoline-powered heavy duty vehicles. In order to develop an overall emission factor for all gasoline powered vehicles, each of these classes had to be weighted according to its "relative travel, allowing for the incorporation of new vehicles and scrappage of older vehicles in the overall vehicle population, allowing for the deterioration of vehicles with age and mileage, and allowing for differential travel as a function of vehicle age."[86] In order to take into consideration the control of motor vehicle emissions, the emission factors are presented on a year-by-year basis, based on applicable Federal standards in effect as of 1971 and including those proposed for 1973 and 1975.[87,88,89]

These emission factors are presented in Table 14 for two types of vehicle operation conditions. Urban travel was assumed to be at an average speed of 25 miles per hour, beginning from a "cold start", and all rural travel was assumed to be at an average speed of 45 miles per hour, beginning from a "hot start". Exhaust emissions of carbon monoxide and hydrocarbons vary considerably with speed. If emission factors are needed for speeds other than the assumed average speeds for urban and rural driving, Figures 1 and 2 should be used. For example, the emission factor for hydrocarbon exhaust emissions under urban driving conditions in 1975 for a speed of 10 miles per hour would be 1.79 times the exhaust hydrocarbon emissions for that year, (1.79 x 12 = 21.4).

TABLE 14[A] EMISSION FACTORS FOR GASOLINE POWERED MOTOR VEHICLES

(grams per vehicle mile)[a]

Emissions	1960	1965	1970	1971	1972	1973	1974	1975
Carbon Monoxide[b]								
Urban	120	120	95	90	85	80	75	60
Rural	70	70	60	55	50	45	40	35
Hydrocarbons[b]								
Evaporation	2.7	2.7	2.7	2.3	2.3	1.8	1.8	1.4
Crankcase[c]	4.1	2.7	0.9	0.45	0.45	0.32	0.22	0.22
Exhausts								
Urban	16	16	12	11	9.5	8.5	7.2	6
Rural	10.5	10.5	8	7	6.5	6	5	4
Nitrogen Oxides (NO_2)[b]								
Urban	8	8.5	9	9	9	8	7.5	7
Rural	9.5	10	10.5	10.5	10.5	9.5	9	8
Particulates[d,e]	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.1
Sulfur Oxides (SO_2)[f]	0.18			No legislation is in effect or has been proposed for these pollutants and thus only one factor is presented				
Adehydes (HCHO)[g]	0.36							
Organic Acids (Acetic)[h]	0.13							

a - To convert emission factors to grams per gallons, assume the average gasoline powered engines get 12.5 miles per gallon

b - Reference 86

c - Crankcase emissions for vehicles after 1962 are neglible. These factors are gased on pre-1962 vehicles left in the vehicle population.

d - Reference 94

e - Urban Factor = Rural Factor

f - Based on sulfur content of 0.04% and a density of 6.17 lb/gallon

g - References 23, 28, 95

h - References 23, 95, 96, 97

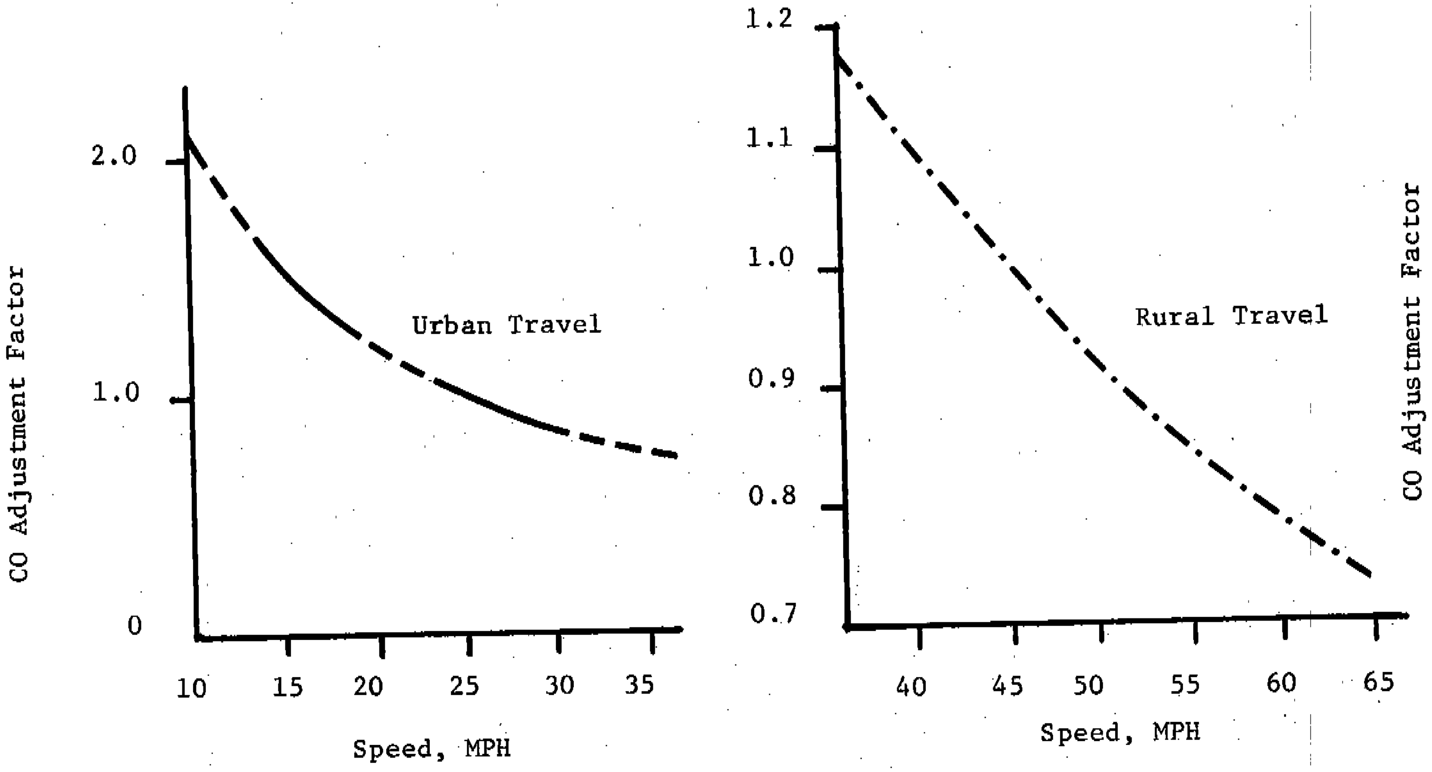

Figure 1. SPEED ADJUSTMENT FACTORS FOR CARBON MONOXIDE EMISSIONS FACTORS

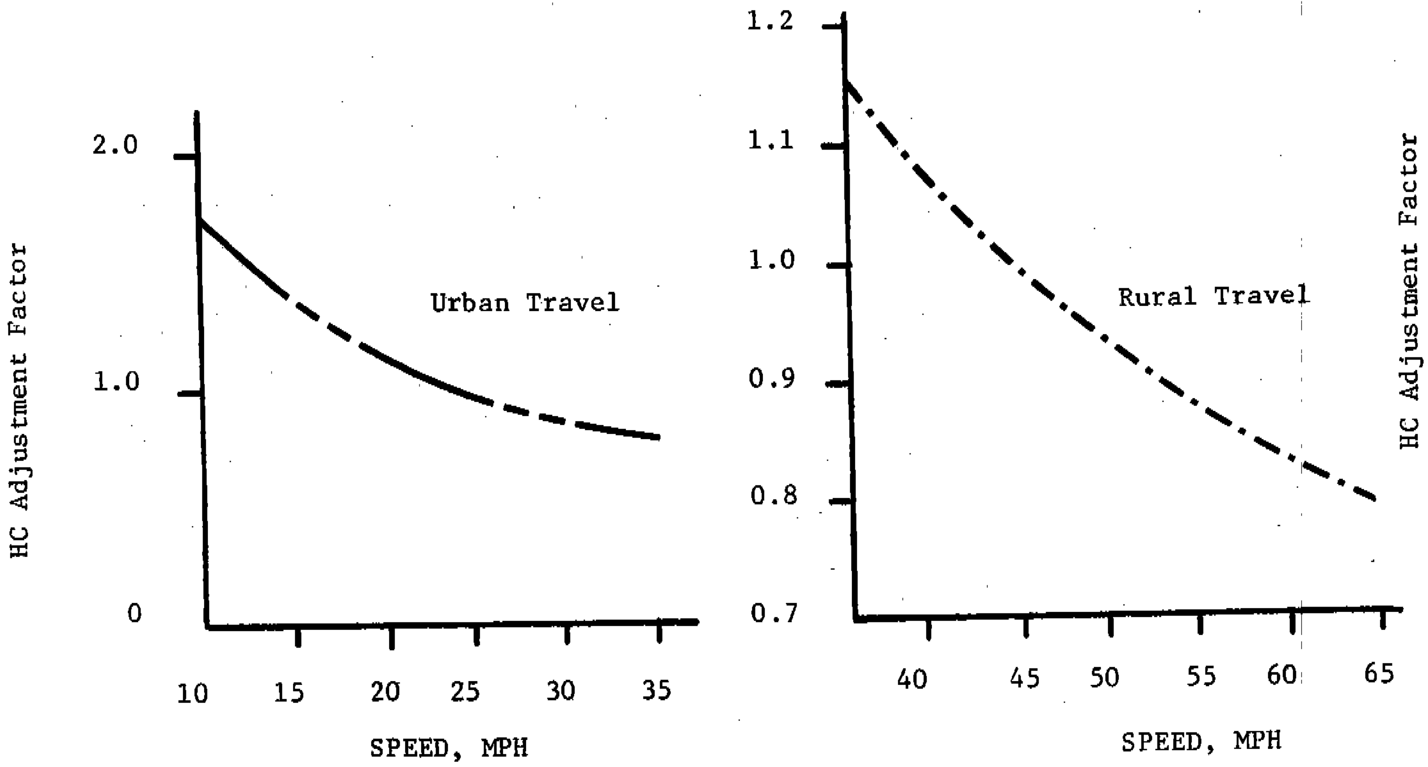

Figure 2. SPEED ADJUSTMENT FACTORS FOR HYDROCARBON EXHAUST EMISSION FACTORS

Since legislation has only been proposed for hydrocarbons, carbon monoxide, particulates and nitrogen oxides it was not necessary to present the emissions of other pollutants on a year-by-year basis. For this reason emission factors for sulfur oxides, aldehydes, and organic acids do not vary by year.

Emissions

Air pollutant emissions from motor vehicles come from three principal sources: exhaust, crankcase blowby, and evaporation from the fuel tank and carburetor. It has been estimated that about 55 percent of the hydrocarbons come from the engine exhaust, 25 percent from the blowby and 20 percent from evaporation from the fuel tank and carburetor for an uncontrolled vehicle, whereas essentially all of the carbon monoxide and nitrogen oxides come from the engine exhaust.[90] As a rough approximation the amount of particulates emitted in the blowby is about one-third to one-half the amount emitted in the exhaust

Evaporative Emissions:[92]

Emissions from the fuel tank result primarily from the evaporation of gasoline in the vehicle tank. These emissions occur under both operating and stationary conditions and are due to temperature changes in the tank fuel and in the vapor volume, which induce breathing through the tank vent.

Carburetor emissions result under two separate conditions. Running losses occur during vehicle operation as a result of internal carburetor pressures that vent hydrocarbon vapors through the external carburetor vents. Hot-soak losses result from evaporation of the fuel in the carburetor float bowl when the vehicle is stationary.

Crankcase Emissions:[92]

The second largest source of hydrocarbon emissions, if uncontrolled is in the gases vented from the engine crankcase through the road draft tube and oil filter tube. These emissions consist predominantly of engine blowby gases with some crankcase ventillation air and a very limited amount of crankcase lubricant fume.

Exhaust Emissions:[90,92]

In contrast to the evaporative and crankcase emissions, which are composed predominantly of hydrocarbons, engine exhaust gases additionally contain carbon monoxide, nitrogen oxides and other combustion products.

The primary factor influencing the formation of carbon monoxide and hydrocarbons is the air fuel ration supplied to the engine. The concentrations of these pollutants increase as the air fuel ratio decreases. Nitrogen oxide formation is influenced by combustion temperature and the amount of oxygen available for reaction with nitrogen. Another major factor in the rate of release of these pollutants is vehicle speed. Hydrocarbon and carbon monoxide emissions decrease with an increase in vehicle speed, whereas nitrogen oxides are independent of average vehicle speed.

Particulates, consisting primarily of lead compounds, carbon particles, and motor oil are also emitted from the engine exhaust. Because of the complex relationships involved, the effects of engine design and other factors on particulate emissions is not well known. Sulfur oxide emissions from engine exhaust are a function of the sulfur content of the gasoline. Due to the low average sulfur content of gasoline (0.035%S) this is not normally a major concern.

DIESEL POWERED MOTOR VEHICLES

General[98,99]

Diesel engines have been divided into three primary user categories--heavy duty trucks, buses and locomotives. The operating characteristics of a diesel engine are significantly different than from the previously discussed gasoline engine.

In a diesel engine fuel and air are not mixed before they enter the cylinder. The air is drawn through an intake valve and then compressed. The fuel is then injected as a spray into this high temperature air and ignites without the aid of a spark. Power output of the diesel engines is controlled by the amount of fuel injected for each cycle.

Emissions

Diesel trucks and buses emit pollutants from the same sources as for gasoline systems-blowby, evaporation and exhaust. Blowby is practically eliminated in the diesel since only air is in the cylinder during the compression stroke. The low volatility of diesel fuel along with the use of closed injection systems essentially eliminates evaporation losses in diesel systems.

Exhaust emissions from diesel engines have the same general characteristics of auto exhausts. Concentrations of some of the pollutants, however, may vary considerably. Emissions of sulfur dioxide are a direct function of the fuel composition. Thus, because of the higher average sulfur content of diesel fuel (0.35% S) as compared to gasoline (0.035% S). sulfur dioxide emissions are relatively higher from diesel exhausts.[100,101]

Because diesel engines have more complete combustion and use less volatile fuels than spark ignited engines, their HC and CO emissions are relatively low. Since hydrocarbons in diesel exhaust are largely just unburned diesel fuel their emissions are related to the volume of fuel sprayed into the combustion chamber. New improved needle vavle injectors have been developed which reduce the amount of fuel which can be burned. These valves can reduce hydrocarbon emissions by as much as 50 percent.[102] Both high temperatures and large excesses of oxygen involved in diesel combustion are conducive to the high nitrogen oxide emissions.[103]

Particulates from diesel exhaust are in two major forms-black smoke and white smoke. White smoke is emitted when the fuel droplets are kept cool in an environment abundant in oxygen, (cold starts). Black smoke, however, is emitted when the fuel droplets are subjected to high temperatures in an environment lacking in oxygen, (road conditions).[103]

Emission factors for the three classes of diesel engines: trucks, buses, and locomotives are presented in Table 15.

TABLE 15[c] EMISSION FACTORS FOR DIESEL ENGINES

(pounds per 1,000 gallons of diesel fuel)[a]

Pollutant	Heavy Duty Trucks and Buses[b] Engines Prior to 1970	 After 1970	Locomotives[c]
Particulates[e]	25	10	25
Oxides of Sulfur(SO_2)[d]	45	45	65
Carbon Monoxide	325	215	70
Hydrocarbons	65	25	50
Oxides of Nitrogen(NO_2)	340	505	75
Aldehydes(HCHO)	5	3	4
Organic Acids	7	3	7

a - All data presented in this table were based on weighting factors applied to actual tests conducted at various load and idle conditions.

b - Reference 104

c - Based on analysis of data from reference 105

d - Trucks and buses based on average sulfur content of 0.35% and locomotives based on average sulfur content of 0.5%.

e - Total particulates, not just smoke. From reference 104 it has been estimated that there is approximately a 50 percent reduction in particulate emissions after 1970.

AIRCRAFT

General[106]

Aircraft engines fall into two major categories-reciprocating or piston engines and gas turbines. There are four basic types of gas turbine engines used for aircraft propulsion: turbofan, turboprop, turbojet and turboshaft. The gas turbine consists of a compressor, a combustion chamber, and a turbine. Air entering the forward end of the engine is compressed and then heated. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine which, in turn, drives the compressor.

The basic element in piston engine aircraft is the combustion chamber, or cycliner, in which fuel and air mixtures are burned and from which energy is extracted through a piston and crank mechanism that drives a propeller. Nearly all aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangements--either "opposed" or "radial." Opposed engines are installed in most light or utility aircraft. Radial engines are used mainly in large transport aircraft.

A representative list of various models of aircraft showing the types of aircraft is shown in Table 16.[106,107,108] It should be noted that both turbofan aircraft and piston engine aircraft have been further subdivided into classes depending on the size of the aircraft. Long-range jets normally have approximately 18,000 lb maximum thrust whereas medium-range jets have about 14,000 lb maximum thrust. For piston engines this division is more pronounced. The large transport pistons are in the 500-3,000 hp range, whereas the smaller light pistons have less than 500 hp.

Emissions

Emissions from the various types of aircraft are presented in Table 17. Emission factors are presented on the basis of pounds per landing-take-off (LTO) cycle per engine. An LTO cycle includes all normal operational modes performed by an aircraft between the time it descends through an altitude of 3,500 feet above the runway on its approach to the time it subsequently reaches the 3,500 foot altitude after take-off. It should be made clear that the term operation used by the FAA to describe either a landing or a take-off is not the same as the LTO cycle. Two operations are involved in one LTO cycle. The LTO cycle incorporates the ground operations of idle, taxi, landing run, and take-off run and the flight operations of take-off and climb-out to 3,500 feet and approach from 3,500 feet to touch down.

The rates of emission of air pollutants by aircraft engines, as with other internal combustion engines, are related to the fuel consumption rate. The average amount of fuel used for each phase of an LTO cycle is shown in Table 18. This data can be used in conjunction with the emission factors presented in Table 17 to determine an emission factor in pounds per gallon per engine.

TABLE 16 AIRCRAFT CLASSIFICATION SYSTEM

Aircraft Type	Examples of Models	Engines Most Commonly Used
Turbofan		
Jumbo-jet	Boeing 747, Douglas DC-10 Lockheed L-1011	Pratt & Whitney JT-9D
Long-Range	Boeing 707, Douglas DC-8	Pratt & Whitney JT-3D
Medium-Range	Boeing 727, Douglas DC-9	Pratt & Whitney JT-8D
Turbojet	Boeing 707, 720 Douglas DC-8	Pratt & Whitney JT-3C Pratt & Whitney JT-4A General Electric CJ 805-3B
Turboprop	Convair 580, Electra L-188 Fairchild Hiller FH-227	General Motors-Allison 501-D13
Turboshaft	Sikorsky S-61, Vertol 107	General Electric CT58
Piston		
Transport	Douglas DC-6, Lockheed L-1049	Pratt & Whitney R-2800
Light	Cessna 210, Piper 32-300	Continental 10-520-A

TABLE 17 EMISSION FACTORS FOR AIRCRAFT

(lbs per engine per LTO cycle)

Type Aircraft	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides	Aldehydes[a]
Turbofan						
Jumbo-Jet[b,c]	10	2	28	3	6	0.5
Long-Range[d,e]	8	2	26	17	5	0.5
Medium-Range[d,f]	7	2	16	(0.6-86)[g]	7	0.5
Turbojet[d,h]	11	2	24	26	5	1.0
Turboprop[i,j]	6	1	2	3	5	0.2
Turboshaft[k,l]	3	1	6	0.5	0.6	0.2
Piston						
Transport[k,m]	5	2	303	40	0.4	0.2
Light[n]	0.2	2	12	0.4	0.2	0.1

a - Estimates based on old data in reference 111.

b - Reference 112

c - Based on Pratt and Whitney JT-9D engine

d - References 109,112

e - Based on Pratt and Whitney JT-3D engine

f - Based on Pratt and Whitney JT-8D engine

g - Use 50 for uncontrolled jets and 3 for jets equipped with smoke burner cans.

h - Based on General Electric CJ805-3B, Pratt and Whitney JT-3C-6 and Pratt and Whitney JT-4A engines.

i - Reference 109

j - Based on General Motors-Allsion 501-D13 engine

k - Reference 106

l - Based on General Electric CT 58 engine

m - Typical engine used is the Pratt & Whitney R-2800

n - References 106,110

TABLE 18 FUEL CONSUMPTION RATES FOR VARIOUS TYPES OF AIRCRAFT DURING AN LTO CYCLE

Type Aircraft	Taxi and Idle	Landing and Approach	Take off and Climb out	Total LTO Cycle
Turbofan				
Jumbo-Jet[c]	75	100	150	325
Long-Range[a]	35	30	115	180
Medium-Range[a]	35	40	95	170
Turbojet[a]	50	50	120	220
Turboprop[a]	30	15	25	70
Turboshaft[b]	5	0	20	25
Piston				
Transport[b]	10	5	30	45
Light[b]	1	0.2	1	2.2

a - Reference 109

b - Reference 106

c - Reference 112

VESSELS

General[113]

Fuel oil is the primary fuel used in vessels. It powers steamships, motorships and gas turbine powered ships. Gas turbines presently are not in widespread use and are thus not included in this section. However, within the next few years they will become increasingly common.[114,115]

Steamships may be considered as any ship with an external combustion engine driven by steam turbines. Motor ships, on the otherhand, have internal combustion engines operated on the diesel cycle.

Emissions

The air pollutant emissions resulting from vessel operations may be divided into two groups--emissions which occur as the ship is underway and emissions which occur when the ship is dockside or in-berth.

UNDERWAY:

Underway emissions may vary considerably for vessels which are maneuvering or docking because of the varying fuel consumption. Under these conditions a vessel will experience a wide range of power demands for a period of 15 minutes to one hour. The high demand mby be 15 times the low demand. However, once the vessel has reached and sustained a normal operation speed, the fuel consumed is reasonably constant. Table 19 shows that 29-65 gallons of fuel oil are consumed per nautical mile for steamships and 7-30 gallons of oil per nautical mile for motorships.

INBERTH:

Unless a ship goes immediately into drydock or otherwise out of operation after arrival in port, she continues her emissions at dockside. Power needs to be generated for the ship's utilities such as light, heat, pumps, refrigeration, ventilation, etc. A few steamships use auxiliary engines to supply power, but generally operate one or two main boilers under reduced draft and lowered fuel rates, which result in a much less efficient process. Motorships generally use diesel-powered generators to furnish auxiliary power.

As shown in Table 19, 840-3,800 gallons of fuel oil are consumed per day in dockside by steamships whereas 240-1,300 gallons of oil are used by motorships per day in dockside. Based on the data presented in Table 19 and the emission factors for residual fuel oil combustion and diesel oil combustion emission factors have been determined for vessels and are presented in Table 20.

