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**A Survey of Potential Health
and Safety Hazards of
Commercial-Scale Ethanol
Production Facilities**

A. P. Watson
J. G. Smith
J. L. Elmore

**OPERATED BY
UNION CARBIDE CORPORATION
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Health and Safety Research Division
Information Division*
Environmental Sciences Division**

A SURVEY OF POTENTIAL HEALTH AND SAFETY HAZARDS OF
COMMERCIAL-SCALE ETHANOL PRODUCTION FACILITIES

A. P. Watson
J. G. Smith*
J. L. Elmore**

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NOTICE This document contains information of a preliminary nature.
It is subject to revision or correction and therefore does not represent a
final report.

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by
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operated by
UNION CARBIDE CORPORATION
for the
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TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	v
LIST OF TABLES.	vi
ACKNOWLEDGMENTS	viii
SUMMARY	ix
1. INTRODUCTION.	1
2. FUEL-ALCOHOL PLANTS (<i>J. L. Elmore</i>).	5
2.1 FEEDSTOCK PREPARATION, FERMENTATION AND BY-PRODUCT RECOVERY.	6
2.1.1 Plants using grains as feedstocks	6
2.1.2 Plants using sugarcane feedstock.	12
2.2 APPROACHES TO DEHYDRATION AND DENATURATION	14
2.2.1 Dehydration	14
2.2.2 Denaturation.	15
2.3 PLANT ENERGY OPTIONS	15
2.3.1 Coal.	24
2.3.2 Bagasse	24
2.3.3 Wood and other biomass.	25
2.3.4 Natural gas	25
2.3.5 Mixed fuels	25
2.4 RESOURCE REQUIREMENTS.	27
2.4.1 Feedstocks.	27
2.4.2 Fuel.	28
2.4.3 Land.	28
2.4.4 Water	31
2.4.5 Employment.	31
2.4.5.1 Construction labor requirements.	31
2.4.5.2 Operating labor requirements	34
REFERENCES FOR SECTION 2.	36
3. EFFLUENTS AND EFFLUENT CONTROL (<i>J. L. Elmore</i>)	39
3.1 LIQUID EFFLUENTS	39
3.1.1 Process waste streams	39
3.1.2 Runoff.	42
3.2 SOLID EFFLUENTS.	46
3.3 ATMOSPHERIC EFFLUENTS.	50
3.3.1 Process waste streams	50
3.3.2 Power plant emissions	53
3.3.3 Stored product emissions.	59
REFERENCES FOR SECTION 3.	61
4. OCCUPATIONAL SAFETY CONSIDERATIONS (<i>A. P. Watson and J. G. Smith</i>).	65
4.1 FEEDSTOCK HANDLING	65
4.2 FUEL HANDLING.	68
4.3 LIQUEFACTION AND SACCHARIFICATION.	71

TABLE OF CONTENTS (cont'd)

	<u>Page</u>
4.4 FERMENTATION	72
4.5 DISTILLATION	74
4.6 SUMMARY.	75
REFERENCES FOR SECTION 4.	81
5. OCCUPATIONAL HEALTH CONSIDERATIONS (<i>J. G. Smith</i>).	85
5.1 ETHANOL DESICCANTS	85
5.1.1 Benzene	85
5.1.2 Gasoline.	87
5.1.3 Ethyl ether	88
5.1.4 Ethylene glycol	89
5.1.5 Alternative desiccation	90
5.1.6 Assessment of desiccants.	90
5.2 ETHANOL DENATURANTS.	93
5.2.1 Methanol.	93
5.2.2 Methyl isobutyl ketone.	94
5.2.3 Aldol	94
5.2.4 Kerosene.	95
5.2.5 Assessment of denaturants	95
REFERENCES FOR SECTION 5.	99
6. PUBLIC HEALTH AND SAFETY CONSIDERATIONS (<i>A. P. Watson</i>).	103
6.1 ATMOSPHERIC RELEASES	103
6.2 STILLAGE DISPOSAL.	105
REFERENCES FOR SECTION 6.	106
APPENDIX A, REGULATORY COMPLIANCE: OCCUPATIONAL.	107
APPENDIX B, REGULATORY COMPLIANCE: PUBLIC.	119
GLOSSARY.	126
LIST OF ABBREVIATIONS	128

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
2.1	Fuel alcohol plant modules.	7
2.2	Dry milling, fermentation and DDG drying.	8
2.3	Wet milling, fermentation and stillage handling	11
2.4	Sugarcane handling, fermentation and stillage evaporation	13
2.5	Distillation and benzene dehydration.	16
2.6	Distillation and ethylene glycol dehydration.	17
2.7	Distillation and ethyl ether dehydration.	18
2.8	Distillation and gasoline dehydration	19
2.9	Coal-fired power plant emissions.	20
2.10	Bagasse-fired boiler emissions.	21
2.11	Wood-fired boiler emissions	22
2.12	Natural gas-fired boiler emissions.	23
3.1	Miscellaneous emissions associated with fuel alcohol production (fluxes based on 60 million liters/year capacity grain dry milling plant)	43
A.1	Comparison of normally-encountered sound levels (Witt, 1980).	112

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 Estimated fuel requirements of fuel alcohol plants producing 60×10^6 L (16×10^6 gal) per year	29
2.2 Estimated water requirements of fuel alcohol plants producing 60×10^6 L (16×10^6 gal) per year	32
2.3 Alcohol fuel facility construction estimates compared with those for a chemical plant.	33
2.4 Craft mix for chemical plant construction.	35
3.1 Estimated flux rates of major liquid effluents from 60×10^6 L (16×10^6 gal) per year fuel alcohol plant. . .	40
3.2 Estimated water quality of major effluents from 60×10^6 L (16×10^6 gal) per year fuel alcohol plants . .	41
3.3 pH values for cold water extractions of plant residues . .	44
3.4 Representative water quality measurements for coal pile leachate and coal pile drainage (all values except pH expressed as mg/L)	45
3.5 Representative water quality measurements for effluents from coal waste disposal (all values except pH expressed as mg/L)	47
3.6 Estimated solid waste effluents from 60 million liter/year (16×10^6 gallons/year) fuel alcohol plants	48
3.7 Composition of distillery stillage (data expressed as mg/L except for pH)	49
3.8 Estimated major atmospheric effluents from 60×10^6 L (16×10^6 gal) per year alcohol plants	54
3.9 Emissions from gasoline and denatured alcohol storage. . .	60
4.1 Potential hazards and their control in fuel-ethanol facilities	76
4.2 Summary of accidents investigated by OSHA for SIC 2041; January, 1979 through April, 1981.	78
4.3 Occupational injury and illness rates in ethanol-related industries; 1978 and 1979.	80

LIST OF TABLES (cont'd)

<u>Table</u>		<u>Page</u>
5.1	Proposed threshold limit values (TLV), human toxicities, relative toxicities, estimated quantity used, and estimated hazard potential of potential alcohol desiccants	91
5.2	Proposed threshold limit values (TLV), human toxicities, relative toxicities, estimated quantity used, and estimated hazard potential of the potential alcohol denaturants.	97
6.1	Estimated release of atmospheric pollutants at ethanol production facilities according to fuel and feedstock used (kg/h).	104
A.1	Permissible workplace noise exposures.	113
B.1	Federal atmospheric pollution control standards for selected combustion products	122

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SUMMARY

Generic safety and health aspects of commercial-scale (60 to 600 million