TABLE 19 FUEL CONSUMPTION RATES FOR STEAMSHIPS AND MOTORSHIPS[a]

Fuel Consumption	Steamships		Motorships	
	Range	Average	Range	Average
Underway				
lb/hp-hr	0.51-0.65	0.57	0.28-0.44	0.34
gal/nautical mile	29-65	44	7-30	14
In-Berth				
gal/day	840-3,800	1,900	240-1,260	660

a = Reference 113

TABLE 20[D] EMISSION FACTORS FOR VESSELS

Pollutant	Steamships[a] lb/vessel-mile	Steamships[a] lb/day	Motorships[b] lb/vessel-mile	Motorships[b] lb/day
Particulate	0.4	15	1.5	66
Sulfur Dioxide	7S	300S	(SO_x) 2S	43
Sulfur Trioxide	0.1S	4S		
Carbon Monoxide	0.002	0.08	0.9	46
Hydrocarbons	0.2	9	0.7	33
Nitrogen Oxides (NO_2)	4.6	200	1	50
Aldehydes (HCHO)	0.04	2	0.05	2

a = Based on data in Table 6 and emission factors for Fuel Oil.

b = Based on data in Table 6 and emission factors for Diesel Fuel.

c-S = weight % sulfur in fuel

EVAPORATION LOSS SOURCES

Evaporation losses include the organic solvents emitted from dry cleaning plants and surface coating operations as well as the volatile matter in petroleum products. This section presents the hydrocarbon emissions from these sources including petroleum storage and gasoline marketing. Where possible the effect of controls to reduce the emissions of organic compounds has been shown.

DRY CLEANING

General[13]

Clothing and other textiles may be cleaned by treating them with organic solvents. This treatment process involves agitating the clothing in a solvent bath, rinsing with clean solvent, and drying with warm air.

There are basically two types of dry cleaning installations: those using petroleum solvents (Stoddard and 140°F) and those using chlorinated synthetic solvents (perchloroethylene). The trend in dry cleaning operations today is toward smaller package operations located in shopping centers and suburban business districts which handle approximately 1500 pounds of clothes per week on the average. These plants almost exclusively use perchlorethylene, whereas the larger older dry cleaning plants use petroleum solvents. It has been estimated that perchloroethylene is used on 50 percent of the weight of clothes dry cleaned in the United States today and that 70 percent of the dry cleaning plants use perchlorethylene.[116]

Emissions and Controls[13]

The major source of hydrocarbon emissions in dry cleaning is the tumbler through which hot air is circulated to dry the clothes. Drying leads to vaporization of the solvent and emissions to the atmosphere unless control equipment is used. The primary control element in use in synthetic solvent plants is a water cooled condenser which is an integral part of the closed cycle in a tumbler or drying system. Up to 95 percent of the solvent that is evaporated from the clothing is recovered here. About half of the remaining solvent is then recovered in an activated-carbon adsorber giving an overall control efficiency of of 97-98 percent. There are no commercially available control units for solvent recovery in petroleum based plants because it is not economical to recover the vapors. Emission factors for dry cleaning operations are shown in Table 21.

It has been estimated that about 18 lb/capita/year of clothes are cleaned in moderate climates[117] and abut 25 lb/capita/year in colder areas.[118] Based on this information and the fact that 50 percent of all plants use petroleum solvents,[116] and 25 percent of the synthetic solvent plants are controlled[119] emission factors can be determined on a pounds per capita basis. Thus approximately 2 lbs/capita/year are emitted from dry cleaning plants in moderate climates and 2.7 lbs/capita/year in colder areas.

TABLE 21[C] HYDROCARBON EMISSIONS FROM DRY CLEANING OPERATIONS
(pounds per ton of clothes cleaned)

Control	Petroleum Solvents	Synthetic Solvents
Uncontrolled[a]	305	210
Average Control[b]	--	95
Good Control[c]	--	35

a - References 116,118,120,121

b - Reference 120

c - Reference 122

SURFACE COATING

Process Description[123,124]

Surface coating operations primarily involve the application of paint, varnish, lacquer, or paint primer for decorative or protective purposes. This is accomplished by brushing, rolling, spraying, flaw coating and dipping. Some of the industries involved in surface coating operations are automobile assemblies, aircraft companies, container manufacturers, furniture manufacturers, appliance manufacturers, job enamelers, automobile repainters, and plastic products manufacturers.

Emissions and Controls[13]

Emissions of hydrocarbons occur in surface coating operations due to the evaporation of the paint vehicles, thinners, and solvents used to facilitate the application of the coatings. The major factor affecting these emissions is the amount of volatile matter contained in the coating. The volatile portion of most common surface coatings averages approximately 50 percent, and most if not all of this is emitted upon applying and drying the coating. The compounds released include aliphatic and aromatic hydrocarbons, alcohols, ketones, esters, alkyl and aryl hydrocarbon solvents and mineral spirits. Table 22 presents emission factors for surface coating operations.

Control of the gaseous emissions can be accomplished by the use of adsorbers (activated carbon) or by afterburners. The collection efficiency of activated carbon has been reported at 90 percent or greater. Watercurtains or filter pads have little or no effect on escaping solvent vapors. These are widely used, however, to stop paint particulate emissions.

TABLE 22[B] HYDROCARBON EMISSIONS FROM SURFACE COATING APPLICATIONS

Type Coating	Emissions Lbs/Ton[b]
Paint	1,120
Varnish and Shellac	1,000
Lacquer	1,540
Enamel	840
Primer (Zinc Chromate)	1,320

a - Reference 123

b - Reported as undefined hydrocarbons, usually organic solvents both aryl and alkyl. Paints weigh 10-15 pounds per gallon, varnishes weigh about 7 pounds per gallon.

PETROLEUM STORAGE

General[125,126]

In the storage and handling of crude oil and its products evaporation losses may occur. These losses may be divided into two categories, breathing loss and working loss. Breathing losses are associated with the thermal expansion and contraction of the vapor space resulting from the daily temperature cycle. Working losses are associated with a change in liquid level in the tank (filling or emptying).

Emissions

There are two major classifications of tanks used to store petroleum products--fixed roof tanks and floating roof tanks. The evaporation losses from both of these types of tanks depend on a number of factors, such as type of product stored (gasoline or crude oil), vapor pressure of the stored product, average temperature of the stored product, tank diameter and construction, color of tank paint and average wind velocity of the area. In order to estimate emissions from a given tank references 125 and 127 should be used. However, by making a few assumptions an average factor can be obtained. These average factors for both breathing losses and working losses for fixed roof and floating roof tanks are presented in Table 23.

TABLE 23[c] HYDROCARBON EMISSION FACTORS FOR EVAPORATION LOSSES FROM THE STORAGE OF PETROLEUM PRODUCTS

		Type Material Stored	
Type Tank[f]		Gasoline or Finished Petroleum Product	Crude Oil
Fixed Roof			
Breathing Loss[a]	lbs/day/1000 gal. storage capacity	0.4	0.3
Working Loss[a,b]	lbs/1000 gal. throughput	11	8
Floating Roof			
Breathing Loss[c]	lbs/day/tank	140(40-210)[d]	100(30-160)[e]
Working Loss[c]	lbs/1000 gal. throughput	Neg.	Neg.

a - Reference 125

b - An average turnover rate for petroleum storage is approximately 6.[128] Thus, the throughput is equal to 6 times the capacity.

c - Reference 127

d - 140 based on average conditions and tank diameter of 100 feet; use 40 for smaller tanks, 50 ft. diameter; use 210 for larger tanks, 150 ft. diameter.

e - Use 30 for smaller tanks, 50 ft. diameter; use 160 for larger tanks, 150 ft. diameter.

f - For tanks equipped with vapor recovery systems emissions are negligible.[128]

GASOLINE MARKETING

General

In the marketing of gasoline from the original storage and distribution to the final use in motor vehicles there are five major points of emission:

1. Breathing and working losses from storage tanks at refineries and bulk terminals.
2. Filling losses from loading tank conveyances at refineries and bulk terminals(included under working losses from storage tanks).
3. Filling losses from loading underground storage tanks at service stations.
4. Spillage and filling losses in filling automobile gas tanks at service stations.
5. Evaporative losses from the carburetor and gas tank of motor vehicles.

In this section only categories 3 and 4 will be discussed. Sections 1 and 2 have been covered in the section on petroleum storage and Section 5 is covered under the section on gasoline powered motor vehicles.

Emissions and Controls

The emissions associated with gasoline marketing are primarily vapors expelled from a tank by displacement as a result of filling. The vapor losses are a function of the method of filling the tank (either splash or submerged fill). Splash and submerged fill have been defined as follows: "In splash fill the gasoline enters the top of the fill pipe and then has a free fall to the liquid surface in the tank. The free falling tends to break up the liquid stream into droplets. As these droplets strike the liquid surface, they carry entrained air into the liquid, and a 'boiling' action results as this air escapes up through the liquid surface. The net effect of these actions is the creation of additional vapors in the tank. In submerged filling, the gasoline flows to the bottom of the tank through the fill pipes and enters below the surface of the liquid. This method of filling creates very little disturbances in the liquid bath and, consequently, less vapor formation than splash filling."[129]

Emission factors for gasoline marketing are shown in Table 24. As is shown in footnote "b", if a vapor return system in which the underground tank vent line is left open is used, losses from filling service station tanks can be greatly reduced. If a displacement type, closed vapor return system is employed, the losses can be almost completely eliminated.

TABLE 24[B] EVAPORATION LOSSES FROM GASOLINE MARKETING
(pounds per 1,000 gallons of throughput)

Point of Emission	Emissions
Filling Service Station Tanks[a,b]	
Splash Fill	12
Submerged Fill	7
50% Splash Fill and 50% Submerged Fill	9
Filling Automobile Tanks[c]	12

a - Reference 129

b - With a vapor return - open system emissions can be reduced to approximately 0.8 lbs/1,000 gallon and with a vapor return - closed system emissions are negligible.

c - References 130, 131

CHEMICAL MANUFACTURING INDUSTRIES

This section deals with the emissions from the manufacture and/or use of chemicals or chemical products. Potential emissions from many of these processes are high, but due to the nature of the compounds, they are usually recovered as an economic necessity. In still other cases, the manufacturing operation is run as a closed system allowing little or no escape to the atmosphere.

In general, the emissions which reach the atmosphere from chemical processes are primarily gaseous and are controlled by incineration, adsorption, or absorption. In some cases particulate emissions may also be a problem. The particulates emitted are generally extremely small and require very efficient treatment for removal. Emission data from chemical processes is sparse. It was therefore necessary to frequently estimate emission factors based on material, balances, yields or similar processes.

ADIPIC ACID

Process Description[132]

Adipic acid, $COOH\cdot(CH_2)_4\cdot COOH$, is a dibasic acid used in the manufacture of synthetic fibers. The acid is made in a continous two step process. In the first step cyclohexane is oxidized by air over a catalyst to a mixture of cyclohexanol and cyclohexanone. In the second step, adipic acid is made by the catalytic oxidation of the cyclohexanol-cyclohexanone mixture using 45 to 55% nitric acid. The final product is then purified by crystallization.[133]

Emissions[132]

The only significant emissions from the manufacture of adipic acid are nitrogen oxides. In oxidizing the cyclohexanol/cyclohexanone, nitric acid is reduced to unrecoverable N_2O and potentially recoverable NO and NO_2. This potential NO and NO_2 can be emitted into the atmosphere. Table 25 shows typical emissions of NO and NO_2 from an adipic acid plant.

TABLE 25[D] UNCONTROLLED EMISSION FACTORS FOR AN ADIPIC ACID PLANT
(pounds per ton of product)[a]

Source	Nitrogen Oxides (NO, NO_2) Emissions
Oxidation of Cyclohexanol/Cyclohexanone	12

a - Reference 132

AMMONIA

Process Description[13]

The manufacture of ammonia (NH_3) is accomplished primarily by the catalytic reaction of hydrogen and nitrogen at high temperatures and pressures. In a typical plant a hydrocarbon feed stream (usually natural gas) is desulfurized, mixed with steam, and catalytically reformed to carbon monoxide and hydrogen. The gases then enter a two-stage shift converter which reacts the carbon monoxide with water vapor to form carbon dioxide and hydrogen. The gas stream is then scrubbed to yield a gas containing less than 1% CO_2. A methanator may then be used to convert quantities of unreacted CO to inert CH_4 before the gases, now largely nitrogen and hydrogen in a ratio of 1:3 are compressed and passed to the converter. Alternatively, the gases leaving the CO_2 scrubber may pass through a CO scrubber and then passed to the converter. The synthesis gases then react in the converter to form ammonia.

Emissions and Controls[13]

When a carbon monoxide scrubber is used before sending the gas to the converter, the regenerator off gases contain significant amounts of carbon monoxide (73%) and ammonia (4%). This gas may be scrubbed to recover ammonia, and then burned to utilize the CO fuel value.[134]

The converted ammonia gases are partially recycled, and the balance are cooled and compressed, to liquify the ammonia. The non-condensable portion of the gas stream consisting of unreacted nitrogen, hydrogen, and traces of inerts such as methane, carbon monoxide, and argon, is largely recycled to the converter. However, to prevent the accumulation of these inerts, some of the non-condensable gases must be purged from the system.

The purge or bleed-off gass stream contains about 15% ammonia.[134] Another source of ammonia is the gases from the loading and storage operations. These gases may be scrubbed with water to reduce the atmospheric emissions. In addition, emissions of CO and ammonia can occur from those plants equipped with CO scrubbing systems. Emission factors are presented in Table 26.

TABLE 26[B] UNCONTROLLED EMISSION FACTORS FROM AMMONIA MANUFACTURING (pounds per ton of product)[a]

Type Source	Carbon Monoxide	Hydro-carbons[b]	Ammonia
Plants with Methanator			
Purge Gas[c]	Neg.	90	3
Storage and Loading[c]	--	--	200
Plants with CO Absorber and Regeneration System			
Regenerator Exit[d]	200	--	7
Purge Gas[c]	Neg.	90	3
Storage and Loading[c]	--	--	200

a - References 134,135

b - Expressed as methane

c - Ammonia emissions can be reduced by 99% by passing through three stages packed tower water scrubber. Hydrocarbons are not reduced.

d - A two stage water scrubber and incineration system can reduce these emissions to a negligible amount.

CARBON BLACK

Carbon black is produced by reacting a hydrocarbon fuel such as oil and/or gas with a limited supply of air at temperatures of 2500°F - 3000°F. Part of the fuel is burned to CO_2, CO and water, thus generating heat for the combustion of fresh feed. The unburnt carbon is collected as a black fluffy particle. The three basic processes for producing this compound are the furnace process accounting for about 83% of production, the older channel process which accounts for about 6% of production, and the thermal process.

Channel Black Process[13]

In the channel black process, natural gas is burned with a limited air supply in long low buildings. The flame from this burning impinges on long steel channel sections that swing continuously over the flame. Carbon black is deposited on the channels, is scrapped off, and falls into collecting hoppers. The combustion gases containing solid carbon which is not collected on the channels, in addition to carbon monoxide and other combustion products, are then vented directly from the building. Approximately 1 to 1.5 pounds of carbon black are produced from the 32 pounds of carbon available in 1000 ft.^{3} of natural gas.[136,137,138] The balance is lost as CO, CO_2, hydrocarbons, and particulates.

Furnace Process[13]

The furnace process is sub-divided into either the gas or oil process depending on the primary fuel used to produce the carbon black. In either case, gas (gas process) or gas and oil (oil process) are injected into a reactor with a limited supply of combustion air. The combustion gases containing the hot carbon are than rapidly cooled to a temperature of about 500°F by water sprays and by radiant cooling.

The largest and most important portion of the furnace process consists of the particulate or carbon black removal equipment. While many combinations of control equipment exist, common practice is to provide an electrostatic precipitator, a cyclone, and a fabric filter system in series to collect the carbon black. Control of gaseous emissions of carbon monoxide hydrocarbons is not practiced in the United States.

Thermal Black Process[13]

In thermal black plants, natural gas is decomposed by heat in the absence of air or flame. In this cyclic operation, methane is pyrolyzed or decomposed by passing it over a heated brick checkerwork at a temperature of about 3000°F. The decomposed gas is then cooled and the carbon black removed by a series of cyclones and fabric filters. The exit gas consisting largely of hydrogen (85%), methane (5%), and nitrogen is then recycled to the process burners or used to generate steam in a boiler. Due to the recycling of the effluent gases, there are essentially no atmospheric emissions from this process, other than from product handling.

Table 27 presents the emission factors from the various carbon black processes. Nitrogen oxide emissions are not included but are believed to be low due to the lack of available oxygen in the reaction.

TABLE 27[C] EMISSION FACTORS FROM CARBON BLACK MANUFACTURING

(lb/ton of product)

Type Process	Particulate	Carbon Monoxide	Hydrogen Sulfide	Hydro-carbons[b]
Channel	2,300	33,500	--	11,500
Thermal	Neg.	Neg.	Neg.	Neg.
Furnace				
Gas	c	5,300	--	1,800
Oil	c	4,500	38S[g]	400
Gas or Oil	220[d]			
	60[e]			
	10[f]			

a - Based on data in References 136,137,139,140

b - As methane

c - Particulate emissions can not be separated by type of furnace and are listed for either gas or oil furnaces.

d - 90% overall collection efficiency, that is, no collection after cyclone.

e - 97% overall collection efficiency, that is, cyclones followed by scrubber.

f - 99.5% overall collection efficiency, that is, fabric filter system.

g - S is the weight % sulfur in feed

CHARCOAL

Process Description[13]

Charcoal is generally manufactured by means of pyrolysis, or destructive distillation of wood waste from members of the deciduous hardwood species. In this process the wood is placed in a retort where it is externally heated for about 20 hours at 500-700°F. While the retort has air intakes at the bottom, these are only used during startup and thereafter are closed. The entire distillation cycle take approximately 24 hours, the last 4 hours being an exothermic reaction. Four tons of hardwood are required to produce one ton of charcoal.

Emissions and Controls[13]

In the pyrolysis of wood, all the gases, tars, oils, acids, and water are driven off leaving virtually pure carbon. All but the gas, which contains methane, carbon monoxide, carbon dioxide, nitrogen oxides, and aldehydes, is a useful by-product if recovered. Unfortunately, economics has rendered the recovery of the distillate by-products unprofitable and they are generally permitted to be discharged to the atmosphere. If a recovery plant is utilized, the gas is passed through water cooled condensers. The condensate is then refined while the remaining cool non-condensable gas is discharged to the atmosphere. Gaseous emissions can be controlled by means of an afterburner, since the unrecovered by-products are combustible. If the afterburner operates efficiently, no organic pollutants should escape into the atmosphere. Emission factors for the manufacture of charcoal are shown in Table 28.

TABLE 28[C] EMISSIONS FACTORS FOR CHARCOAL MANUFACTURING (pounds per ton of product)[a]

	Type Operation	
Pollutant	With Chemical Recovery Plant	Without Chemical Recovery Plant
Particulate (Tar, Oil)	--	400
Carbon Monoxide	320[b]	320[b]
Hydrocarbons[c]	100[b]	100[b]
Crude Methanol	--	152
Acetic Acid	--	232
Other Gases (HCHO, N_2, NO)	60	60[b]

a - Calculated values based on data in reference 141.

b - Emissions are negligible if afterburner is used.

d - Expressed as methane

CHLOR-ALKALI INDUSTRY

Process Description[142]

Chlorine and caustic are produced concurrently by the electrolysis of brine in either the diaphragm or mercury cell. In the diaphragm cell hydrogen is liberated at the cathode and a diaphragm is used to prevent contact of the chlorine produced at the anode with either the alkali hydroxide formed or the hydrogen. In the mercury cell liquid mercury is used as the cathode and forms an amalgam with the alkali metal. The amalgam is removed from the cell and is allowed to react with water in a separate chamber called a denuder to form the alkali hydroxide and hydrogen.

Chlorine gas leaving the cells is saturated with water vapor and is cooled to condense some of the water. After water cooling the gas is further dried by direct contact with strong sulfuric acid. The dry chlorine gas is then compressed for in-plant use or is cooled further by refrigeration to liquify the chlorine.

Caustic as produced in diaphragm cell plants leaves the cell as a dilute solution along with unreacted brine. The solution is evaporated to increase the concentration to 50 to 73%, which also precipitates most of the residual salt which is then removed by filtration. In mercury cell plants high purity caustic can be produced in any desired strength and needs no concentration.

Emissions and Controls[142]

Emissions from diaphragm and mercury cell chlorine plants include chlorine gas, carbon dioxide, carbon monoxide, and hydrogen. Gaseous chlorine is present in the blow gas from liquefaction, from vents in tank cars and tank containers during loading and unloading, and from storage tanks and process transfer tanks. Other emissions include mercury vapor from mercury cathode cells, chlorine from compressor seals, header seals, and air blowing of depleted brine in mercury cell plants.

Chlorine emissions from chlor-alkali plants may be controlled by one of three general methods: (1) use of the gas in other plant processes, (2) neutralization in alkaline scrubbers and (3) recovering the chlorine from effluent gas streams. The affect of specific control practices is shown to some extent in the table on emission factors (Table 29).

TABLE 29[B] EMISSION FACTORS FROM CHLOR-ALKALI PLANTS
(pounds per 100 tons of chlorine liquefied)[a]

Type Source	Chlorine Gas
Liquifaction Blow Gases	
Diaphragm Cell - Uncontrolled	2,000 - 10,000
Mercury Cell - Uncontrolled	4,000 - 16,000
Water Absorber	25 - 1,000
Caustic or Lime Scrubber	1
Loading of Chlorine	
Tank Car Vents	450
Storage Tank Vents	1,200
Mercury Cells	1.5[b]
Air-Blowing of Mercury Cell Brine	500

a - References 111,142

b - Loss of mercury to atmosphere, not chlorine gas.

EXPLOSIVES

General

An explosive is a material which, under the influence of thermal or mechanical shock, decomposes rapidly and spontaneously with the evolution of large amounts of heat and gas.[143] Explosives fall into two major categories--high explosives and low explosives. Although there is a multitude of different types of explosives, this section will deal only with an example of each major category: TNT as the high explosive and nitrocellulose as the low explosive.

TNT Production[144]

TNT is usually prepared by a batch three stage nitration process using toluene, nitric acid and sulfuric acid as raw materials. A combination of nitric acid and fuming sulfuric acid (oleum) is used as the nitrating agent. Spent acid from the nitration vessels is fortified with make-up nitric acid before entering the next nitrator. The spent acid from the primary nitrator and the fume from all the nitrators is sent to the acid-fume recovery system. This system supplies the make-up nitric acid needed in the process. After nitration, the undesired byproducts are removed from the TNT by agitation with a solution of sodium sulfite and sodium hydrogen sulfite (Sellite process). The wash waste (commonly called red water) from this purification process is either discharged directly in a stream or is concentrated to a slurry and incinerated. The TNT is then solidified, granulated and moved to the packing house for shipment or storage.

Nitrocellulose[144]

Nitrocellulose is prepared in the United States by the "mechanical dipper" process. This batch process involves dripping the cellulose into a reactor (niter pot) containing a mixture of concentrated nitric acid and a dehydrating agent such as sulfuric acid, phosphoric acid, or magnesium nitrate. When nitration is complete the reaction mixtures are centrifuged to remove most of the spent acid. The centrifuged nitrocellulose is "drowned" in water and pumped as a water slurry to the final purification area.

Emissions

Emissions of sulfur oxides and nitrogen oxides from processes which produce some of the raw materials for explosives production, such as nitric acid and sulfuric acid, can be considerable. Since all of the raw materials are not manufactured at the explosives plant it is imperative to obtain detailed process information for each plant in order to estimate emissions. The emissions from the manufacture of nitric acid and sulfuric acid are not included in this section as they are discussed in other sections of this publication.

The major emissions from the manufacturing of explosives are nitrogen oxides. The nitration reactors for TNT production and the reactor pots and centrifuges for nitrocellulose represents the largest NOx sources. Sulfuric acid regenerators or concentrators, considered an integral part of the process, are the major source of sulfur oxide emissions. Emission factors for exploxives manufacturing are presented in Table 30.

TABLE 30[c] UNCONTROLLED EMISSION FACTORS FROM EXPLOSIVE MANUFACTURING
(pounds per ton of product)

Type Process	Particulate	Sulfur Oxides(SO_2)	Nitrogen Oxides(NO_2)
High Explosives			
TNT			
Nitration Reactors[a]	--	--	160
Nitric Acid Concentrators[b]	--	--	1
Sulfuric Acid Regenerators[c]	0.4	18	--
Red Water Incinerator[c,d]	50	13	6
Nitric Acid Manufacture	(See Section on Nitric Acid)		
Low Explosives			
Nitrocellulose[e]			
Reactor Pots	--	--	12
Sulfuric Acid Concentrators	--	65	29

a - With bubble cap absorption system 90-95% efficient.

b - References 145,146

c - Reference 146

d - Not employed in manufacture of TNT for commercial use.[147]

e - Reference 148

HYDROCHLORIC ACID

Hydrochloric acid is manufactured by a number of different chemical processes. Approximately 80% of the hydrochloric acid is produced by the by-product hydrogen chloride process. The synthesis process and the Mannheim process are of secondary importance. This section will deal only with the by-product hydrogen chloride process.

Process Description[149]

By-product hydrogen chloride is produced when chlorine is added to an organic compound such as benzene, toluene, and vinyl chloride. The hydrochloric acid is produced as a by-product of this reaction. An example of a process that generates hydrochloric acid as a by-product is the direct chlorination of benzene. In this process benzene, chlorine, hydrogen, air and some trace catalysts are the raw materials to produce chlorobenzene. The gases from the reaction of benzene and chlorine consist of hydrogen chloride, benzene, chlorobenzenes and air. These gases are first scrubbed in a packed tower with a chilled mixture of monochlorobenzene and dichlorobenzene to condense and recover any benzene or chlorobenzene. The hydrogen chloride is then absorbed in a falling film absorption plant.

Emissions

The recovery of the hydrogen chloride from the chlorination of an organic compound is the major source of hydrogen chloride emissions. The exit gas from the absorption or scrubbing system is the actual source of the hydrogen chloride emitted. Emission factors for hydrochloric acid produced as by-product hydrogen chloride are presented in Table 31.

TABLE 31[B] EMISSION FACTORS FOR THE MANUFACTURE OF HYDROCHLORIC ACID
(pounds per ton of final acid)[a]

Type Process	Hydrogen Chloride Emissions
By-Product Hydrogen Chloride	
With Final Scrubber	0.2
Without Final Scrubber	3

a - Reference 149

HYDROFLUORIC ACID

Process Description[13]

All hydrofluoric acid in the United States is currently produced by reacting acid-grade fluorspar with sulfuric acid for 30-60 minutes in externally fired rotary kilns at a temperature of 400-500°F.[150,151,152] The resulting gas is then cleaned, cooled, and absorbed in water and weak hydrofluoric acid to form a strong acid solution. Anhydrous hydrofluoric acid is formed by distilling 80% hydrofluoric acid and condensing the gaseous HF which is driven off.

Emissions and Controls[13]

Air pollutant emissions are minimized by the scrubbing and absorption systems used to purify and recover the HF. The initial scrubber utilizes concentrated sulfuric acid as a scrubbing medium and is designed to remove dust, SO_2, and SO_3, sulfuric acid mist, and water vapor present in the gas stream leaving the primary dust collector. The exit gases from the final absorber contain small amounts of HF, silican tetrafluoride (SiF_4), CO_2, and SO_2 and may be scrubbed with a caustic solution to further reduce emissions. A final water ejector, sometimes used to draw the gases through the absorption system, will reduce fluoride emissions. Dust emissions may also result from raw fluorspar grinding and drying operations. Table 32 lists the emission factors for the various operations.

TABLE 32[c] EMISSIONS FACTORS FOR HYDROFLUORIC ACID MANUFACTURING[a]

Type Operation	Fluorides (lb/ton of acid)	Particulates (lb/ton fluorspar)
Rotary Kiln		
Uncontrolled	50	--
Water Scrubber	0.2	--
Grinding and Drying of fluorspar	--	20[b]

a - References 150,153

b - Factor given for well controlled plant.

NITRIC ACID

Process Description[154]

The ammonia oxidation process (AOP) is the principal method of producing commercial nitric acid. It involves high temperature oxidation of ammonia with air over a platimun catalyst to form nitric oxide. The nitric oxide air mixture is cooled, and additional air is added to complete the oxidation to nitrogen dioxide. The nitrogen dioxide is absorbed in water to produce an aqueous solution of nitric acid. The major portion of this 55 to 65% HNO_3 is consumed at this strength. However, a fairly substantial amount of this weak acid is concentrated to 95-99% HNO_3 in nitric acid concentrations and used as the strong acid.

Emissions[154]

The main source of atmospheric emissions from the manufacture of nitric acid is the tail gas from the absorption tower, which contains unabsorbed nitrogen oxides. These oxides are largely in the form of nitric oxide and nitrogen dioxide. In addition, trace amounts of nitric acid mist are present in the gases as they leave the absorption system. Small amounts of nitrogen dioxide are also lost from the acid concentrators and storage tanks. Table 33 summarizes the emission factors for nitric acid manufacturing.

TABLE 33[B] UNCONTROLLED EMISSION FACTORS FOR NITRIC ACID PLANTS

(pounds per ton of nitric acid, 100% basis)

Type Process	Nitrogen Oxides (NO_2)[c]
Ammonia - Oxidation	
Old Plant[a,c]	57
New Plant[b]	2
Nitric Acid Concentrators	
Old Plant[a]	5
New Plant[b]	0.2

a - Reference 154

b - Reference 155

c - Catalytic combustors can reduce emissions by 36-99.8% with 80% the average control. Alkaline scrubbers can reduce emmissions by 90%.

PAINT AND VARNISH

Paint[13]

The manufacture of paint involves the dispersion of a colored oil or pigment in a vehicle, usually an oil or resin, followed by the addition of an organic solvent for visiosity adjustment. Only physical processes of weighing, mixing, grinding, tinting, thinning and packaging are involved; no chemical reactions. These processes take place in large mixing tanks at approximately room temperature.

The primary factors affecting emissions from paint manufacture are care in handling dry pigments, types of solvents used, and mixing temperature.[156,157] About 1 to 2% of the solvents are lost even under well controlled conditions. Particulate emissions amount to 0.5 to 1.0% of the pigment handled.[158]

Varnish [13]

The manufacture of varnish also involves the mixing and blending of various ingredients to produce a wide range of products. However, in this case chemical reactions are initiated by heating, to produce the desired product. Varnish cooking is accomplished in, either open or enclosed, gas-fired kettles for periods of 4 to 16 hours at a temperature of 200-650°F.

Varnish cooking emissions, largely in the form of organic compounds, depend on the cooking temperatures and times, solvent used, degree of tank enclosure, and type of air pollution controls used. The emissions from varnish cooking amount to 1-6% of the raw material.

Control techniques used to reduce hydrocarbons from the manufacture of paint and varnish include condensers and/or adsorbers on solvent handling operations, and scrubbers and afterburners on cooking operations. Emissions factors for paint and varnish are shown in Table 34.

TABLE 34[C] UNCONTROLLED EMISSION FACTORS FOR PAINT AND VARNISH MANUFACTURING[a,b]

Type Product	Particulate (lb/ton of pigment)	Hydrocarbons[c] lb/tons of product)
Paint	2	30
Varnish		
Bodying Oil	--	40
Oleoresinous	--	150
Alkyd	--	160
Acrylic	--	20

a - References 156, 158-162

b - Afterburners can reduce gaseous hydrocarbon emissions by 99% and particulates by about 90%. A water spray and oil filter system can reduce particulates by about 90% (159)

c - Expressed as undefined organic compounds whose composition depends upon the type of varnish or paint.

PHOSPHORIC ACID

Phosphoric acid is produced by two principal methods, the wet process and the thermal process. The wet process is usually employed when the acid is to be used for fertilizer production. Thermal-process acid is normally of higher purity and is used in the manufacture of high-grade chemical and food products.

WET PROCESS[163,164]

In the wet process finely-ground phosphate rock is fed into a reactor with sulfuric acid to form phosphoric acid and gypsum. There is usually little market value for the gypsum produced and it is handled as waste material in gypsum ponds. The phosphoric acid is separated from the gypsum and other insolubles by vacuum filtration. The acid is then normally concentrated to about 50-55% P_2O_5. When super-phosphoric acid is made, the acid is concentrated to between 70 and 85% P_2O_5.

Emissions of gaseous fluorides, consisting mostly of silicon tetrafluoride and hydrogen fluoride are the major problem from wet process acid. Table 35 summarizes the emission factors from both wet process acid and thermal process acid.

THERMAL PROCESS[163]

In the thermal process, phosphate rock, siliceous flux, and coke are heated in an electric furnace to produce elemental phosphorous. The gases containing the phosphorous vapors are passed through an electrical precipitator to remove entrained dust. In the "one step" version of the process, the gases are next mixed with air to form P_2O_5 before passing to a water scrubber to form phosphoric acid. In the "two step" version of the process, the phosphorous is condensed and pumped to a tower in which it is burned with air, and the P_2O_5 formed is hydrated by a water spray in the lower portion of the tower.

The principal emission from thermal-process acid is P_2O_5 acid mist from the absorber tail gas. Since all plants are equipped with some type of acid mist collection system the emission factors presented in Table 35 are based on the listed types of control.

TABLE 35[B] UNCONTROLLED EMISSION FACTORS FOR PHOSPHORIC ACID PRODUCTION

Type Process		Particulates	Fluorides
WET	lbs/ton of phosphate rock		
Reactor-Uncontrolled,		--	18
Gypsum Pond		--	1[b]
Condenser-Uncontrolled		--	20
THERMAL	lbs/ton of phosphorous burned		
Packed Tower		4.6	--
Venturi Scrubber		5.6	--
Glass-Fiber Mist Eliminator		3.0	--
Wire-Mesh Mist Eliminator		2.7	--
High-Pressure-Drop Mist Eliminator		0.2	--
Electrostatic Precipitator		1.8	--

a - References 165,166

b - pounds per acre per day; approximately 0.5 acre are required per ton of P_2O_5 produced daily.

c - Reference 167

PHTHALIC ANHYDRIDE

Process Description[168,169]

Phthalic anhydride is produced primarily by oxidizing napthalene vapors with excess air over a catalyst, usually V_2O_5. O-xylene can be used instead of napthalene, but is not used as much. Following the oxidation of the napthalene vapors, the gas stream is cooled to separate the phthalic vapor from the effluent. Phthalic anhydride crystallizes directly from this cooling without going through the liquid phase. The phthalic anhydride is then purified by a chemical soak in sulfuric acid, caustic or an alkali metal salt, followed by a heat soak. To produce 1 ton of phthalic anhydride, 2,500 pounds of napthalene and 830,000 scfm of air are required.

Emissions and Controls[168]

The excess air from the production of phthalic anhydride contains some uncondensed phthalic anhydride, maleic anhydride, quinines, and other organics. The venting of this stream to the atmosphere is the major source of organic emissions. These emissions can be controlled with catalytic combustion. Table 36 presents emission factor data from phthalic anhydride plants.

TABLE 36[E] EMISSION FACTORS FOR PHTHALIC ANHYDRIDE PLANTS
(pounds per ton of product)[a]

Overall Plant	Organics (As Hexane)
Uncontrolled	32
Following Catalytic Combustion	11

a - Reference 171

PLASTICS

Process Description[13]

The manufacture of most resins or plastics begins with the polymerization or linking of the basic compound (monomer) usually a gas or liquid, into high molecular weight non-crystalline solids. The manufacture of the basic monomer, is not considered part of the plastics industry, and is usually accomplished at a chemical or petroleum plant.

The manufacture of most plastics involves an enclosed reaction or polymerization step, a drying step, and final treating and forming step. These plastics are polymerized or otherwise reacted in completely enclosed stainles steel or glass lined vessels. Treatment of the resin after polymerization varies with the proposed use. Resins for moldings are dried and crushed or ground into molding powder. Resins, such as the alkyd resins, to be used for protective coatings are normally transferred to an agitated thinning tank, where they are thinned with some type of solvent and then stored in large steel tanks equipped with water-cooled condensers to prevent loss of solvent to the atmosphere. Still other resins are stored in latex form as they come from the kettle.

Emissions and Controls[13]

The major sources of air contamination in plastic manufacturing are the emissions of raw materials or monomer, emissions of solvents or other volatile liquids during the reaction, emissions of sublimed solids such as phthalic anhydride in alkyd production, and emissions of solvents during storage and handling of thinned resins. Emission factors for the manufacture of plastics are shown in Table 37.

Much of the control equipment used in this industry is a basic part of the system and serves to recover a reactant or product. These controls include: floating roof tanks or vapor recovery systems on volatile material, storage units, vapor recovery systems (adsorption or condensers), purge lines which vent to a flare system, and recovery systems on vacuum exhaust lines.

TABLE 37^{E} UNCONTROLLED EMISSION FACTORS FOR PLASTICS MANUFACTURING[a]
(lb/ton product)

Type Plastic	Particulate	Gases
Polyvinyl Chloride	35[b]	17[c]
Polypropylene	3	0.7[d]
General	5-10	--

a - References 172,173
b - Usually controlled with fabric filter efficiency of 98-99%
c - As vinyl chloride
d - As propylene

PRINTING INK

Process Description[13]

There are four major classes of printing ink. These vary considerably in physical appearance, composition, method of application, and drying mechanism. These four classes are letterpress and lithographic inks, commonly called oil or paste inks, and flexographic and rotogravure inks, which are referred to as solvent inks. Flexographic and rotogravure inks have many elements in common with the paste inks, but differ in that they are of very low viscosity, and they almost always dry be evaporation of highly volatile solvents.[174]

There are three general processes in the manufacture of printing inks, namely:

1. Cooking the vehicle and adding dyes
2. Grinding of a pigment in a vehicle using a roller mill
3. Replacing water in the wet pigment pulp by an ink vehicle (commonly known as the flushing process).[175]

The ink "varnish" or vehicle is generally cooked in large kettles at 200-600°F for an average of 8-12 hours in much the same way that regular varnish is made. Mixing of the pigment and vehicle is done in dough mixers or in large agitated tanks. Grinding is most often carried out in three-roller or five-roller horizontal or vertical mills.

Emissions and Controls[13,176]

Varnish or vehicle preparation by heating is by far the largest source of ink manufacturing emissions. Cooling the varnish components--resins, drying oils, petroleum oils, and solvents--products odorous emissions. At about 350°F the products begin to decompose, resulting in the emission of decomposition products from the cooking vessel. Emissions continue throughout the cooking process with the maximum rate of emissions occuring just after the maximum temperature has been reached. Emissions from the cooking phase can be reduced by more than 90% with the use of scrubbers or condensers, followed by afterburners.[176,177]

Compounds emitted from the cooking of oleoresinous (resin plus varnish) varnish include water vapor, fatty acids, glycerine, acrolein, phenols, aldehydes, ketones, terpene oils, terpenes, and carbon dioxide. Emissions of thinning solvents used in flexographic and rotogravure inks may also occur.

The quantity, composition, and rate of emissions from ink manufacturing depend upon the ingredients in the cook, the cooking temperature and time, the method of introducing additives, the degree of stirring, the extent of air or inert gas blowing. Particulate emissions resulting from the addition of pigments to the vehicle are affected by the type of pigment and its particle size. Emission factors for the manufacture of printing ink are presented in Table 38.

TABLE 38^{E} EMISSIONS FROM PRINTING INK MANUFACTURING[a]

Type Process	Gaseous Organics[b] (lb/ton product)	Particulate (lb/ton pigment)
Vehicle Cooking		
General	120	--
Oils	40	--
Oleoresinous	150	--
Alkyds	160	--
Pigment Mixing	--	2

a - Based on data from section on paint and varnish

b - Emitted as a gas, but rapidly condense as the effluent is cooled.

SOAP AND DETERGENTS

Soap[13]

The manufacture of soap entails the catalytic hydrolysis of various fatty acids with sodium or potassium hydroxide to form a glycerol-soap mixture. This mixture is separated by distillation, neutralized and blended to produce soap. The main atmospheric pollution problem in the manufacture of soap is odor, and if a spray drier is used a particulate emission problem may also occur. Vent lines, vacuum exhausts, product and raw material storage, and waste streams are all potential odor sources. Control of these odors may be achieved by scrubbing all exhaust fumes and if necessary incinerating the remaining compounds. Odors emanating from the spray drier may be controlled by scrubbing with an acid solution.

Detergents[13]

The manufacture of detergents generally begins with the sulfuration by sulfuric acid of a fatty alcohol or linear alkylate. The sulfurated compound is then neutralized with caustic solution (NaOH), and various dyes, perfumes, and other compounds, are added.[178,179] The resulting paste or slurry is then sprayed under pressure into a vertical drying tower where it is dried with a stream of hot (400-500°F) air. The dried detergent is then cooled and packaged. The main source of particulate emissions is the spray drying tower. Odors may also be emitted from the spray drying operation and from storage and mixing tanks.

Particulate emissions from spray drying operations are shown in Table 39.

TABLE 39[B] PARTICULATE EMISSIONS FROM DETERGENTS SPRAY DRYING[a]
(lb/ton of product)

Control Device	Overall Efficiency, %	Particulate Emissions
None	--	90
Cyclone[b]	85	14
Cyclone followed by:		
Spray Chamber	92	7
Packed Scrubber	95	5
Venturi Scrubber	97	3

a - Based on analysis of data in references 96, 178-181

b - Some type of primary collector such as cyclone is considered an integral part of the spray drying system.

SODIUM CARBONATE (Soda Ash)

Process Description[13]

Soda ash is manufactured by three processes: 1) natural or Lake Brine process, 2) Solvay process (ammonia-soda), and 3) electrolytic soda ash process. Since the Solvay accounts for over 80 percent of the total production of soda ash it will be the only process discussed in this section.

In the Solvay process, the basic raw materials include ammonia, coke, limestone (calcium carbonate) and salt (sodium chloride). The salt, usually in the unpurified form of a brine, is first purified in a series of absorbers by precipitation of the heavy metal ions with ammonia and carbon dioxide. In this process sodium bicarbonate is formed. This bicarbonate coke is heated in a rotary kiln and the product soda ash is cooled and conveyed to storage.

Emissions

The major source of emissions from the manufacture of soda ash is the release of ammonia. Small amounts of ammonia are emitted in the vent gases from the brine purification system. Intermittant losses of ammonia can also occur during the unloading of tank trucks into storage tanks. The major sources of dust emissions include rotary dryers, dry solids handling, and processing of lime. Dust emissions of fine soda ash also occur from conveyor transfer points, air classification systems, tank car loading and during packaging. Emission factors are summarized in Table 40.

TABLE 40[D] UNCONTROLLED EMISSION FACTORS FROM SODA ASH PLANTS
(pounds per ton of product)

Type Source	Particulates	Ammonia
Ammonia Recovery[a,b]	--	7
Conveying, Transfering,[c] Loading, etc.	6	--

a - Reference 182

b - Represents ammonia loss following the recovery system.

c - Based on data in references 183,184,185

SULFURIC ACID

Process Description[186]

All sulfuric acid is made by either the chamber or the contact process. Since the contact process accounts for over 90 percent of the total U. S. production of sulfuric acid, it will be the only process discussed in this section. Contact plants may be classified according to the raw materials used: 1) elemental sulfur-burning plants, 2) sulfide ores and smelter gas plants, and 3) spent-acid and hydrogen sulfide burning plants. A separate description of each type of plant will be given.

Elemental Sulfur-Burning Plants[186]

Frasch-process or recovered sulfur from oil refineries is melted, settled, or filtered to remove ash and is fed into a combustion chamber. The sulfur is burned in clean air that has been dried by scrubbing with 93 to 99 percent sulfuric acid. The gases from the combustion chamber are cooled and then enter the solid catalyst (vanadium pentoxide) converter. Usually 95 to 98 percent of the sulfur dioxide from the combustion chamber is converted to sulfur trioxide, with an accompanying large evolution of heat. The converter exit gas after being cooled, enters an absorption tower where the sulfur trioxide is absorbed with 98 to 99 percent sulfuric acid. The sulfur trioxide combines with the water in the acid and forms more sulfuric acid.

Sulfide Ores and Smelter Gas Plants[186]

Sulfur dioxide gas from smelters is available from such equipment as copper converters, reverberatory furnaces, roasters, and flash smelters. The sulfur dioxide is contaminated with dust, acid mist, and gaseous impurities. To remove the impurities the gases must be cooled to essentially atmospheric temperature and passed through purification equipment consisting of cyclone dust collectors, electrostatic dust and mist precipitators and scrubbing and gas-cooling towers. After the gases are cleaned and the excess water vapor removed, they are scrubbed with 66° Bé acid in a drying tower. Beginning with the drying tower these plants are essentially the same as the elemental sulfur plants.

Spent-Acid and Hydrogen Sulfide Burning Plants[186]

Two types of plants are used to process this type of sulfuric acid. In one the sulfur dioxide and other combustion products from the combustion of spent acid and/or hydrogen sulfide with undried atmospheric air are passed through gas-cooling and mist-removal equipment. Following this the air stream passes through a drying tower. A blower draws the gas from the drying tower and discharges the sulfur dioxide gas to the sulfur trioxide converter.

In a "wet-gas plant" the wet gases from the combustion chamber are charged directly to the converter with no intermediate treatment.

The gas from the converter then flows to the absorber, through which 60 to 66° Bé sulfuric acid is circulating.

Emissions[186]

The major source of emissions from contact sulfuric acid plants is waste gas from the absorber exit stack. The discharge gas to the atmosphere contains predominantly nitrogen and oxygen but also contains unreacted sulfur dioxide, unabsorbed sulfur trioxide and sulfuric acid mist and spray. When the waste gas reaches the atmosphere, sulfur trioxide is converted to acid mist. Minor quantities of sulfur dioxide and sulfur trioxide may come from storage tank vents, from tank truck and tank car vents during loading operations, from sulfuric acid concentrators, and from leaks in process equipment. Emission factors for contact plants are summarized in Table 41.

TABLE 41[B] EMISSION FACTORS FOR SULFURIC PLANTS

(pounds per ton 100% H_2SO_4 produced)[a]

% Conversion of SO_2 to SO_3	SO_2 Emissions[b]
93	97
94	84
95	70
96	55
97	40[c]
98	26
99	15
99.5	7

a - Acid mist emissions range from 0.3-7.5 pounds per ton of acid produced for plants without acid mist eliminators to 0.02-0.2 pounds per ton of acid produced for plants with acid mist eliminators.

b - Reference 186

c - Use 40 as an average factor if percent conversion of SO_2 to SO_3 is not known.

SYNTHETIC FIBERS

Process Description[13]

Synthetic fibers are classified into two major categories--semi synthetic, or "true synthetic". Semi-synthetics, such as viscose rayon and acetate fibers, result when natural polymeric materials such as cellulose are brought into a dissolved or dispersed state and then spun into fine filaments. True synthetic polymers, such as nylon, orlon and dacron result from addition and polymerization reactions to form long chain molecules.

True synthetic fibers begin with the preparation of extremely long, chainlike molecules. The polymer is spun in one of four ways:[187]

1. Melt Spinning--in which molten polymer is pumped through spinneret jets, the polymer solidifying as it strikes the cool air,
2. Dry Spinning--in which the polymer is dissolved in a suitable organic solvent, and the resulting solution forced through spinnerets,
3. Wet Spinning--in which the solution is coagulated in a chemical both as it emerges from the spinneret, and
4. Core Spinning--the newest method in which a continuous filament yarn together with short length "hard" fibers, is introduced onto a spinning frame in such a way as to form a composite yarn.

Emissions and Controls[13]

In the manufacture of viscose rayon carbon disulfide and hydrogen sulfide are the major gaseous emissions. Air pollution controls are not normally used to reduce these emissions, but adsorption in activated carbon at an efficiency of 80-95%, with subsequent recovery of the CS_2 can be accomplished.[188] Emissions of gaseous hydrocarbons may also occur, from the drying of the finished fiber. Table 42 presents emission factors for semi-synthetic and true synthetic fibers.

TABLE 42[E] EMISSION FACTORS FOR SYNTHETIC FIBERS MANUFACTURE

(pounds per ton of fiber)

Type Fiber	Hydrocarbons	Carbon Disulfide	Hydrogen Sulfide	Oil Vapor or Mist
Semi-Synthetic				
Viscose Rayon[a,b]	--	55	6	--
True Synthetic[c]				
Nylon	7	--	--	15
Dacron	--	--	--	7

a - Reference 189

b - May be reduced by 80-95% absorption in activated charcoal.[188]

c - Reference 190

SYNTHETIC RUBBER

Process Description[13]

Copolymers of butadiene and styrene commonly known as SBR account for more than 70% of all synthetic rubber produced in the U. S. In a typical SBR manufacturing process, the monomers of butadiene and styrene are mixed and additives such as soaps and mercaptans are added. The mixture is polymerized to approximately a 60% conversion point. The latex product is then mixed with various ingredients such as oil, carbon black, etc.; coagulated and precipitated from the latex emulsion. The rubber particles are then dried and baled.

Emissions and Controls[13]

Emissions from synthetic rubber manufacturing process consist of organic compounds (largely the monomers used) emitted from the reactor and blow-down tanks, and particulate matter and odors from the drying operations.

Drying operations are frequently controlled with fabric filter systems to recover any particulate emissions since this represents a product loss. Potential gaseous emissions are largely controlled by recycling the gas stream back to the process. Emission factors from synthetic rubber plants are summarized in Table 43.

TABLE 43[E] EMISSION FACTORS FROM SYNTHETIC RUBBER PLANTS-
BUTADIENE-ACRYLONITRILE AND BUTADIENE-STYRENE
(pounds per ton of product)

Compound	Emissions[a]
Alkenes	
Butadiene	40
Methyl Propene	15
Butyne	3
Pentadiene	1
Alkanes	
Dimethylheptane	1
Pentane	2
Ethanenitrile	1
Carbonyls	
Acrylonitrile	17
Acrolein	3

a - The butadiene emission is not continuous and is greatest right after a batch of partially polymerized latex enters the blowndown tank.

b - References 191,192

TEREPHTHALIC ACID

Process Description[132,193]

Terephthalic acid is an intermediate in the production of polyethylene terephthalate, which is used in polyester films and other miscellaneous products. Terephthalic acid can be produced in various ways, one of which is by the oxidation of paraxylene by nitric acid. In this process an oxygen-containing gas (usually air), paraxylene, and HNO_3 are all passed into a reactor where oxidation of the nitric acid takes place in two steps. The first step yields primarily N_2O, while the second step yields mostly NO in the offgas. The precipitated terephthalic acid from the reactor effluent is recovered by conventional crystallization, separation, and drying operations.

Emissions

The NO in the offgas from the reactor is the major air contaminant from the manufacture of terephthalic acid. The amount of nitrogen oxides emitted are roughly estimated in Table 44.

TABLE 44[D] NITROGEN OXIDES EMISSIONS FROM TEREPHTHALIC ACID PLANTS

(pounds per ton of product)[a]

Type Operation	Emissions (NO)
Reactor	13

a - Reference 132

FOOD AND AGRICULTURAL INDUSTRY

Before food and agricultural products are used by the consumer they undergo a number of processing steps, such as refining, preservation and product improvement, as well as storage and handling, packaging and shipping. This section deals with the manufacture of food and agricultural products and the intermediate steps which present an air pollution problem. Emission factors are presented for industries where data were available. The primary pollutant emitted from these processes is particulate matter.

ALFALFA DEHYDRATING

General[194,195]

An alfalfa dehydrating plant produces an animal feed from alfalfa. The dehydration and grinding of alfalfa to produce alfalfa meal is a dusty operation most commonly carried out in rural areas.

Wet, chopped alfalfa is fed into a direct-fired rotary drier. The dried alfalfa particles are conveyed to a primary cyclone, where heavy trash is removed. A second cyclone discharges material to the grinding equipment, which is usually a hammer mill. The ground material is collected in an air-meal separator and either conveyed directly to bagging or storage, or blended with other ingredients.

Emissions and Controls

Sources of dust emissions are the primary cyclone, grinders and air-meal separator. Overall dust loss have been reported as high as 7 percent[195] but average losses are around 3 percent by weight of the meal produced.[196] The use of a baghouse as a secondary collection system can greatly reduce emissions. Emission factors for alfalfa dehydrating are presented in Table 1.

TABLE 45^E PARTICULATE EMISSION FACTORS FOR ALFALFA DEHYDRATION[a]

Particulate Emissions	lb/Ton of Meal Produced
Uncontrolled	60
Baghouse Collector	3

a - Reference 196

COFFEE ROASTING

Process Description[198,199]

Coffee, which is imported in the form of green beans, must be cleaned, blended, roasted and packaged before being sold. In a typical coffee roasting operation, the green coffee beans are freed of dust and chaff by dropping the beans in a current of air. The cleaned beans are then sent to a batch or continuous roaster. During the roasting, moisture is driven off, the beans swell, and chemical changes take place that give the roasted beans their typical color and aroma. When the roasting has reached a certain color the beans are quenched, cooled, and stoned.

Emissions[198,199]

Dust, chaff, coffee bean oils (as mists) smoke, and odors are the principal air contaminants emitted from coffee processing. The major source of particulate emissions and practically the only source of aldehydes, nitrogen oxides and organic acids is the roasting process. In a direct-fired roaster gases are vented without recirculation through the flame. However, in the indirect-fired roaster, a portion of the roaster gases are recirculated and particulate emissions are reduced Essentially complete removal of both smoke and odors from the roasters can be obtained with a properly designed afterburner.

Particulate emissions also occur from the stoner and cooler. In the stoner contaminating materials heavier than the roasted beans are separated from the beans by an air stream. In the cooler, quenching the hot roasted beans with water causes emissions of large quantities of steam and some particulate matter.[197] Table 46 summarizes the emissions from the various operations involved in coffee processing.

TABLE 46[B] UNCONTROLLED EMISSION FACTORS FOR ROASTING PROCESSES

(pounds per ton of green beans)

		Pollutant		
Type Process	Particulates[a]	NOx[b]	Aldehydes[b]	Organic Acids[b]
Roaster				
Direct-Fired	7.6	0.1	0.2	0.9
Indirect-Fired	4.2	0.1	0.2	0.9
Stoner and Cooler[c]	1.4	--	--	--
Instant Coffee Spray Dryer	1.4[d]	--	--	--

a - Reference 197 b - Reference 198

c - If cyclone is used emissions can be reduced by 70 percent.

d - Cyclone plus wet scrubber always used and thus this represents controlled factor.

COTTON GINNING

General[200]

The primary function of a cotton gin is to take raw seed cotton and separate the seed and the lint. A large amount of trash is found in the seed cotton which must be removed. The problem of collecting and disposing of gin trash falls into two main areas. The first consists of collecting the coarse heavier trash such as burs, sticks, stems, leaves, sand, and dirt. The second problem area is that of collecting the finer dust, small leaf particles and fly lint that are discharged from the lint after the fibers are removed from the seed. From one ton of seed cotton approximately one 500 pound bale of cotton can be made.

Emissions and Controls

The major sources of particulates from cotton ginning include the unloading fan, the cleaner and the stick and bur machine. From the cleaner and stick and bur machine a large percentage of the particles settle out in the plant. Thus an attempt has been made in Table 47 to present emission factors which take this into consideration. Where cyclone collectors are used emissions have been reported to be about 90 percent less.[200]

TABLE 47[c] UNCONTROLLED EMISSIONS FROM COTTON GINNING OPERATIONS[a]

Process	Estimated Total Particulates	Atmospheric Emission Settled Out $>100\ \mu$	(lbs/bale cotton)[b] Estimated Emission Factor
Unloading Fan	15	0	15
Cleaner	10	70	3
Stick and Bur Machine	6	95	0.3
TOTAL	31	--	18

a - References 200,201

b - One bale equals 500 pounds.

FEED AND GRAIN MILLS AND ELEVATORS

General[13]

Grain elevators are primarily transfer and storage units and are classified as either the smaller more numerous country elevators or the larger terminal elevators. At grain elevator locations the following operations can occur: receiving, transfer and storage, cleaning, drying, and milling or grinding. Many of the large terminal elevators also process grain at the same location. The grain processes may include wet and dry milling (cereals), flour milling, oil seed crushing and distilling. Feed manufactruing invloves the receiving, conditioning (drying, sizing, cleaning), blending and pelleting of grains and their subsequent bagging or bulk loading.

Emissions[13]

Emissions from feed and grain operations may be separated into those occurring at elevators, and those occurring at grain processing operations or feed manufacturing operations. Emission factors for these operations are presented in Table 48. Since dust collection systems are generally applied to most phases of these operations to reduce product and component losses, the selection of the final emission factor should take into consideration the overall efficiency of these control systems.

The emissions from grain elevator operations are dependent on the types of grain, the moisture content of the grain (usually 10-30%), amount of foreign material in the grain (usually 5% or less), the degree of enclosure at loading and unloading areas, the type of cleaning and conveying, and the amount and type of control used.

Factors affecting emissions from grain procesing operations include the type of processing (wet or dry), the amount of grain processed, the amount of cleaning, the degree of drying or heating, the amount of grinding, the temperature of the process, plus the degree of control applied to the particulates generated.

Factors affecting emissions from feed manufacturing operations include the type and amount of grain handled, the degree of drying, the amount of liquid blended into the feed, the type of handling (conveyor or peneumatic), and the degree of control.

TABLE 48[B] UNCONTROLLED PARTICULATE EMISSION FACTORS FROM GRAIN HANDLING AND PROCESSING

(pounds per ton of grain processed)

Type Source	Emissions
Terminal Elevators[a]	
Shipping or Receiving	1
Transferring, Conveying, etc.	2
Screening and Cleaning	5
Drying	6
Country Elevators[b]	
Shipping or Receiving	5
Transferring, Conveying, etc.	3
Screening and Cleaning	8
Drying	7
Grain Processing	
Corn Meal[d]	5
Soybean Processing[b]	7
Barley or Wheat Cleaner[e]	0.2[e]
Milo Cleaner[g]	0.4[e]
Barley Flour Milling[c]	3[e]
Feed Manufacturing	
Barley[g]	3[e]

a - References 202,203

b - Reference 203

c - References 203,204

d - References 96,205

e - At cyclone exit (only non-ehter soluble particulates)

f - Reference 205

FERMENTATION

General Process Description[13]

For the purpose of this report only the fermentation industries associated with food will be considered. This includes the production of beer, whiskey and wine.

The manufacturing process for each of these is similar. The four main brewing production states and their respective sub-stages are: (1) Brewhouse operations, which includes a) malting of the barley, b) addition of adjuncts (corn, grits and rice) to barley mash, c) conversion of starch in barley and adjuncts to maltose sugar by enzymatic processes, d) separation of wort from grain by straining, and e) hopping and boiling of the wort; (2) fermentation, which includes a) cooling of the wort, b) additional yeast cultures, c) fermentation for 7 to 10 days, d) removal of settled yeast, and e) filtration and carbonation; (3) aging, which lasts from 1 to 2 months under refrigeration and (4) packaging, which includes a) bottling-pasteurization and b) racking draft beer.

The major differences between beer production and whiskey production are the purification and distillation necessary to obtain distilled liquors and the longer period of aging. The primary difference between wine making and beer making is that grapes are used as the initial raw material rather than grains.

Emissions[13]

Emissions from fermentation processes are nearly all gases and primarily consist of carbon dioxide, hydrogen, oxygen, and water vapor, none of which presents an air pollution problem. However, emissions of particulates can occur in the handling of the grain in the manufacture of beer and whiskey. Gaseous hydrocarbons are also emitted from the drying of spent grains and yeast in beer and whiskey production and from the whiskey aging warehouses. No significant emissions have been reported for the production of wine. Emission factors for the various operations associated with beer, wine and whiskey production are shown in Table 49.

TABLE 49[E] EMISSION FACTORS FOR FERMENTATION PROCESSES

Type Product	Particulates	Hydrocarbons
Beer (lb/ton of grain processed)		
Grain Handling[a]	3	--
Drying Spent Grains, etc.[a]	5	NA
Whiskey (lbs/ton of grain processed)		
Grain Handling[a]	3	--
Drying Spent Grains, etc.[a]	5	NA
Aging (lbs/year/barrel of[b] whiskey stored)	--	10
Wine	Neg.[c]	Neg.[c]

a - Based on section of grain processing.

b - Reference 206

c - No significant emissions.

NA - No emission factor available, but emissions do occur.

FISH PROCESSING

Process Description[207]

The canning, dehydration, smoking of fish, and the manufacture of fish meal and fish oil are the important segments of fish processing. There are two types of fish canning operations--the "wet-fish" method in which the trimmed fish are cooked directly in the can and the "pre-cooked" process in which the whole fish is cooked and then hand-sorted before canning.

A large fraction of the fish received in a cannery is processed into by-products. The most importatnt of these by-products is fish meal. In the manufacture of fish meal fish scrap from the canning lines is charged to continuous live-stream cookers. After the material leaves the cooker it is pressed to remove oil and water. The press cake is broken up, usually in a hammer mill, and dried in a direct-fired rotary drier or in a steam-tube rotary drier.

Emissions and Controls[207]

The biggest problem from fish processing is odor emissions. The principal odorous gases generated during the cooking process of fish meal manufacturing are hydrogen sulfide and trimethylamine. Some of the methods used to control odors include activated carbon adsorbers, scrubbing with some oxidizing solution and incineration. The only significant sources of dust emissions in fish processing are the driers and grinders used to handle dried fish meal. Emission factors for fish meal manufacturing are shown in Table 50.

TABLE 50[c] EMISSION FACTORS FOR FISH MEAL PROCESSING

Emission Source	Particulates	Trimethylamine $(CH_3)_3N$	Hydrogen Sulfide H_2S
Coolers[a] (lbs/ton fish meal produced)			
Fresh Fish	--	0.3	0.01
Stale Fish	--	3.5	0.2
Driers[b] (lbs/ton fish scrap)	0.1	--	--

a - Reference 208

b - Reference 207

MEAT SMOKEHOUSES

Process Description[13]

Smoking is a diffusion process in which food products are exposed to an atmosphere of hardwood smoke, causing various organic compounds to be absorbed by the food. Smoke is produced commercially in the United States by three major methods: (1) burning dampened sawdust (20-40% moisture), (2) burning dry (5-9% moisture) sawdust continuously, and (3) by friction. Burning dampened sawdust and kiln-dried sawdust are the most widely used methods. Most large, modern, production meat smokehouses are the recirculating type, in which smoke is circulated at reasonable high temperatures throughout the smokehouse.

Emissions and Controls[13]

The emissions from smokehouses are generated from the burning hardwood, rather than from the cooked product itself. Based on approximately 110 pounds of meat smoked per pound of wood burned, emission factors have been derived for meat smoking. These factors are presented in Table 51.

Emissions from meat smoking are dependent on several factors, including the type of wood, type of smoke-generator, moisture content of the wood, air supply, and amount of smoke recirculated. Both low voltage electrostatic precipitators and direct-fired afterburners may be used to reduce particulate and organic emissions. Thus controlled emission factors have also been shown in Table 51.

TABLE 51[D] EMISSION FACTORS FOR MEAT SMOKING (pounds per ton of meat)[a,b]

Pollutant	Uncontrolled	Controlled[c]
Particulates	0.3	0.1
Carbon Monoxide	0.6	Neg.[d]
Hydrocarbons (CH_4)	0.07	Neg.[d]
Aldehydes (HCHO)	0.08	0.05
Organic Acids (Acetic)	0.2	0.1

a - Based on 110 pounds of meat smoked per pound of wood burned.[209]

b - References 209,210 and section on charcoal production.

c - Controls consist of a wet collector and low voltage precipitator in series, or direct-fired afterburner.

d - With afterburner

NITRATE FERTILIZERS

General[13,211]

For this report nitrate fertilizers are defined as the product resulting from the reaction of nitric acid and ammonia to form ammonium nitrate solutions or granules. Essentially three steps are involved in producing ammonium nitrate: neutralization, evaporation of the neutralized solution, and control of the particle size and characteristics of the dry product.

Anhydrous ammonia and nitric acid (57-65% HNO_3)[212,213] are brought together in the neutralizer to produce ammonium nitrate. An evaporator or concentrator is then used to increase the ammonium nitrate concentration. The resulting solutions may be formed into granules by the use of prilling towers or by ordinary granulators. Limestone may be added in either process, to produce calcium ammonium nitrate.[214, 215]

Emissions and Controls

The main emissions from the manufacture of nitrate fertilizers occur in the neutralization and drying operations. By keeping the neutralization process on the acidic side, losses of ammonia and nitric oxides are kept at a minimum. Nitrate dust or particulate matter is produced in the granulation or prilling operation. Particulate matter would also be produced in the drying, cooling, coating, and material handling operations. Additional dust may escape from the bagging and shipping facilities.

Typical operations do not use collection devices on the prilling tower. Wet or dry cyclones, however, are used for various granulating, drying or cooling operations in order to recover valuable product. Table 52 presents emission factors for the manufacture of nitrate fertilizers.

TABLE 52[B] UNCONTROLLED EMISSION FACTORS FOR NITRATE FERTILIZER MANUFACTURING, AMMONIUM NITRATE

(pounds per ton of product)

Type Process[a]	Particulates	Nitrogen Oxides (NO_3)	Ammonia
With Prilling Tower[b]			
Neutralizer[c,d]	--	--	2
Prilling Tower	0.9	--	--
Dryers and Coolers[e]	12	--	--
With Granulator[b]			
Neutralizer[c,d]	--	--	2
Granulator[e]	0.4	0.9	0.5
Dryers and Coolers[e,f]	7	3	1.3

a - Plants will use either a prilling tower or a granulator but not both.

b - Reference 216

c - Reference 217

d - Controlled factor based on 95% recovery in recycle scrubber.

e - Use of wet cyclones can reduce emissions by 70%.

f - Use of wet screen scrubber following cyclone can reduce emissions by 95-97%.

PHOSPHATE FERTILIZERS

Nearly all phosphatic fertilizers are made from naturally occuring phosphorous-containing minerals such as phosphate rock. The phosphorous content of these minerals is not in a form that is readily available to growing plants so that the minerals must be treated to convert the phosphorous to a plant-available form. This can be done by either the process of acidulation or a thermal process. The intermediate steps of the mining of phosphate rock and the manufacture of phosphoric acid are not included in this section as they are discussed in other sections of this publication. It should be kept in mind that large integrated plants may have all of these operations taking place at one location.

In this section phosphate fertilizers have been divided into three categories: (1) normal superphosphate, (2) triple superphosphates, and (3) ammonium phosphates. Emission factors for the various processes involved are shown in Table 53.

NORMAL SUPERPHOSPHATE

General[218,219]

Normal superphosphate (also called single or ordinary superphosphate) is the product resulting from the acidulation of phosphate rock with sulphuric acid. Normal superphosphate contains from 16-22 percent phosphoric anhydride (P_2O_5). The physical steps involved in making superphosphate are (1) mixing rock and acid, (2) allowing the mix to assume a solid form (denning), and (3) storage (curing) to allow the acidulation reaction to go to completion. Following the curing period, the product can be ground and bagged for sale, the cured superphosphate can be sold directly as run of pile product or the material can be granulated for sale as granulated superphosphate.

Emissions

The gases released from the acidulation of phosphate rock contain silicon tetrafluoride, carbon dioxide, steam and sulfur oxides. The sulfur oxide emissions arise from the reaction of phosphate rock and sulfuric acid.[220]

If a granulated superphosphate is produced the vent gases from the granulator-ammoniator may contain particulates, ammonia, silicon tetrafluoride, hydrofluoric aicd, ammonium chloride and fertilizer dust. Emissions from the final drying of the granulated product will include gaseous and particulate fluorides, ammonia and fertilizer dust.

TRIPLE SUPERPHOSPHATE

General[218,219]

Triple Superphosphate (also called double or concentrated superphosphate) is the product resulting from the reaction between phosphate rock and phosphoric acid. The product general contains 44-52 percent

P_2O_5, which is about 2 1/2 times the P_2O_5 usually found in normal superphosphates.

Presently, there are three principal methods of manufacturing triple superphosphate. One of these uses a cone mixer to produce a pulverized product which is particularly suited to the manufacture of ammoniated fertilizers. The second produces a granulated product in a multi-step process, which is well suited for direct application as a phosphate fertilizer. The third method combines the features of quick drying and granulation in a single step. In the first process the product can be sold as run of pile (ROP), or it can be granulated.

Emissions

Most triple superphosphate is the nongranular type. The exit gases from a plant producing the nongranular product will contain considerable quantities of silicon tetrafluoride, some hydrogen fluoride and a small amount of particulates. Plants of this type also emit fluorides from the curing buildings.

In the cases where ROP triple superphosphate is granulated, one of the greatest problems is the emission of dust and fumes from the dryer and cooler. Emissions from ROP granualtion plants include silicon tetrafluoride, hydrogen fluoride, ammonia, particulate matter and ammonium chloride.

In direct granulation plants wet scrubbers are usually used to remove the silicon tetrafluoride and hydrogen fluoride generated from the initial contact between the phosphoric acid and the dried rock. Screening stations and bagging stations are a source of fertilizer dust emissions in this type of process.

AMMONIUM PHOSPHATES

General

The two general classes of ammonium phosphates are monoammonium phosphate and diammonium phosphate. The production of these phosphate fertilizers is starting to displace that of other phosphate fertilizers because of its higher plant food content and the lower shipping cost per pound of P_2O_5.

There are various processes and process variations in use for manufacturing ammonium phosphates. In general, phosphoric acid, sulphuric acid and anhydrous ammonia are reacted to produce the desired grade of ammonium phosphate. Potash salts are added, if desired, and the product is granulated, dried, cooled, screened and stored.

Emissions

The major pollutants from ammonium phosphate production are fluoride, particulates and ammonia. The largest source of particulate emissions are the cage mills, where oversized product from the screens is ground before being recycled to the ammoniator. Vent gases from the ammoniator tanks are the major source of ammonia. However, this gas is usually scrubbed with acid to recover the residual ammonia.

TABLE 53[c] EMISSION FACTORS FOR THE PRODUCTION OF PHOSPHATE FERTILIZERS (pounds per ton of product)

Type Product	Particulates[a]	Fluorides[b]
Normal Superphosphate[c]		
Grinding, Drying	9	--
Main Stack	--	0.15
Triple Superphosphate[c]		
Run-of-Pile (ROP)	--	0.03
Granular	--	0.10
Diammonium Phosphate[d]		
Dryer, Cooler	80	(e)
Ammoniator-Granulator	2	0.04

a - Control efficiencies of 99% can be obtained with fabric filters.

b - Total fluorides including particulate fluorides. Factors all represent outlet emissions following control devices. Control efficiencies of 95-99% can be obtained with scrubber systems.

c - References 221, 226, 227

d - References 219, 221-225

e - Included in ammoniator-granulator total.

STARCH MANUFACTURING

General Process Description[228]

The basic raw material in the manufacture of starch is dent corn which contains starch. The starch in the corn is separated from the other components by "wet milling."

The shelled grain is prepared for milling in cleaners which remove both the light chaff and any heavier foreign material. The cleaned corn is then softened by soaking (steeping) it in warm water acidified with sulfur dioxide. The softened corn goes through attrition mills, which tear the kernels apart freeing the germ and loosening the hull. The remaining mixture of starch, gluten and hulls is finely ground and the coarser fiber particles are removed by screening. The mixture of starch and gluten is separated by centrifuges. After separation from the gluten, the starch is filtered and washed. At this point it may be dried and packaged for market.

Emissions

The manufacture of starch from corn can result in significant dust emissions. The various cleaning, grinding and screening operations are the major sources of dust emissions. Table 54 presents emission factors for starch manufacturing.

TABLE 54[D] EMISSIONS FACTORS FOR STARCH MANUFACTURING[a]
(pounds per ton of starch produced\

Overall Emissions	Particulates
Uncontrolled	8
Controlled[b]	0.02

a - Reference 229

b - Based on centrifugal gas scrubber

SUGAR CANE PROCESSING

General[230]

The processing of sugar cane starts with the harvesting of the crops, either by hand or by mechanical means. If mechanical harvesting is used much of the unwanted foliage is left and it thus is standard practice to burn the cane before mechanical harvesting to remove the greater part of the foliage.

Following harvesting, the cane goes through a series of processes to be converted to the final sugar product. It is washed to remove larger amounts of dirt and trash, crushed and shredded to reduce the size of the stalks and then the juice is extracted by two methods, milling or diffusion, In milling the cane is pressed between heavy rollers to press out the juice and in diffustion the sugar is leached out by water and thin juices. The raw sugar then goes through a series of operations including clarification, evaporation and crystallization in order to produce the final product.

Most mills operate without supplement fuel because of the sufficient bagasse (the fibrous residue of the extracted cane) that can be burned as fuel.

Emissions

The largest sources of emissions from sugar cane processing are the open field burning in the harvesting of the crop and the burning of bagasse as fuel. In the various processes including crushing, evaporation and crystallization some particulates are emitted but in relatively small quantities. Emission factors for sugar can processing are shown in Table 55.

TABLE 55[D] EMISSION FACTORS FOR SUGAR CANE PROCESSING

Type Process	Particulate	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides
Field Burning[a,b] (lbs/acre burned)	225	1,500	300	30
Bagasse Burning[c] (lbs/ton bagasse)	22	--	--	--

a - Based on emission factors for open burning of agricultural waste.

b - There are approximately 4 tons/acre of unwanted foliage on the cane and 11 ton/acre of grass and weed all of which is combustible.[231]

c - Reference 231

METALLURGICAL INDUSTRIES

The metallurgical industries can be broadly divided into primary and secondary metal production operations. The primary metals refers to production of the metal from ore. The secondary metals industry includes the recovery of the metal from scrap and salvage and production of alloys from ingot.

The primary metals industries discussed in this section includes the nonferrous operations of aluminum ore reduction, copper smelters, lead smelters, and zinc smelters. These industries are characterized by the large quantities of sulfur oxides and particulates emitted. The primary metals industry also includes iron and steel mills, ferroalloys and metallurgical coke manufacture.

The secondary metallurgical industries discussed in this section are aluminum operations, brass and bronze ingots, gray iron foundries, lead smelting, magnesium smelting, steel foundries, and zinc processing. The major air contaminants from these operations are particulates in the forms of metallic fumes, smoke and dust.

PRIMARY METALS INDUSTRY

ALUMINUM ORE REDUCTION

Process Description[232-234]

Bauxite, a hydrated oxide of aluminum associated with silicon, titanium, and iron, is the base ore for aluminum production. Most bauxite ore is purified by the Bayer process in which the ore is dried, ground in ball mills, and mixed with sodium hydroxide. By settling, dilution, and filtration, iron oxide, silica, and other impurities, are removed. Aluminum hydroxide is precipitated from the diluted, cooled solution and calcined to produce pure alumina, Al_2O_3.

The recovery of the aluminum from the purified oxide is accomplished by an electrolytic process called the Hall-Heroult process. In this process alumina is dissolved in a fused mixture of fluoride salts and reduced to metallic aluminum and oxygen. This takes place in an electrolytic cell commonly known as a pot. Three types of cells are in common use: the Prebake, the Horizontal Stud Soderberg, and the Vertical Stud

Soderberg. In the Prebake, the carbon anodes are baked before mounting in the cells. In the Soderberg method, the position of the metal studs (which carry the electric current) with respect to the anode can either be horizontal or vertical. Four tons of bauxite is required to make 2 tons of alumina, which yields 1 ton of metallic aluminum. To produce 1 ton of aluminum 16,000 kwh of electricity is required.

Emissions

During the pot reduction process, the effluent released contains some fluoride particulate and gaseous hydrogen fluoride. Particulate matter such as alumina and carbon from the anodes are also emitted. The calcining of aluminum hydroxide for the production of alumina generates vast amounts of dust. However, because of the value of this dust, extensive controls are employed which reduce these emissions to an insignificant amount. Table 56 summarizes emission factors for aluminum production.

TABLE 56 UNCONTROLLED EMISSION FACTORS FOR ALUMINUM ORE REDUCTION
(pounds per ton of aluminum produced)

Type Operation	Particulates[a]	Fluorides[b]
Electrolytic Cells		
Prebake	55	80
Horizontal Stud Soderberg	140	80
Vertical Stud Soderberg	80[e]	80
Calcining Aluminum Hydroxide[c,d]	20	--

a - References 235,237

b - Reference 236

c - Reference 232

d - Represents controlled factor since all calcining units are controlled to remove the valuable dust.

e - Uncontrolled emissions from burner

METALLURGICAL COKE MANUFACTURE

Process Description[13]

Coking is the process of heating coal in atmosphere of low oxygen content, i.e. destructive distillation. During this process organic compounds in the coal break down to yield gases and a residue of relatively non-volatile nature. Two processes are used for the manufacture of metallurgical coke, the beehive process and the by-product process. The by-product process accounts for about 98% of the coke produced.

BEEHIVE OVEN:[13] The beehive is a refractory lined enclosure with a dome-shaped roof. The coal charge is deposited onto the floor of the beehive and leveled to give a uniform depth of material. Openings to the beehive oven are then restricted to control the amount of air reaching the coal. The carbonization process begins in the coal at the top of the pile and works down through the pile. The volatile matter being distilled escapes to the atmosphere through a hole in the roof. At the completion of the coking time, the coke is "watered out" or quenched.

BY-PRODUCT PROCESS:[13] The by-product process is oriented toward the recovery of the gases produced during the coking cycle. The rectangular coking ovens are grouped together in a series called a coke battery. Coal is charged to the oven through ports in the top and then sealed. Heat is supplied to the ovens by burning some of the coke gas produced. Coking is largely accomplished at temperatures of 2000°F to 2100°F for a period of 16 to 20 hours. Upon completion of the coking period, the coke is pushed from the oven by a ram and quenched with water.

Emissions[13]

Visible smoke, hydrocarbons, carbon monoxide, and other emissions originate from the following by-product coking operations: (1) charging of the coal into the red-hot ovens, (2) oven leakage during the coking period, (3) pushing the coke out of the ovens and (4) quenching the hot coke. Virtually no attempts have been made to prevent gaseous emissions from beehive ovens. Gaseous emissions from the by-product ovens are drawn off to a collection main and are subjected to various operations for separating ammonia, coke oven gas, tar, phenol, light oil (benzene, toluene, xllene), and pyridine. These unit operations are potential sources of hydrocarbon emissions.

Oven charging operations and leakage around poorly sealed coke oven doors and lids are major sources of gaseous emissions from by-product ovens. Sulfur is present in the coke oven gas in the form of hydorgen sulfide and carbon disulfide. If the gas is not desulfurized the combustion process will emit sulfur dioxide.

Associated with both coking processes are material handling operations of unloading coal, storage of coal, grinding and sizing of coal, screening and crushing coke, and coke storage and loading. All of these operations are potential particulate emission sources. In addition, the operations of oven-charging, coke pushing, and quenching produce particulate emissions. The emission factors for coking operations are summarized in Table 57.

TABLE 57[c] UNCONTROLLED EMISSION FACTORS FOR METALLURGICAL COKE MANUFACTURE (pounds per ton of coal charged)

Type Operation	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[f]	--	10	--	--	--	--
Beehive Ovens[e]	200	--	1	8	--	2

a - SO_2

b - Expressed as Methane

c - NO_2

d - References 238,239

e - References 13,240

f - Battelle Memorial Institute, A Systems Study of the Integrated Iron and Steel Industry, May 15, 1969.

COPPER SMELTERS

Process Description[241,242]

Copper is produced primarily from low-grade sulfide ores, which are concentrated by gravity and flotation methods. Copper is recovered from the concentrate by four steps: roasting, smelting, converting, and refining. Copper sulfide concentrates are normally roasted in multiple hearth roasters to remove the sulfur and then calcined in preparation for smelting in a reverberatory furnace. Smelting removes other impurities as a slag with the aid of fluxes. The matte that results from smelting is blown with air to remove the sulfur as sulfur dioxide. The end product is a crude metallic copper. A refining process further purifies the metal by air-blowing and slagging in reverberatory furnaces.

Emissions and Controls[242]

The high temperatures attained in roasting, smelting, and converting cause volatilization of a number of the trace elements present in copper ores and concentrates. The raw waste gases from these processes contain not only these fumes but also dust and sulfur oxide. Carbon monoxide and nitrogen oxides may also be emitted, but no quantitative data have been reported in the literature.

The value of the volatilized elements, dictates efficient collection of fumes and dusts. A combination of cyclones and electrostatic precipitators seems to be the most often used. Table 58 summarizes the uncontrolled emissions of particulates and sulfur oxides from copper smelters.

TABLE 58[c] UNCONTROLLED EMISSIONS FACTORS FOR PRIMARY COPPER SMELTERS (pounds per ton of concentrated ore)[a]

Type Operation	Particulates[b,c]	Sulfur Oxides[d,e]
Roasting	45	60
Smelting (Reverberatory Furnace)	20	320
Converting	60	870
Refining	10	--
Total Uncontrolled	135	1,250

a - Approximately 4 tons of concentrate are required to produce 1 ton of copper metal.
b - References 240,242
c - Reference 243
d - Electrostatic precipitators have been reported to reduce emissions by 99.7%.
e - For plants that have sulfuric acid units, sulfur oxide emissions are approximately 50% less.

FERROALLOY PRODUCTION

Process Description[13,244]

Farroalloys is the generic term for alloys consisting of iron and one or more other metals. Ferroalloys are used in steel production as alloying elements and deoxidants. There are three basic types of ferroalloys: silicon based alloys including ferrosilicon and calciumsilicon; manganese based alloys including ferromanganese and silocomanganese and; chromium based alloys including ferrochromium and ferrosilicochrome.

There are four major methods used to produce ferroalloy and high purity metallic additives for steelmaking. These are: (1) blast furnace, (2) electric smelting furnace, (3) alumina silico-thermic process and (4) electrolytic deposition. Since over seventy-five percent of the ferroalloys are produced in electric smelting furnaces this section deals only with this type of furnace.

The oldest, simplest and most widely used electric furnaces are the submerged arc open type. Semi-covered furnaces are also used. The alloys are made in the electric furnaces by reduction of suitable oxides. For example, in making ferrochromium the charge may consist of chrome ore, limestone, quartz (silica), coal and wood chips, along with scrap iron.

Emissions[245]

The production of ferroalloys has many dust or fume producing steps. The dust resulting from raw material handling, mix delivery, and crushing and sizing of the solidified product can be handled by conventional techniques and is ordinarily not a pollution problem. By far the major pollution problem arises from the ferroalloy furnaces themselves. The conventional submerged arc furnace utilizes carbon reduction of metallic oxides and continuously produces large quantities of carbon monoxide. This escaping gas carries large quantities of particulates of submicron size making control a difficult problem.

In an open furnace essentially all of the carbon monoxide burns with induced air at the top of the charge and CO emissions are small. However, particulate emissions from the open furnace can be quite large. In the semi-closed furnace most or all of the CO is withdrawn from the furnace and burns with dilution air introduced into the system. The unburned CO goes through particulate control device and can be used as boiler fuel or be flared directly. Particulate emission factors from electrid smelting furnaces are presented in Table 59. No carbon monoxide emission data have been reported in the literature.

TABLE 59[c] EMISSION FACTORS FOR FERROALLOY PRODUCTION IN ELECTRIC SMELTING FURNACES
(pounds per ton of specified product)

Type Furnace and Product	Particulates
Open Furnace	
50% FeSi[a]	200
75% FeSi[b]	315
90% FeSi[a]	565
Silicon Metal[c]	625
Silicomanganese[d]	195
Semi-covered Furnace	
Ferromanganese[d]	45

a - Reference 246
b - Reference 247,248
c - Reference 246,249
d - Reference 248

IRON AND STEEL MILLS

General

To make steel, iron ore is reduced to pig iron, and some of its impurities are removed in a blast furnace. The pig iron is further purified in open hearths, Bessemer converters, the basic oxygen furnace, or electric furnaces. Other operations including the production of by-product coke and sintering are not discussed in much detail in this section as they are covered in other sections of this publication.

Blast Furnace

The blast furnace is a large refractory lined chamber into which iron ore, coke, and limestone are charged and reacted with large amounts of hot air to produce molten iron. Slag and blast furnace gases are by-products from this reaction. To produce 1 ton of pig iron requires, on the average 1.7 tons of iron ore; 0.9 tons of coke; 0.4 tons of limestone; 0.2 tons of cinder, scale and scrap; and 4.0 to 4.5 tons of air. Most of the coke used in the blast furnaces is produced in "by-product" coke ovens. Sintering plants are used to convert iron ore fines and blast furnace flue dust into products more suitable for charging to the blast furnace.

As blast furnace gas leaves the top of the furnace it contains large amounts of particulates. This dust contains about 30% iron, 15% carbon, 10% silicon dioxide, and small amounts of aluminum oxide, manganese oxide, calcium oxide, and other materials. Blast furnace gas cleaning systems, composed of settling chambers, low efficiency wet scrubbers, and high efficiency wet scrubbers or electrostatic precipitators connected in series, are used to reduce particulate emissions. All of the carbon monoxide generated in the blast furnace is normally used for fuel. However, abnormal conditions such as "slips" can cause emissions of carbon monoxide.

Open Hearth Furnace[250,251]

In the open-hearth process for making steel, a mixture of scrap iron, steel, and pig iron is melted in a shallow rectangular basin, or "hearth", in which various liquid or gaseous fuels provide the heat. Impurities are removed in a slag. Oxygen injection (lancing) into the furnace speeds the refining process, saves fuel, and increases steel production.

The fume from open hearth furnaces consists predominantly of iron oxides. The use of oxygen lancing increases the amount of fume and dust produce. Control of iron oxide requires high-efficiency collection equipment such as venturi scrubbers and electrostatic precipitators.

Basic Oxygen Furnaces[250,251,253]

The basic oxygen process, the LD or Linz-Donawitz process is employed to produce steel from hot blast-furnace metal and some added scrap metal, by use of a stream of commercially pure oxygen to oxidize the impurities, principally carbon and silicon.

The reaction which converts the crude molten iron into steel generates considerable particulate emissions largely in the form of oxide. Carbon monoxide is also generated in this process, but after ignition of the gases above the furnace is emitted in small amounts. Electrostatic precipitators, high-energy venturi scrubbers, and baghouse systems have been used to control dust emissions.

Electric Air Furnaces[250,251,253]

Electric furnaces are used primarily to produce special alloy steels. Heat is furnished by direct-arc-type electrodes extending through the roof of the furnace. In recent years oxygen has been used to increase the rate of uniformity of scrap melt-down and to decrease power consumption.

The dust which occurs when steel is being processed in an electric furnace results from the exposure of molten steel to the extremely high temperatures. The excess carbon added to stir and purge the metal when oxidized creates a source of carbon monoxide emissions. For electric furnaces, venturi scrubbers and electrostatic precipitators are the most widely used control devices.

Scarfing[250,251]

Scarfing is a method of surface preparation of semifinished steel. A scarfing machine removes surface defects from the steel billets and slabs before they are shaped or rolled. This is done by applying jets of oxygen to the surface of the steel and thus removing a thin upper layer of the metal by rapid oxidation.[254]

The scarfing process generates an iron oxide fume. The rate of emissions is affected by the steel analysis and amount of metal removal required.

Table 60 summarizes the emission factors for the production of iron ore and steel and the associated operations.

TABLE 60^{A} UNCONTROLLED EMISSION FACTORS FOR IRON AND STEEL MILLS

(pounds per ton of product)

Type Operation	Particulates	Carbon Monoxide[l]
Iron Production		
Blast Furnace[a,g]		
Ore Charge	110	1,400-2,100[i]
Agglomerates Charge	40	
Coke Ovens	(see section on Metallurgical Coke)	
Sintering[h]		
Windbox[e]	20	--
Discharge[f]	22	44[j]
Steel Production		
Open Hearth Furnace[b,g]		
Oxygen Lance	22	--
No Oxygen Lance	12	--
Basic Oxygen Furnace[c,g]	46	120-150[k]
Electric Arc Furnace[d,g]		
Oxygen Lance	11	18
No Oxygen Lance	7	18
Scarfing[h]	20	--

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a - Preliminary cleaner (settling chamber or dry cyclone) collection efficiency = 60
Primary cleaner (wet scrubber in series with preliminary cleaner) collection efficiency = 90%.
Secondary cleaner (electrostatic precipitator or venture scrubber in series with primary cleaner) collection efficiency = 90%.

b - Electrostatic precipitator collection efficiency = 98%.
Venturi scrubber collection efficiency = 85-98%.
Baghouse collection efficiency = 99%.

c - Venturi scrubber collection efficiency = 99%.
Electrostatic precipitator collection efficiency = 99%.

d - High efficiency scrubber collection efficiency = up to 98%.
Electrostatic precipitator collection efficiency = 92-97%.
Baghouse collection efficiency = 98-99%.

e - Dry cyclone collection efficiency = 90%.
Electrostatic precipitator (in series with dry cyclone collection efficiency = 95%.

f - Dry cyclone collection efficiency = 93%.

g - Reference 255

h - References 254,256

i - Represents the amount of CO generated; normally all of the CO generated is used for fuel. Abnormal conditions may cause the emission of CO.

j - Pounds per ton of finished sinter.

k - Represents generated CO, after ignition of the gas above the furnace, the CO amounts to 0-3 lbs/ton of steel produced.

l - Reference 253

LEAD SMELTERS

Process Description[257,258]

The ore from which primary lead is produced contains both lead and zinc. Thus both a lead and zinc concentrate are made by concentration and flotation from the ore. If substantial impurities remain, the lead concentrate is roasted in multiple reverberatory hearth roasters in which sulfur is removed and lead oxide formed. The concentrate is then sintered on a hearth to remove additional sulfur and prepare a suitable material for the blast furnace. The lead, sinter, coke, and flux (usually limestone) are fed to the blast furnace, in which oxide is reduced to metallic lead. The lead may be further refined by a variety of other processes.

Emissions and Controls

Effluent gases from the roasting, sintering, and smelting operations contain considerable particulate matter and sulfur dioxide. Dust and fumes are recovered from the gas stream by settling in large flues and by precipitation in Cottrell treaters or filtration in large baghouses. The emission factors for lead smelting are summarized in Table 61. The effect of controls has been shown in this table.

TABLE 61[B] UNCONTROLLED EMISSION FACTORS FOR PRIMARY LEAD SMELTERS (pounds per ton of concentrated ore)[a]

Type Operation	Particulates[b]	Sulfur Oxides
Sintering and Sintering Crushing[c]	50[d]	660
Blast Furnace[e]	75	f
Reverberatory Furnace[e]	12	f

a - Approximately 2 tons of concentrated ore are required to produce 1 ton of lead metal.

b - Electrostatic precipitators collection efficiency = 96%.
Baghouses collection efficiency = 99.5%.

c - References 243,258

d - Pounds per ton of sinter

e - Reference 240

f - Included in SO_2 losses from sintering.

ZINC SMELTERS

Process Description[259,260]

As stated previously, most domestic zinc comes from zinc and lead ores. Another important source of raw material for zinc metal has been zinc oxide from fuming furnaces. For efficient recovery of zinc, sulfur must be removed from concentrates to less than 2%. This is done by multiple hearth or Ropp roasting followed by sintering. Metallic zinc can be produced from the roasted ore by the horizontal or vertical retort process or if a high purity zinc is needed by the electrolytic process.

Emissions and Controls[259,260]

Dust, fume, and sulfur dioxide are evolved from zinc concentrate roasting or sintering. Particulates may be removed by electrostatic precipitators or baghouses. Sulfur dioxide may be converted directly into sulfuric acid or vented. Emission factors for zinc smelting are presented in Table 62.

TABLE 62[B] UNCONTROLLED EMISSION FACTORS FOR PRIMARY ZINC SMELTING (pounds per ton of concentrated ore)[a]

Type Operation	Particulates	Sulfur Oxides
Roasting (Multiple-Hearth)[b]	120	1,100
Sintering[c]	90	d
Horizontal Retorts[e]	8	--
Vertical Retorts[e]	100	--
Electrolytic Process	3	--

a - Approximately 2 tons of concentrated ore are required to produce 1 ton of zinc metal.

b - References 240,243

c - References 240,260

d - Included in SO_2 losses from roasting.

e - Reference 240

ALIMINUM OPERATIONS

Process Description[261,262]

Secondary aluminum operations involve making lightweight metal alloys for industrial castings and ingots. Copper, magnesium, and silicon are the most common alloying constituents. Aluminum alloys for castings are melted in small crucible furnaces charged by hand with pigs and foundry returns. Larger melting operations use open-hearth reverberatory furnaces charged with the same type of materials but by mechanical means. Small operators sometimes use sweating furnaces to treat dirty scrap in preparation for smelting.

To produce a high-quality aluminum product, fluxing is practiced to some extent in all secondary aluminum melting. Aluminum fluxes are expected to remove dissolved gases and oxide particles from the molten bath. Various mixtures of potassium or sodium chloride with cryolite and chlorides of aluminum zinc, and sodium are used as fluxes. Chlorine gas is usually lanced into the molten bath to reduce the magnesium content by reacting to form magnesium and aluminum chlorides.[263,264]

Emissions[262]

Emissions from secondary aluminum operations include fine particulate matter and small quantities of gaseous chloride and fluorides. A large part of the material charged to a reverberatory furnace is low-grade scrap and chips. Paint, dirt, oil, grease, and other contaminants from this scrap cause large quantities of smoke and fumes to be discharged. Even if the scrap is clean, large surface-to-volume ratios require the use of more fluxes, which can cause serious air pollution problems. Table 63 presents particulate emission factors for secondary aluminum operations.

TABLE 63[B] PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS
(pounds per ton of metal processed)[a]

Type Operation	Uncontrolled	Baghouse	Electrostatic Precipitator
Sweating Furnace	14.5	3.3	--
Smelting			
Crucible Furnace	1.9	--	--
Reverberatory Furnace	4.3	1.3	1.3
Chlorination Station[b]	1000	50	--

a - Reference 265

b - Pounds per ton of chlorine used.

BRASS AND BRONZE INGOTS (Copper Alloys)

<u>Process Description</u>[266]

Obsolete domestic and industrial copper-bearing scrap is the basic raw material of the brass and bronze ingot industry. The scrap frequently contains any number of metallic and non-metallic impurities, which can be removed by such methods as hand sorting or magnetizing, heat methods such as sweating or burning, or gravity separation in a water medium.

Brass and bronze ingots are produced from a number of different furnaces through a combination of melting, smelting, refining and alloying of the process scrap material. Reverberatory, rotary, and crucible furnaces are the most widely used, and the choice depends on the size of the melt and the desired alloy. Both the reverberatory and the rotary furnaces are normally heated by direct firing, in which the flame and gases come into direct contact with the melt. Processing is essentially the same in any furnace except for the differences in the types of alloy being handled. Crucible furnaces are usually much smaller and used principally for special-purpose alloys.

Emissions and Controls[266]

The principal source of emissions in the brass and bronze ingot industry is the refining furnace. The exit gas from the furnace may contain the normal combustion products such as fly ash, soot and smoke. Appreciable amounts of zinc oxide are also present in this exit gas. Other sources of particulate emissions include the preparation of raw materials and the pouring of ingots.

The only air pollution control equipment that is generally accepted in the brass and bronze ingot industry is the baghouse filter. The use of this collection device can reduce emissions by as much as 99.9%. The affect of baghouses or emissions is shown in Table 64. This table also summarizes uncontrolled emissions from various brass and bronze melting furnaces.

TABLE 64[A] UNCONTROLLED PARTICULATE EMISSION FACTORS FOR BRASS AND BRONZE MELTING FURNACES

(pounds per ton of charge)[a]

Type Furnace	Uncontrolled Emissions[c]
Blast[b]	18
Crucible	16
Cupola	73
Electric Induction	2
Reverberatory	70
Rotary	60

a - Reference 267

b - Represents emissions following precleaner.

c - The use of a baghouse can reduce emissions by 95-99.6%.

GRAY IRON FOUNDRY

Process Description[268]

Three types of furnaces are used to produce gray iron castings: cupolas, reverberatory furnaces, and electric induction furnaces. The cupola is the major source of molten iron for the production of castings. In operation, a bed of coke is placed over the sand bottom in the cupola. After the bed of coke has begun to burn properly, alternate layers of coke, flux and metal are charged into the cupola. Combustion air is forced into the cupola causing the coke to burn and melt the iron. The molten iron flows out through a taphole.

Electric furnaces are commonly used where special alloys are to be made. Pig iron and scrap iron are charged to the furnace and melted, and alloying elements and fluxes are added at specific intervals. Small reverberatory furnaces are also used in preparing gray and white cast iron alloys.

Emissions[268]

Emissions from cupola furnaces include gases, dust and fumes, and smoke and oil vapors. Dust arises from dirt on the metal charge and from fines in the coke and limestone charge. Smoke and oil vapor arise primarily from the partial combustion and distillation of oil from greasy scrap charged to the furnace. Also the effluent from the cupola furnace has a high carbon monoxide content which can be controlled by an afterburner. Emissions from reverberatory and electric induction furnaces consist primarily of metallurgical fumes and are relatively low. Table 65 presents emission factors for the manufacture of iron castings.

TABLE 65[B] EMISSION FACTORS FOR GRAY IRON FOUNDRIES
(pounds per ton of metal charged)[a,b]

Type Furnace	Particulates	Carbon Monoxide
Cupola		
Uncontrolled	17	145[c]
Wet Cap	8	--
Impingement Scrubber	5	--
High-Energy Scrubber	3	--
Electrostatic Precipitator	2.7	--
Baghouse	2.2	--
Reverberatory	2	--
Electric Induction	2	--

a - References 265,269,270,271

b - Approximately 85% of the total charge is metal. For every 1 pound of coke in the charge, 7 pounds of gray iron are produced.

c - A well designed afterburner can reduce emissions to 9 pounds per ton of metal charged.[265]

d - A. T. Kearney and Company, Inc., Air Pollution Aspects of the Iron Foundry Industry, February, 1971.

SECONDARY LEAD SMELTING

General Description[13]

There are three types of furnaces used to produce the common types of lead: pot furnace, reverberatory furnace and the blast furnace or cupola. The pot furnaces are used for the production of the purest lead products and operate under closely controlled temperature conditions. Reverberatory furnaces are used for the production of semi-soft lead from lead scrap, oxides and drosses. The third common type of furnace, the blast furnace, is used to produce hard lead (typically averaging 8% anitmony and up to 2% additional metallic impurity).[272] The charge to these furnaces consists of rerun, slag, and reverberatory slags.

Emissions and Controls[13]

The primary emissions from lead smelting are particulates consisting of lead, lead oxides, and contaminants in the lead charged. Carbon monoxide is released by the reduction of lead oxide by carbon in the cupola. Nitrogen oxides are formed by fixation of atmospheric nitrogen due to the high temperatures associated with the smelting.

Factors affecting emissions from the pot furnace include the composition of the charge, temperature of the pot, and the degree of control (usually hooding followed by a baghouse.) Emissions from the reverberatory furnace are affected by the sulfur content in the charge, the temperature in the furnace and the amount of air pulled across the furnace. Lead blast furnace emissions are dependent on the amount of air passed through the charge, the temperature of the furnace, and the amount of sulfur and other impurities in the charge. In addition significant quantities of carbon monoxide and hydrocarbons are emitted from blast furnaces which must be controlled by incineration. Table 66 summarizes the emission factors from lead smelting.

TABLE 66[C] LEAD SMELTING EMISSION FACTORS

(pounds per ton processed)

Type Furnace	Particulates		Sulfur Oxides	
	Uncontrolled	Controlled	Uncontrolled	Controlled
Pot Furnace[a]	0.8	Neg.	--	--
Reverberatory Furnace[b]	130	1.6	85	--
Blast (Cupola) Furnace[c]	190	2.3	90	0.8[e], 46[f]
Rotary Reverberatory Furnace[d]	70	--	--	--

a - References 264,273,274,275

b - References 264,272,275

c - References 272,275,276

d - Reference 274

e - With NaOH scrubber

f - With water spray chamber

SECONDARY MAGNESIUM SMELTING

Process Description[13]

Magnesium smelting is carried out in crucible or pot type furnaces charged with magnesium scrap and fired by gas, oil or electric heating. A flux is used to cover the surface of the molten metal as magnesium will burn in air at the pouring temperature (approximately $1500^{\circ}F$). Melts are usually purified by lancing with chlorine gas. The molten magnesium, usually cast by pouring into molds, is annealed in ovens utilizing an atmosphere devoid of oxygen.

Emissions[13]

Emissions from magnesium smelting include particulate magnesium (MgO) from the melting, oxides of nitrogen from the fixation of atmospheric nitrogen by the furnace temperatures, sulfur dioxide losses from annealing oven atmospheres and chloride gases from lancing. Carbon monoxide is reduced to magnesium metal by coke. Factors affecting emissions include the capacity of the furnace, the type of flux used on the molten material, the amount of lancing used, and the amount of contamination of the scrap including oil and other hydrocarbons, and the type and extent of control equipment used on the process. The emission factor for a pot furnace is shown in Table 67.

TABLE 67[c] MAGNESIUM SMELTING EMISSIONS
(pounds per ton processed)

Type Furnace	Particulates
Pot Furnace	
Uncontrolled	4
Controlled	0.4

a - Reference 275
b - Reference 264

STEEL FOUNDRIES

Process Description[13]

Steel foundries produce steel castings by melting steel metal and pouring it into molds. The melting of steel for castings is accomplished in one of five types of furnaces: direct electric arc, electric induction, open hearth, crucible, and pneumatic converter. The crucible and pneumatic converter are not in widespread use and this section deals only with the remaining three types of furnaces. Raw materials supplied to the various melting furnaces include: steel scrap of all types, pig iron, ferroalloys and limestone. The basic melting process operations are furnace charging, melting, tapping the furnace into a ladle and pouring the steel into molds. An integral part of the steel foundry operation is the preparation of casting molds and the shakeout and cleaning of these castings. Some common materials used in molds and cores for hollow casting include sand, oil, clay, and resin. Shakeout is the operation in which the cool casting is separated from the mold. The castings are commonly cleaned by shot-blasting and surface defects such as fins may be removed by burning and grinding.

Emissions[13]

Particulate emissions from steel foundry operations include iron oxide fume, sand fines, graphite and metal dust. Gaseous emissions from foundry operations include oxides of nitrogen, oxides of sulfur, and hydrocarbons. Factors affecting emissions from the melting process include quality and cleanliness of the scrap and increased oxygen lancing. The concentrations of oxides of nitrogen will be dependent upon operating conditions in the melting unit such as temperature and the rate of cooling of the exhaust gases. The concentration of carbon monoxide in the exhaust gases is dependent on the amount of draft on the melting furnace. Emissions from the shakeout and cleaning operations, being mostly particulate, will vary according to type and efficiency of dust collection. Gaseous emissions from the mold and baking operations are dependent upon the fuel used by the ovens and the temperature reached in these ovens. Table 68 summarizes the emission factors for steel foundries.

TABLE 68[A] EMISSION FACTORS FOR STEEL FOUNDRIES
(pounds per ton processed)

Type Process	Particulates[a]	Nitrogen Oxides
Melting		
Electric Arc[b,f]	13 (4-40)	0.2
Open Hearth[c,g]	11 (2-20)	0.01
Open Hearth Oxygen Lanced[d,h]	10 (8-11)	--
Electric Induction[e]	0.1	--

a - If the scrap metal is quite dirty or oily or increased oxygen lancing is employed the emission factor should be chosen from the high side of the factor range.
b - Electrostatic precipitator 92-98% control efficiency, baghouse (fabric filter) 98-99% control efficiency, venturi scrubber 94-98% control efficiency.
c - Electrostatic precipitator 95-98.5% control efficiency, baghouse 99.9% control efficiency, venturi scrubber 96-99% control efficiency.
d - Electrostatic precipitator 95-98% control efficiency, baghouse 99% control efficiency, venturi scrubber 95-98% control efficiency.
e - Usually not controlled.
f - References 254,277-285
g - References 254,286,287,288
h - References 281,289

SECONDARY ZINC PROCESSING

Process Description[13]

Zinc processing includes zinc reclaiming, zinc oxide manufacturing, and zinc galvanizing. Separations of zinc from scrap containing lead, copper, aluminum, and iron are made by careful control of temperature in the furnace allowing each metal to be removed at its melting range. The furnaces typically employed are the pot, muffle, reverberatory or electric induction. Further refining of the zinc can be done in retort distilling or vaporization furnaces where the vaporized zinc is condensed to the pure metallic form. Zinc oxide is produced by distilling metallic zinc into a dry air stream and capture of the subsequently formed oxide in a baghouse. Zinc galvanizing is carried out in a vat or bath type dip tanks utilizing a flux cover. Iron and steel pieces to be coated are cleaned and dipped into the vat through the covering flux.

Emissions[13]

A potential for particulate emissions, mainly zinc oxide, occurs if the temperature of the furnace exceeds 1100°F. Zinc oxide (ZnO) may escape from condensers or distilling furnaces, and due to its extremely small particle size (0.03-0.5 microns), may pass through even the most efficient collection systems. Some loss of zinc oxides occurs during the galvanizing processes but these losses are small due to the flux cover on the bath and the relatively low temperature maintained in the bath. Some emissions of particulate ammonium chloride occur when galvanized parts are dusted after coating to improve their finish. Another source of potential emission of particulates and gaseous zinc is the tapping of zinc vaporizing muffle furnaces to remove accumulated slag residue. Emissions of carbon monoxide occur when zinc oxide is reduced by carbon. Nitrogen oxide emissions are also possible due to the high temperature associated with the smelting and the resulting fixation of atmospheric nitrogen. Table 69 summarizes the emission factors from zinc processing.

TABLE 69[c] PARTICULATE EMISSION FACTORS FOR ZINC SMELTING (pounds per ton of product)[a]

Type Furnace	Emissions
Retort Reduction	47
Horizontal Muffle	45
Pot Furnace	0.1
Sweat Furnace	11
Galvanizing Kettles	5
Calcining Kiln	89

a - References 264,274,275

MINERAL PRODUCTS

This section involves the processing and production of various minerals. Mineral processing is characterized by particulate emissions in the form of dust. Frequently, as in the case of crushing and screening, this dust is identical to the material being handled. Emissions also occur through handling and storage of the finished product since this material is often dry and fine. Particulate emissions from some of the processes such as quarrying, yard storage, and road dust are difficult to control. However, most of the emissions from the manufacturing processes discussed in this section can be reduced by conventional particulate control equipment such as cyclones, scrubbers and fabric filters. Because of the wide variety in processing equipment and final product, emissions cover a wide range. However, average emission factors have been presented for general use.

ASPHALT BATCH PLANTS

Process Description[290,291]

Hot-mix asphalt paving consists of a combination of aggregates uniformly mixed and coated with asphalt cement. The coarse aggregates usually consist of crushed stone, crushed slag, crushed gravel, or combinations of these materials. The fine aggregates usually consist of natural sand and may contain added materials such as crushed stone, slag or gravel.

An asphalt batch plant involves the use of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins, and conveying equipment. Sand and aggregate are charged from bins into a rotary dryer. The dried aggregate is conveyed to the screening equipment where it is classified and dumped into storage bins. Asphalt and weighed quantities of sized aggregates are then dropped into the mixer where the batch is mixed and then dumped into trucks for transportation to the paving site.

Emissions and Controls[290,291]

The largest source of dust emissions is the rotary dryer. The combustion gases and fine dust from the rotary dryer are exhausted through a precleaner, usually consisting of a single cyclone, but twin or multiple cyclones are also used. The exit gas stream of the precleaner usually passes through air pollution control equipment.[292] Other sources of dust emissions include the hot aggregate bucket elevator, vibrating screens, hot aggregate bins, aggregate weigh hopper and the mixer. Emission factors for asphalt batching plants are presented in Table 70.

TABLE 70[B] PARTICULATE EMISSION FACTORS FOR ASPHALT BATCHING PLANTS
(pounds per ton of product)

Source and Type of Control	Emissions
Rotary Dryer[a]	
Uncontrolled[b,c]	35
Precleaner	5
High-efficiency cyclone	0.8
Multiple centrifugal scrubber	0.2
Baffle spray tower	0.2
Orifice-type scrubber	0.08
Baghouse	0.005
Other Sources (Vibrating screens, hot aggregate bins, aggregate weigh hopper and mixer) Uncontrolled[b]	10

a = References 236, 291, 292, 293

b = References 240, 291, 294

c = Almost all plants have at least a precleaner following the rotary dryer.

Process Description[13]

The manufacture of asphalt roofing felts and shingles involves saturating a fiber media with asphalt by means of dipping and/or spraying. While not always done at the same site, an integral part of the operation is the preparation of the asphalt saturant. This preparation called "blowing" consists of oxidizing the asphalt and is accomplished by bubbling air through liquid asphalt for 8 to 16 hours. After blowing, the saturant is transported to the saturation tank or spray area. The saturation of the felts is accomplished by dipping, by high pressure sprays or both. The final felts are made in varying weights: 15, 30 and 55 lb./100 square foot. Regardless of the weight of the final product, the makeup is approximately 40% dry felt and 60% asphalt saturant.

Emissions and Controls[13]

The major sources of particulate emissions from asphalt roofing plants are the asphalt blowing operations and the felt saturation. Another minor source of particulates is the covering of the roofing material with roofing granules. Gaseous emissions from the saturation process are unknown but are thought to be slight due to the initial driving off of these contaminants during the blowing process.

Common methods of control at asphalt saturating plants include complete enclosure of the spray area and saturator followed by good ventilation through one or more collection devices including combinations of wet scrubbers, and two-stage low voltage electrical precipitators, or cyclones and fabric filters. Emission factors for asphalt roofing are presented in Table 71.

TABLE 71[D] UNCONTROLLED EMISSION FACTORS FOR ASPHALT ROOFING
(pounds per ton of saturated felt)[a]

Operation	Particulates[b]	Carbon Monoxide	(CH_4) Hydrocarbons
Asphalt Blowing[c]	2.5	0.9	1.5
Felt Saturation[d]			
Dipping only	1	--	--
Spraying only	3	--	--
Dipping and spraying	2	--	--

a = It requires approximately 0.65 tons of asphalt input to produce 1 ton of saturated felts.

b = Low voltage precipitator can reduce emissions by about 60%; when used in combination with a scrubber, overall efficiency is about 85%.

c = Reference 295

d = References 296, 297

BRICKS AND RELATED CLAY PRODUCTS

Process Description[13, 298, 299, 300]

The manufacture of brick and related products such as clay pipe, pottery and some types of refractory brick involves the grinding, screening, blending of the raw materials, forming, drying or curing, firing, and final cutting or shaping.

The drying and firing of pressed bricks, both common and refractory, are accomplished in many types of ovens, the most popular being the long tunnel oven. Common brick or building brick is prepared by molding a wet mix (20-25% water, 75-80% clay) followed by baking in chamber kilns. Common brick is also prepared by extrusion of a stiff mix (10-12% water), followed by pressing and baking of the sections cut from the extrusion.

Emissions and Controls[13]

Particulate emissions similar to those obtained in clay processing are emitted from the materials handling process in refractory and brick manufacturing. Combustion products from the fuel consumed in the curing, drying, and firing portion of this process are also emitted. Fluorides, largely in a gaseous form, are also emitted from brick manufacturing operations. Sulfur dioxide may also be emitted from the bricks when firing temperatures of 2500° F or more occur, or when the fuel contains sulfur.

A variety of control systems may be used to reduce both particulate and gaseous emissions. Almost any type of particulate control system will reduce emissions from the material handling process. Fluoride emissions can be reduced to very low levels by using a water scrubber. Emission factors for brick manufacturing are presented in Table 72.

TABLE 72[D] UNCONTROLLED EMISSION FACTORS FOR BRICK MANUFACTURING (pounds per ton of product)[a]

Type Process	Particulate	Nitrogen Oxides (NO_2)	Fluorides[b]
Raw Material Handling[c]			
Drying	70	--	--
Grinding	76	--	--
Storage	34	--	--
Curing and Firing[d]			
Gas Fired	Neg.	0.6	0.8
Oil Fired	Neg.	1.3	0.8
Coal Fired	5A-10A[e]	1.5	0.8

a = One brick weighs about 6.5 pounds

b = Expressed as HF and based on a raw material content of 0.05% by weight fluoride.

c = Based on data from section on ceramic clays

d = References 299, 301, 302, 303

e = A is the percent ash in the coal and gives the emission on a pounds per ton of fuel used basis. This is an estimate based on coal-fired furnaces.

CALCIUM CARBIDE

Process Description[304,305]

Calcium carbide is manufactured by heating a mixture of quicklime (CaO) and carbon in an electric arc furnace where the lime is reduced by the coke to calcium carbide and carbon monoxide. Metallurgical coke, petroleum coke or anthracite coal is used as the source of carbon. About 1,900 pounds of lime and 1,300 pounds of coke yield 1 ton of calcium carbide. There are two basic types of carbide furnaces: (1) the open furnace, in which the carbon monoxide burns to carbon dioxide when it comes in contact with air above the charge and (2) the closed furnace in which the gas is collected from the furnace. The molten calcium carbide from the furnace is poured into chill cars or bucket conveyors and allowed to solidify. The finished calcium carbide is dumped into a jaw crusher followed by a cone crusher to produce a product of the desired size.

Emissions and Controls

Particulates, acetylene, sulfur compounds and some carbon monoxide are emitted from calcium carbide plants. Table 73 contains emission factors based on one plant in which some particulates escape from the hoods over each furnace and the remainder pass through wet impingement type scrubbers before being vented to the atmosphere through a stack. The coke dryers and the furnace room vents are also sources of emissions.

TABLE 73[C] EMISSION FACTORS FOR CALCIUM CARBIDE PLANTS
(pounds per ton of product)[a]

Type Source	Particulate	Sulfur Oxides	Acetylene
Electric Furnace			
Hoods	18	--	--
Main Stack	20	3	--
Coke Dryer	2	3	--
Furnace Room Vents	26	--	18

a = Reference 306

CASTABLE REFRACTORIES

Process Description[13, 307, 308]

Castable or fused-cast refractories are manufactured by carefully blending such components as alumina, zirconia, silica, chrome, and magnesia, melting the mixture in an electric arc furnace at temperatures of 3200-4500° F, pouring into molds, and slowly cooling to the solid state. Fused refractories are less porous and more dense than kiln-fired refractories.

Emissions and Controls[13]

Particulate emissions occur from the drying, crushing, handling, and blending phases of this process, the actual melting process, and in the molding phase. Fluorides largely in the gaseous form may also occur during the melting operations.

The general types of particulate controls may be used on the materials handling aspects of refractory manufacturing. However, emissions from the electric arc furnace are largely condensed fumes and consist of very fine particles. Fluoride emissions can be effectively controlled with a scrubber. Emission factors for castable refractories manufacturing are presented in Table 74.

TABLE 74[c] PARTICULATE EMISSION FACTORS FOR CASTABLE REFRACTORIES MANUFACTURING
(pounds per ton of feed material)[a]

Type Process	Uncontrolled	Controlled	Type Control
Raw Material Dryer[b]	30	0.3	Baghouse
Raw Material Crushing and Processing[c]	120	7 45	Scrubber Cyclone
Electric Arc Melting[d]	50	0.8 10	Baghouse Scrubber
Curin Oven[e]	0.2		
Molding and Shakeout[b]	25	0.3	Baghouse

a = Fluoride emissions from the melt average about 1.3 pounds of HF per ton of melt.

b = Reference 309

c = References 309, 310

d = References 309, 310, 311

e = Reference 310

Process Description[312]

The raw materials required to make cement may be divided into the following components: lime (calcareous), silica (siliceous), alumina (argillaceous), and iron (ferriferous). The four major steps in the production of portland cement are (1) quarrying and crushing, (2) grinding and blending, (3) clinker production, and (4) finish grinding and packaging.

In the first step the cement rock limestone, clay, and shale are worked in opened quarries. The rock from the quarries is sent through a primary and a secondary crusher. The various crushed raw materials are properly mixed and then go through the grinding operation. After the raw materials are crushed and ground, they are introduced into a rotary kiln that is fired with pulverized coal, oil or gas. In the kiln the materials are dried, decarbonated, and calcined to produce a cement clinker. The clinker is cooled, mixed, ground with gypsum, and bagged for shipment as cement.

Emissions and Controls[312, 313]

Particulate matter is the primary emission in the manufacture of portland cement and is emitted from crushing operations, storage silos, rotary dryers, and the rotary kilns. Dust production in the crusher area depends on the type and moisture content of the raw material, and the characteristics and type of crusher. In the process of conveying the crushed material to storage silos, sheds, or open piles, dust is generated at the various conveyor transfer points. A hood is normally placed over each of these points to control particulate emissions.

Another major source of particulate matter is the rotary dryer. The hot gases passing through the rotary dryer will entrain dust from the limestone, shale, or other materials being dried. Control systems in common use generally include multicyclones, electrostatic precipitators or combinations of these types of control.

The largest source of emissions within cement plants is the kiln operation, which may be considered to have three units: the feed system, a fuel-firing system, and a clinker-cooling and handling system. The complications of kiln burning and the larger volumes of materials handled have led to many control systems for dust collection. Because of the diversity of these control systems, they will not be discussed in this publication. The effect of control devices on emission is shown in Table 75. This table summarizes particulate emissions from cement manufacturing.

TABLE 75[B] PARTICULATE EMISSION FACTORS FOR CEMENT MANUFACTURING
(pounds per barrel of cement)[a]

Type Process	Uncontrolled Emissions[b]
Dry Process	
Kilns[c]	46 (35-75)
Dryers, Grinder, etc.[d]	18 (10-30)
Wet Process	
Kilns[c]	38 (15-55)
Dryers, Grinders, etc.[d]	6 (2-10)

a = One barrel of cement weighs 376 pounds.

b = Typical collection efficiencies are:
80 percent for multicyclones
90 percent for old electrostatic precipitators
95 percent for multicyclones plus old electrostatic precipitators
99 percent for multicyclones plus new electrostatic precipitators
99.5 percent for fabric filter units

c = Reference 312

d = Reference 240

CERAMIC CLAY MANUFACTURING

Process Description[13]

The manufacture of ceramic clay involves the conditioning of the basic ores by several methods. These include the separation and concentration of the minerals by screening, floating, wet and dry grinding and blending of the desired ore varieties. The basic raw materials in ceramic clay manufacture are kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) and montmorillonite (Mg, Ca) $O \cdot Al_2O_3 \cdot 5SiO_2 \cdot \underline{n}H_2O$) clays. These clays are refined by separation and bleaching, blended and after kiln drying are formed into such items as whiteware, heavy clay products (brick, etc.) and various stoneware and other products such as diatomaceous earth used as a filter aid.

Emissions and Controls[13]

Emissions consist primarily of particulates, but some fluorides and acid gases are also emitted in the drying process. The high temperatures of the firing kilns are also conducive to the fixation of atmospheric nitrogen and the subsequent release of NO. No published information has been found for gaseous emissions. Particulate emissions also occur from the grinding process and storage of the ground product.

Factors affecting emissions include the amount of material processed, the type of grinding (wet or dry), the temperature of the drying kilns, the gas velocities and flow direction in the kilns, and the amount of fluorine in the ores.

Common control techniques include settling chambers, cyclones, wet scrubbers, electrostatic precipitators and bag filters. Cyclones for the coarser material followed by wet scrubbers, bag filters or electrostatic precipitators for dry dust are the most effective control. Emission factors for ceramic clay manufacturing are presented in Table 76.

TABLE 76[A] PARTICULATE EMISSION FACTORS FOR CERAMIC CLAY MANUFACTURING
(pounds per ton of input to process)

Type Process	Uncontrolled	Cyclone[a]	Multiple-Unit Cyclone and Scrubber[b]
Drying[c]	70	18	7
Grinding[d]	76	19	--
Storage[d]	34	8	--

a = Approximate collection efficiency 75%

b = Approximate collection efficiency 90%

c = References 264, 314, 315, 316

d = Reference 264

CLAY AND FLY ASH SINTERING

Process Description[13]

While the processes for sintering fly ash and clay are similar, there are some distinctions which justify a separate discussion of each process. Fly ash sintering plants are generally located near the source--the fly ash being delivered to a storage silo at the plant. The dry fly ash is moistened with a water solution of lignin and agglomerated into pellets or balls. The material then goes to a traveling grate sintering machine where direct contact with hot combustion gases sinters the individual particles of the pellet and completely burns off the residual carbon in the fly ash. After sintering, the product is crushed, screened, graded and stored in yard piles.

Clay sintering involves the driving off of entrained volatile matter. It is desirable that the clay contain a sufficient amount of volatile matter so that the resultant aggregate will not be too heavy. Thus it is sometimes necessary to mix the clay with finely pulverized coke (up to 10% coke by weight).[317,318] To sinter clay, it is first mixed with pulverized coke, if necessary, and then pelletized. After pelletizing, the clay is sintered in a rotating kiln, or on a traveling gate. The sintered pellets are then crushed, screened, and stored, similar to fly ash pellets.

Emissions and Controls[13]

In fly ash sintering improper handling of the fly ash creates a dust problem. Adequate design features including fly ash wetting systems, and particulate collection systems on all transfer points and on crushing and screening operations will greatly reduce emissions. Normally, fabric filters are used to control emissions from the storage silo and emissions are low. However, the absence of this dust collection system would create a major emission problem. Upon discharge from the silo to the agglomerator moisture is added and very little emissions occur. Normally, there is little emission from the sintering machine, but if the grate is not properly maintained a dust problem is created. After sintering, the crushing, screening, handling, and storage of the sintered product also create dust problems.

In clay sintering the addition of pulverized coke presents an emission problem. The sintering of coke impregnated dry pellets produces more particulate emissions than the natural clay. The crushing, screening, handling, and storage of the sintered clay pellets creates dust problems similar to those encountered in fly ash sintering. Emission factors for both clay and fly ash sintering are shown in Table 77.

TABLE 77[c] PARTICULATE EMISSION FACTORS FOR SINTERING OPERATIONS (pounds per ton of finished product)

Type Material	Sintering Operation[a]	Crushing, Screening and Yard Storage[a,b]
Fly Ash[c]	110	d
Clay Mixed[e,f] with Coke	40	15
Natural Clay[g,h]	12	12

a = Cyclones would reduce this emission by about 80%.
Scrubbers would reduce this emission by about 90%.

b = Based on data in section on Stone Quarrying and Processing.

c = Reference 13

d = Included in sintering losses.

e = 90% clay, 10% pulverized coke; traveling grate, single-pass up-draft sintering machine.

f = References 315, 316, 318

g = Rotary dryer sinterer

h = Reference 317

COAL CLEANING

Process Description[13]

Coal cleaning is the process by which undesirable materials are removed from both bituminous and anthracite coal. The coal is screened, classified, washed and dried at coal preparation plants. The major source of air pollution from these plants is the thermal dryers. Seven types of thermal dryers are presently used: rotary, screen, cascade, continuous carrier, flash or suspension, multilouver and fluidized bed. The three major types are the flash, multilouver and fluidized bed.

In the flash dryer coal is fed into a stream of hot gases where instantaneous drying occurs. The dried coal and wet gases are drawn up a drying column and into the cyclone for separation. In the multilouver dryer hot gases are passed through falling curtains of coal. The coal is raised by flights of a specially designed conveyor. In the fluidized bed the coal is suspended and dried in a fluid state above a perforated plate by rising hot gases.

Emissions and Controls[13]

Particulates in the form of coal dust constitute the major air pollution problem from coal cleaning plants. The crushing, screening, or sizing of coal are minor sources of dust emissions. The major sources of dust emissions are the thermal dryers. The concentration, quantity and particle size range of emissions depend upon the type of collection equipment used to reduce particulate emissions from the dryer stack. The various types of control equipment used are shown in the emission factor table (Table 78) with the possible efficiencies obtained from each type. The emission factors are summarized in this table.

TABLE 78[B] UNCONTROLLED PARTICULATE EMISSION FACTORS FROM THERMAL COAL DRYERS
(pounds per ton of coal dried)

Type Dryer	Uncontrolled Emissions[a]
Fluidized Bed[b]	20
Flash[b]	16
Multilouvered[c]	25

a = Typical collection efficiencies are:

Cyclone collectors - 70%
Multiple cyclones - 85%
Water sprays following cyclones - 95%
Wet scrubber following cyclones - 99-99.9%

b = References 319, 320

c = Reference 321

CONCRETE BATCHING

Process Description[13, 322, 323]

Concrete batching involves the proportioning of sand, gravel, and cement by means of weight hoppers and conveyors into a mixing receiver such as a transit mix truck. The required amount of water is also discharged into the receiver along with the dry materials. In some cases, the concrete is prepared for on-site building construction work or the manufacture of concrete products such as pipe and pre-fabricated construction parts.

Emissions and Controls[13]

Particulate emissions consist primarily of cement dust, but some sand and aggregate gravel dust emissions do occur during batching operations. There is also a potential for dust emissions during the unloading and conveying of concrete and aggregates at these plants and during the loading of dry batched concrete mix. Another source of dust emissions is the traffic of heavy equipment over unpaved or dusty surfaces in and around the concrete batching plant.

Control techniques include enclosure of dumping and loading areas, and of conveyors and elevators, filters on storage bin vents and the use of water sprays. Table 79 presents emission factors for concrete batch plants.

TABLE 79[c] PARTICULATE EMISSION FACTORS FOR CONCRETE BATCHING (pounds per cubic yard of concrete)[a]

Concrete Batching[b]	Emissions
Uncontrolled	0.2
Good Control	0.02

a = 1 cubic yard of concrete equals 4,000 pounds

b = Reference 264

Process Description[13]

Fiber glass is manufactured by melting various raw materials to form glass, drawing the molten glass into fibers, and coating the fibers with an organic material. The glass-forming reaction takes place at 2800°F in a large rectangular, gas-or-oil fired reverberatory furnace. The melting furnaces are equipped with either regenerative or recuperative heat recovery systems. After refining, the molten glass passes to a forehearth where the glass is either formed into marbles for subsequent remelting, or passed directly through orifices to form a filament. After forming, the continuous filaments are treated with organic binder material, wound, spooled, and sent to a high-humidity curing area where the binder sets. The product is then cooled by blowing air over it.

Emissions and Controls[13]

The major emissions from fiber glass manufacturing processes are particulates from the glass melting furnace, the forming line, the curing oven, and the product cooling line. In addition gaseous organic emissions occur from the forming line and curing oven. Particulate emissions from the glass melting furnace are affected by basic furnace design, type of fuel (oil or gas), raw material size and composition, and type and volume of furnace heat recovery system.[324] Regeneration heat recovery systems generally allow more particulate matter to escape than do recuperative systems. Control systems are not generally used on the glass furnace. Organic and particulate emissions from the forming line are most affected by the composition and quantity of the binder, and the spraying techniques used to coat the fibers. Very fine spray and volatile binders increase emissions. Emissions from the curing oven are affected by the oven temperature and binder composition. Direct-fired afterburners with heat exchangers may be used to control these emissions. Particulate emission factors for fiber glass manufacturing are summarized in Table 80.

TABLE 80[c] UNCONTROLLED PARTICULATE EMISSION FACTORS FOR FIBER GLASS MANUFACTURING

(pounds per ton of material processed)[a]

Type Process	Emissions
Glass Furnace[b,c]	
Reverberatory	
With Regenerative Heat Exchanger	3
With Recuperative Heat Exchanger	1
Electric Induction	Negligible
Forming Line[d]	50
Curing Oven[e]	7

a = Overall emissions may be reduced by approximately 50% by using:

1) an afterburner on the curing oven
2) a filtration system on the product cooling
3) process modifications for the forming line

b = Only one type is usually used at any one plant.

c = References 325, 326

d = References 325, 327

e = References 327, 328

FRIT MANUFACTURING

Process Description[329,330]

Frit is used in enameling iron and steel or in glazing porcelain and pottery. In a typical plant, the raw materials consist of a combination of materials such as borax, feldspar, sodium fluoride or fluorspar, soda ash, zinc oxide, litharge, silica, boric acid, and zircon. Frit is prepared by fusing various minerals in a smelter. The molten material is then quenched with air or water. This quenching operation causes the melt to solidify rapidly and shatter into numerous small glass particles, called frit. After a drying process, the frit is finely ground in a ball mill where other materials are added.

Emissions and Controls[330]

Significant dust and fume emissions are created by the frit-smelting operation. These emissions consist primarily of condensed metallic oxide fumes that have volatilized from the molten charge. They also contain mineral dust carryover and sometimes hydrogen fluoride. Emissions can be reduced by not rotating the smelter too rapidly, (to prevent excessive dust carryover), and by not heating the batch too rapidly or too long, (to prevent volatilizing the more fusible elements.)

The two most feasible control devices for frit smelters are baghouses, and venturi water scrubbers. The collection efficiencies obtainable for venturi scrubbers are shown in Table 81. Emission factors for frit smelters are also shown in this table.

TABLE 81[C] UNCONTROLLED EMISSION FACTORS FOR FRIT SMELTERS
(pounds per ton of charge)[a]

Type Furnace	Particulates[b]	Fluorides[b]
Rotary	16	5

a = Reference 330

b = A venturi scrubber with a 21 inch water gauge pressure drop can reduce particulate emissions by 67 percent and fluorides by 94 percent.

GLASS MANUFACTURING

Process Description[322,331]

Nearly all glass produced commercially is one of five basic types: soda-lime, lead, fused silica, borosilicate, and 96 percent silica. Of these, the modern soda-lime glass constitutes 90 percent of the total glass produced and will thus be the only type discussed in this section. Soda-lime glass is produced on a massive scale in large, direct-fired, continuous melting furnaces in which the blended raw materials are melted at 2700°F to form glass.

Emissions and Controls[331,332]

Emissions from the glass melting operation consist primarily of particulates and fluorides, if fluoride-containing fluxes are used in the process. Because the dust emissions contain particles only a few microns in diameter, cyclones and centrifugal scrubbers are not as effective as baghouses or filters in collecting particulate matter. Table 82 summarizes the emission factors for glass melting.

TABLE 82[D] EMISSION FACTORS FOR GLASS MELTING
(pounds per ton of glass produced)

Type Glass	Particulates[a]	Fluorides[b]
Soda-Lime	2	4F[c]

a = Reference 263

b = Reference 303

c = F equals weight percent fluoride in input to furnace, e.g., if fluoride content is 5%, emission factor would be 4F or 20.

GYPSUM

Process Description[13]

Gypsum or hydrated calcium sulfate is a naturally occurring mineral which is an important building material. When heated gypsum loses its water of hydration and becomes plaster of paris, or when blended with fillers it serves as wall plaster. In both cases the material hardens as water reacts with it to form the solid crystalline hydrate.[333,334]

The usual method of calcination of gypsum consists of grinding the mineral and placing it in large externally heated calciners. Complete calcination takes about 3 hours and requires about 1.0 million BTU to calcine 1 ton of plaster.[335,336]

Emissions[13]

Calcining gypsum appears to be devoid of any air pollutants, since the process involved is simply relative low temperature removal of the water of hydration. However, the resultant gases created by the release of the water of crystallization carry gypsum rock dust and partially calcined gypsum dust into the atmosphere.[337] In addition, dust emissions from the grinding of the gypsum before calcining, and from the mixing of the calcined gypsum with filler also occur. Table 83 presents emission factors for gypsum processing.

TABLE 83[C] PARTICULATE EMISSION FACTORS FOR GYPSUM PROCESSING[a]
(pounds per ton of throughput)

Type Process	Uncontrolled Emissions	With Fabric Filter	With Cyclone and Electrostatic Precipitator
Raw Material Dryer (if used)	40	0.2	0.4
Primary Grinder	1	0.001	--
Calciner	90	0.1	--
Conveying	0.7	0.001	--

a = Reference 338

LIME MANUFACTURING

General[13]

Lime (CaO) is the high temperature product of the calcination of limestone ($CaCO_3$). Lime is manufactured in vertical or rotary kilns fired by coal, oil, or natural gas.

Emissions and Controls[13]

Atmospheric emissions in the lime manufacturing industry include the particulate emissions from the mining, handling, crushing, screening and calcining of the limestone and the combustion products from the kilns. The vertical kilns, because of the use of larger size of charge material, lower air velocities and less agitation, have considerably less particulate emission. Control of emissions from vertical kilns is accomplished by sealing the exit of the kiln and exhausting the gases through control equipment.

Particulate emission problems are much greater on the rotary kilns due to smaller size of charge material, higher fuel consumption, and greater air velocities through the rotary chamber. Methods of control on rotary kiln plants include simple and multiple cyclones, wet scrubbers, baghouses and electrostatic precipitators.[339] Emission factors for lime manufacturing are summarized in Table 84.

TABLE 84[B] UNCONTROLLED PARTICULATE EMISSION FACTORS FROM LIME MANUFACTURING (pounds per ton processed)[a]

Operation	Emissions
Crushing[b]	
Primary	31
Secondary	2
Calcining[c]	
Vertical Kiln	8
Rotary Kiln	200

a = Cyclones could reduce this factor by about 70%. Venturi scrubbers could reduce this factor by about 95-99%.
Fabric filters could reduce this factor by about 99%.

b = Reference 340

c = References 339, 341, 342

MINERAL WOOL

Process Description[343,344]

The product mineral wool used to be divided into three categories: slag wool, rock wool, and glass wool. Today, however, straight slag wool and rock wool as such are no longer manufactured. A combination of slag and rock constitutes the charge material now yielding a product classified as a mineral wool, used mainly for thermal and acoustical insulation.

Mineral wool is made primarily in cupola furnaces charged with blast furnace slag, silica rock, and coke. The charge is heated to a molten state at about 3000°F and then fed to a blow chamber, where steam atomizes the molten rock into globules, which develop long fibrous tails as they are drawn to the other end of the chamber. The wool blanket formed is then conveyed to an oven to cure the binding agent and then to a cooler.

Emissions and Controls

The major source of emissions is the cupola or furnace stack. Its discharge consist primarily of condensed fumes that have volatilized from the molten charge, and gases such as sulfur oxides and fluorides. Minor sources of particulate emissions include the blowchamber, curing oven, and cooler. The effect of control devices on emissions has been shown in Table 85. This table also presents emission factors for various mineral wool processes.

TABLE 85[C] UNCONTROLLED EMISSION FACTORS FROM MINERAL WOOL PROCESSES (pounds per ton of charge)[a]

Type Process	Particulates	Sulfur Oxides
Cupola	22	0.02
Reverberatory Furnace	5	Neg.
Blow Chamber[b]	17	Neg.
Curing Oven[c]	4	Neg.
Cooler	2	Neg.

a = Reference 344

b = A centrifugal water scrubber can reduce particulate emissions by 60%.

c = A direct-flame afterburner can reduce particulate emissions by 50%.

PERLITE MANUFACTURING

Process Description[345,346]

Perlite is a glassy, volcanic rock consisting or oxides of silicon and aluminum combined as a natural glass by water of hydration. By a process called exfoliation, the material is rapidly heated to release water of hydration and thus expand the spherules into low-density particles used primarily as aggregate in plaster and concrete. A plant for the expansion of perlite consists of ore-unloading and storage facilities, a furnace-feeding device, expanding furnace, provisions for gas and product cooling, product-classifying and product collecting equipment. Vertical furnaces, horizontal stationary furnaces and horizontal rotary furnaces are used for the exfoliation of perlite, the vertical types being the most numerous. Cyclone separators are used to collect the product.

Emissions and Controls[346]

A fine dust is emitted from the outlet of the last product collector in a perlite expansion plant. The fineness of the dust varies from one plant to another, depending upon the desired product. In order to achieve complete control of these particulate emissions a baghouse is needed. Simple cyclones and small multiple cyclones are not adequate for collecting the fine dust from the perlite furnaces. Table 86 summarizes the emissions from perlite manufacturing.

TABLE 86[C] UNCONTROLLED PARTICULATE EMISSION FACTORS FOR PERLITE EXPANSION FURNACES
(pounds per ton of charge)[a]

Type Furnace	Emissions[b]
Vertical	21

a = Reference 347

b = Primary cyclones will collect 80% of the particulates above 20 microns and baghouses will collect 96% of the particles above 20 microns.[346]

Process Description[348]

Phosphate rock preparation involves the benefication to remove impurities, drying to remove moisture, and grinding to improve reactivity. Usually, direct fired rotary kilns are used to dry phosphate rock. These dryers use natural gas or fuel oil as fuel and are fired countercurrently. From the dryers, the material may be ground before storage and is finally conveyed to large storage silos. Air-swept ball mills are preferred for grinding phosphate rock.

Emissions and Controls[348]

Although there are no significant emissions from phosphate rock benefication plants, emissions in the form of fine rock dust may be expected from drying and grinding operations. Phosphate rock dryers are usually equipped with dry cyclones followed by wet scrubbers. Particulate emissions are usually higher when drying pebble rock than concentrate, because of the small adherent particles of clay and slime on the rock. Phosphate rock grinders can be a considerable source of particulates. Because of the extremely fine particle size, baghouse collectors are normally used to reduce emissions. Emission factors for phosphate rock processing are presented in Table 87.

TABLE 87[C] UNCONTROLLED PARTICULATE EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING

(pounds per ton of phosphate rock)

Type Source	Emissions
Drying[a,e]	15
Grinding[a,d]	20
Transfer and Storage[b,d]	2
Open Storage Piles[c]	40

a = References 349,350,351

b = Reference 350

c = Reference 352

d = Dry cyclones followed by fabric filters can reduce emissions by 99.5-99.9%.

e = Dry cyclones followed by wet scrubbers can reduce emissions by 95-99%.

STONE QUARRYING AND PROCESSING

Process Description[13]

Rock and gravel products are loosened by drilling and blasting from their deposit beds and removed with the use of heavy earth moving equipment. This mining of rock is done primarily in open pits. The use of pneumatic drilling and cutting as well as the blasting and transferring cause considerable dust formation. Further processing includes crushing, regrinding, and removal of fines.[353] Dust emissions can occur from all of these operations as well as from quarrying, transferring, loading, and storage operations. Drying operations, when used, can also be a source of dust emissions.

Emissions[13]

As discussed above dust emissions occur from many operations in stone quarrying and processing. Since a big portion of these emissions are heavy particles and settle out within the plant an attempt has been made to estimate the suspended particulates. These emission factors are shown in Table 88. Factors affecting emissions include the amount of rock processed, the method of transfer of the rock, the moisture content of the raw material, the degree of enclosure of the transferring, processing or storage areas, and the degree to which control equipment is used on the processes.

TABLE 88[c] PARTICULATE EMISSION FACTORS FROM ROCK HANDLING PROCESSES

Type Process	Uncontrolled[a] Total	% Settled Out in Plant	Suspended Emission
Crushing Operations	lbs/ton of raw material[b,c]		
Primary Crushing	0.5	80	0.1
Secondary Crushing and Screening	1.5	60	0.6
Tertiary Crushing and Screening (if used)	6.0	40	3.6
Recrushing and Screening	5.0	50	2.5
Fines Mill	6.0	25	4.5
Miscellaneous Operations		Total Particulates lbs/ton of product	
Screening, Conveying and Handling[d]		2	
Storage Pile Losses[e]		10	

a = Typical collection efficiencies: Cyclone 70-85%, Fabric Filter 99%

b = All values are based on raw material entering primary crusher except for recrushing and screening which is based on throughput for that operation.

c = Reference 354

d = Reference 355

e = Reference 356

PETROLEUM INDUSTRY

PETROLEUM REFINERY

General[357]

Although a modern refinery is a complex system of many processes, the entire operation can be divided into four major steps: separation, conversion, treating, and blending. The crude oil is first separated into selected fractions (e.g., gasoline, kerosine, fuel oil, etc.). Since the relative volumes of each fraction produced by merely separating the crude may not conform to the relative demand for each fraction, some of the less valuable products such as heavy naptha, are converted to products with a greater sale value such as gasoline. This is done by splitting, uniting, or rearranging the original molecules. The final step is the blending of the refined base stocks with each other and various additives to meet final product specifications. The various unit operations involved at petroleum refineries will be briefly discussed in the following sections.

Crude Oil Distillation:[357]

Since crude oil is composed of hydrocarbons of different physical properties, it can be separated by physical means into its various constituents. The primary separation is usually accomplished by distillation. The fractions from the distillation include refinery gas, gasoline, kerosine, light fuel oil, diesel oils, gas oil, lube distillate and heavy bottoms. These "straight run products" are treated to remove impurities and used as base stocks, feedstock for other refinery units of sold as finished products.

Catalytic Cracking:[357]

To obtain the desired product distribution and quality, heavy hydrocarbon molecules are cracked or split to form low-boiling hydrocarbons in the gasoline range. Catalytic cracking units are classified according to the method used for catalyst transfer. The two most widely used methods are the moving-bed, typified by the Thermofor Catalytic Cracking Units (T.C.C.) and the fluidized bed system of Fluid Catalytic Cracking Units (F.C.C.).

In a typical "cat" cracker the catalyst in the form of beads or pellets, passes through the reactor, then through a regeneration zone where coke deposited on the catalyst is burned off in a continuous process.

Catalytic Reforming:[357]

Unlike catalytic cracking, catalytic reforming does not increase the gasoline yield from a barrel of crude oil. Reforming uses gasoline as a feedstock and by molecular rearrangement, usually including hydrogen removal, produces a gasoline of higher quality and octane number. Coke deposition is not severe in reforming operations and thus catalyst regeneration is not always used. In this case the catalyst is physically removed and replaced periodically. Some of the fixed-bed catalytic reforming processes which require catalyst regeneration include: Fixed-Bed Hydroforming, Ultraforming, and Powerforming. Some of the fixed-bed processes in which the catalyst is infrequently regenerated include: Platforming, Rexforming, and Catforming.

Polymerization, Alkylation, Isomerization:[357]

Polymerization and alkylation are processes used to produce gasoline from the gaseous hydrocarbons formed during cracking operations. Polymerization joins two or more olefins, and alkylation unites an olefin and an isoparaffin. In the process of isomerization the arrangement of the atoms in a molecule is altered, usually to form branched-chain hydrocarbons.

Treating, Blending:[357]

The products from both the separation and conversion steps are treated, usually for the removal of sulfur compounds and gum-forming materials. As a final step, the refined base stocks are blended with each other and with various additives to meet product specifications.

Emissions[357]

Emissions from refineries vary greatly in both the quantity and type. The most important factors affecting refinery emissions are crude oil capacity, air pollution control equipment used, general level of maintenance and the processing scheme used. The major pollutants emitted are sulfur oxides, nitrogen oxides, hydrocarbons, carbon monoxide, and malodorous materials. Other emissions of lesser importance include particulates, aldehydes, ammonia, and organic acids. Boilers, process heaters, and catalytic cracking unit regenerators are major sources of sulfur oxides, nitrogen oxides and particulates. The catalytic cracking unit regenerators are also large sources of carbon monoxide, aldehydes and ammonia. The many hydrocarbon sources include: waste water separators, blow-down systems, catalyst regenerators, pumps, valves, cooling towers, vacuum jets, compressor engines, process heaters and boilers. A summary of emission factors for the various refinery operations is summarized in Table 89.

TABLE 89^{B} EMISSION FACTORS FOR PETROLEUM REFINERIES[a]

Type Process	Particulates	Sulfur Oxides	Carbon Monoxide	Hydro-Carbons	Nitrogen Oxides	Aldehydes	Ammonia
Boilers & Process Heaters							
lb/1000 bbl oil burned	840	NA	Neg.	140	2,900	25	--
lb/1000 ft^3 gas burned	0.02	NA	Neg.	0.03	0.23	0.003	--
Fluid Catalytic Cracking Units (FCC)							
lb/1000 bbl of fresh feed	61	525	13,700	220	63	19	54
Moving-bed Catalytic Cracking Units (TCC)							
lb/1000 bbl of fresh feed	17	60	3,800	87	5	12	6
Compressor Internal Combustion Engines							
lb/1000 ft^3 of gas burned	--	--	Neg.	1.2	0.9	0.1	0.2
Blowdown Systems							
lb/1000 bbl refinery capacity							
with control	--	--	--	5	--	--	--
without control	--	--	--	300	--	--	--
Process Drains							
lb/1000 bbl waste water							
with control	--	--	--	8	--	--	--
without control	--	--	--	210	--	--	--
Vacuum Jets							
lb/1000 bbl vacuum distillation							
with control	--	--	--	Neg.	--	--	--
without control	--	--	--	130	--	--	--
Cooling Tower							
lb/1,000,000 gal. cooling water	--	--	--	6	--	--	--
Miscellaneous Losses							
lb/1000 bbl refinery capacity							
Pipeline Valves & Flangers	--	--	--	28	--	--	--
Vessel Relief Valves	--	--	--	11	--	--	--
Pumps Seals	--	--	--	17	--	--	--
Compressor Seals	--	--	--	5	--	--	--
Others (Air Blowing, Sampling, etc.)	--	--	--	10	--	--	--

a = Reference 1

NA = Information not available

WOOD PROCESSING

Wood processing involves the conversion of raw wood to either pulp or pulpboard. This section presents emission data for two types of pulpboard--paperboard and fiber board and emission data for wood pulping operations. The burning of wood waste in boilers and conical burners are not included as they are discussed in other sections of this publication.

WOOD PULPING INDUSTRY

General[358]

Wood pulping involves the production of cellulose from wood by dissolving the lignin that binds the cellulose fiber together. The three major chemical processes for pulp production are the kraft or sulfate process, the sulfite process and the neutral sulfite semichemical process. The choice of the pulping process is determined by the product being made, by the type of wood species available, and by economic considerations. There is a lack of valid emission data for the sulfite and neutral sulfite semichemical processes. For this reason only the kraft process will be discussed in this section.

Process Description (Kraft Process)[358,359]

The kraft process involves the cooking of wood chips in either a batch or continuous digester, under pressure, in the presence of a cooking liquor. The cooking liquor, an aqueous solution of sodium sulfide and sodium hydroxide, dissolves the lignin that binds the cellulose fibers together.

When cooking is completed, the bottom of the digester is suddenly opened, and its contents forced into the blow tank. Here, the major portion of the spent cooking liquor, containing the dissolved lignin, is drained, and pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter, where unreacted chunks of wood are removed. The pulp is then processed through intermittent stages of washing and bleaching, after which it is pressed and dried into the finished product.

Most of the chemicals from the spent cooking liquor are recovered for re-use in subsequent cooks. These spent chemicals and organics, called "black liquor," are concentrated in multiple-effect evaporators and/or direct contact evaporators.

The concentrated black liquor is then sprayed into the recovery furnace, where the organic content supports combustion. The inorganic compounds fall to the bottom of the furnace and are withdrawn as a molten smelt, which is dissolved to form a solution called "green liquor." The green liquor is then pumped from the smelt dissolving tank, treated with slaked lime, and then clarified. The resulting liquor referred to as "white liquor" is the cooking liquor used in the digestors.

Emissions and Controls[360]

Particulate emissions from the kraft process occur primarily from the recovery furnace, the lime kiln and the smelt dissolving tank. They are caused mainly by the carry-over of solids plus the sublimation and condensation of inorganic chemicals.

The characteristic kraft mill odor is principally due to the presence of a variable mixture of hydrogen sulfide, and dimethyl disulfide. Hydrogen sulfide emissions are derived from the breakdown of the weak base, sodium sulfide, which is the characteristic of kraft cooking liquor. It may also be generated by improper operation of a recovery furnace. Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignins.

Sulfur dioxide emissions in the kraft process result from the oxidation of reduced sulfur compounds. A potential source of sulfur dioxide is the recovery boilers, where reduced sulfur gases present can be oxidized in the furnace atmosphere.

Potential sources of carbon monoxide emissions from the kraft process include the recovery furnace and lime kilns. The major cause of carbon monoxide emissions is furnace operation well above rated capacity, making it impossible to maintain oxidizing conditions.

Rather than presenting a lengthy discussion on the presently available control techniques for each phase of the kraft process, the most used controls are shown, where applicable, in the table for emission factors. Table 90 presents these emission factors for both the controlled and uncontrolled sources.

PULPBOARD

General[13]

Pulpboard manufacturing includes the manufacture of fibrous boards from a pulp slurry. This includes two distinct types of product, paperboard and fiberboard. Paperboard is a general term which describes a sheet 0.012 inches or more in thickness made of fibrous material on a paper machine.[362] Fiberboard, also referred to as particle board, is much thicker than paperboard and is made somewhat differently.

There are two distinct phases in the conversion of wood to pulpboard. These are (1) the manufacture of pulp from the raw wood and (2) the manufacture of pulpboard from the pulp. This section deals only with the latter as the first is covered under the wood pulping industry.

Process Description[13]

In the manufacture of paperboard the stock is sent through screens into the head box from which it flows onto a moving screen. Approximately 15 percent of the water is removed by suction boxes located under the screen. Another 50-60 percent of the moisture content is removed in the drying section. After drying, the board enters the calendar stack which imparts the final surface to the product.

TABLE 90[A] EMISSION FACTORS FROM (SULFATE) PULPING[a]

(pounds per air dry ton of unbleached pulp)

SOURCE	Particulates[d]	Sulfur Dioxides (SO_2)[d]	Carbon Monoxide[b]	Hydrogen Sulfide[d]	RSH, RSR RSSR[d]	Type of Control
Blow Tank Accumulator	--	--	--	0.1	3.0	Untreated
Washers and Screens	--	--	--	0.02	0.2	Untreated
Multiple-effect Evaporators	--	--	--	0.5	0.4	Untreated
Recovery Boilers and Direct-Contact Evaporators	105	5.0	60	12	0.9	Untreated
	7	5.0	60	12	0.9	Electrostatic Precipitators
	47	5.0	60	12	0.9	Venturi-Scrubbe
Smelt Dissolving Tank	2	--	--	0.03	0.04	Untreated
Lime Kilns	45	--	10	1.0	0.6	Untreated
	4	--	10	1.0	0.6	Scrubber
Turpentine Condenser	--	--	--	0.01	0.5	Untreated
Fluidized-Bed[e] Calciner	72	--	--	--	--	Untreated
	0.7	--	--	--	--	Scrubber

a = for more detailed data on specific types of plants consult reference 358

b = Reference 361

c = RSH - Mercaptans, RSR - Sulphides, RSSR - Disulphides

d = Reference 358

e = Only a few plants in the Western United States use this process.

In the manufacture of fiberboard the slurry remaining after pulping, is washed and enters the stock chests where sizing is added. The refined fiber from the stock chests are fed to the head box of the board machine. The stock is then fed onto the forming screens and sent to dryers. After drying, the product is cut and fabricated.

Emissions[13]

Emissions from the paperboard machine consist only of water vapor.[46,363,364] Little or no particulates are emitted from the dryers. Particulate emissions from the drying operation of fiberboard do occur. Additional particulate emissions occur from the cutting and sanding operations but no data were available to estimate these emissions. Emission factors for pulpboard manufacturing are shown in Table 91.

TABLE 91[E] PARTICULATE EMISSION FACTORS FOR PULPBOARD MANUFACTURING
(pounds per ton of finished product)

Type Product	Emissions
Paperboard	Negligible
Fiberboard[a]	0.6

a = Reference 365

APPENDICES

A. CONVERSION FACTORS

TABLE A-1. THERMAL CONVERSION FACTORS

Type Fuel	BTU (Gross)
Solid Fuels	
Bituminous Coal & Lignite	$26.2\text{x}10^6$/ton
Anthracite Coal	$25.3\text{x}10^6$/ton
Wood	$21.0\text{x}10^6$/cord
Liquid Fuels	
Residual Fuel Oil	$6.3\text{x}10^6$/bbl
Distillate Fuel Oil	$5.9\text{x}10^6$/bbl
Gaseous Fuels	
Natural Gas	1,050/cu. ft.
Liquified Petroleum Gas	
Butane	337,000/gal.
Propane	308,000/gal.

TABLE A-2. WEIGHTS AND VOLUMES OF SELECTED SUBSTANCES

Type Fuel	Pounds/Gallon
Asphalt	8.57
Butane	16.7
Crude	7.08
Distillate Oil	7.05
Gasoline	6.17
Propane	13.8
Residual Oil	7.88
Water	8.4

TABLE A-3 GENERAL CONVERSION FACTORS

Type Source	Conversion Factors
Fuel Combustion	
Oil	1 barrel = 42 gallons
Natural Gas	1 therm = 100,000 BTU ≈ 95 cu. ft.
Food and Agriculture	
Corn	1 bushel = 56 pounds
Milo	1 bushel = 56 pounds
Oats	1 bushel = 32 pounds
Barley	1 bushel = 48 pounds
Wheat	1 bushel = 60 pounds
Cotton	1 bale = 500 pounds
Mineral Products	
Brick	1 brick = 6.5 pounds
Cement	1 barrel = 375 pounds
Cement	1 cubic yard = 2500 pounds
Concrete	1 cubic yard = 4000 pounds
Mobile Sources	
Gasoline Powered Motor Vehicle	12.5 miles per gallon
Diesel Powered Motor Vehicle	5.1 miles per gallon
Steamship	44 gallon per nautical mile
Motorship	14 gallon per nautical mile
Other Industries	
Paint	1 gallon = 10-15 pounds
Varnish	1 gallon = 7 pounds
Whiskey	1 barrel = 50 gallons
Water	1 gallon = 8.4 pounds
Miscellaneous Factors	1 pound = 7000 grains
	1 cubic foot = 7.48 gallons
Metric System	1 foot = 0.3048 meters
	1 mile = 1609 meters
	1 pound = 453,6 grams
	1 ton (short) = 907.2 kilograms
	1 ton (short) = 0.9072 tons (metric)

B. NATIONWIDE EMISSION ESTIMATES

TABLE B-1. NATIONWIDE EMISSIONS FOR 1968
(million tons per year)[a]

Source	Particulates	Sulfur Oxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides
Stationary Combustion	8.9	24.4	1.9	0.7	10.0
Solid Waste Disposal	1.1	0.1	7.8	1.6	0.6
Mobile Combustion	1.2	0.8	63.8	16.6	8.1
Industrial Process	7.5	7.3	9.7	4.6	0.2
Miscellaneous	9.6	0.6	16.9	8.5	1.7
TOTAL	28.3	33.2	100.1	32.0	20.6

a - Reference 1

C. PARTICLE SIZE DATA

TABLE C-1. PARTICLE SIZE DISTRIBUTION FROM SELECTED SOURCES WITHOUT CONTROL EQUIPMENT

Type Source	Percent less than 5 microns	Percent 5-10 microns	Percent 10-20 microns	Percent 20-44 microns	Percent greater than 44 microns
Stationary Combustion					
Bituminous Coal					
Pulverized	15	17	20	23	25
Cyclone	65	10	8	7	10
Stoker	4	6	11	18	61
Anthracite Coal	35	5	8	7	45
Fuel Oil	50	NA	NA	NA	0
Natural Gas	100	--	--	--	--
Solid Waste Disposal					
Refuse Incineration	12	10	15	18	45
Mobile Combustion					
Gasoline-Powered Motor Vehicles	100	--	--	--	--
Diesel-Powered Motor Vehicles	63	NA	NA	0	0
Aircraft	100	--	--	--	--
Chemical Process					
Phosphoric Acid	100	--	--	--	--
Soap and Detergents	5	15	40	30	10
Sulfuric Acid	100	--	--	--	--
Food and Agriculture					
Alfalfa Dehydrating		Average size 2-10 microns			
Cotton Ginning	NA	NA	NA	NA	40
Feed and Grain	5	15	20	45	15
Fish Meal	1	1	3	8	87
Phosphate Fertilizer	6	6	10	8	70
Metallurgical					
Primary Aluminum	13	12	12	13	50
Primary Zinc	14	17	40	NA	NA
Iron and Steel					
Sintering	0	0	15	15	85
Blast Furnace	NA	NA	NA	NA	70
Open Hearth	46	22	17	20	5
	64	8	8	14	14
Basic Oxygen	99.5	0.5	0	0	0
Bessemer Converter	--	--	--	100	--
Secondary Aluminum	34	30	23	10	3
Brass & Bronze	100	--	--	--	--
Gray Iron Foundry	18	8	12	14	48
Secondary Lead	95	3	2	0	0
Secondary Steel	60	14	11	9	6
Secondary Zinc	100	--	--	--	--
Mineral Products					
Asphalt Batching	35	25	17	20	3
Asphalt Roofing	100	--	--	--	--
Ceramic Clay	36	NA	NA	40	6
Castable Refractories	100	--	--	--	--
Cement	22	25	25	20	8
Concrete	13	21	27	25	14
Frit	45	15	15	15	10
Glass	26	NA	NA	NA	0
Gypsum		95% smaller than 10 microns			
Lime	2	8	24	38	28
Mineral Wool	0.5	2.5	10	27	60
Perlite	32	10	10	13	35
Phosphate Rock	80	15	5	0	0
Stone Quarrying & Processing					
Crushing	5	5	5	10	75
Conveying & Screening	30	20	20	18	12
Petroleum Refinery					
Catalyst Regenerator	50	15	NA	NA	NA
Wood Processing					
Fiberboard	NA	NA	NA	NA	25

NA = No further breakdown of particle distribution available.

D. PARTICULATE CONTROL EQUIPMENT

TABLE D-1. AVERAGE COLLECTION EFFICIENCIES FOR VARIOUS PARTICLE SIZES AND VARIOUS PARTICULATE CONTROL EQUIPMENT[a,b]

Type Collector	Efficiency, %					
	Overall	0-5	5-10	10-20	20-44	>44
Baffled Settling Chamber	58.6	7.5	22	43	80	90
Simple Cyclone	65.3	12	33	57	82	91
Long-cone Cyclone	84.2	40	79	92	95	97
Multiple Cyclone (12 in. diameter)	74.2	25	54	74	95	98
Multiple Cyclone (6 in. diameter)	93.8	63	95	98	99.5	100
Irrigated Long-cone Cyclone	91.0	63	93	96	98.5	100
Electrostatic Precipitator	97.0	72	94.5	97	99.5	100
Irrigated Electrostatic Precipitator	99.0	97	99	99.5	100	100
Spray Tower	94.5	90	96	98	100	100
Self-induced Spray Scrubber	93.6	85	96	98	100	100
Disintegrator Scrubber	98.5	93	98	99	100	100
Venturi Scrubber	99.5	99	99.5	100	100	100
Wet Impingement Scrubber	97.9	96	98.5	99	100	100
Baghouse	99.7	99.5	100	100	100	100

a - References 366,367

b - Data based on standard silica dust with the following particle distribution:

Particle Size Range Microns	Percent by Weight
0-5	20
5-10	10
10-20	15
20-44	20
>44	35

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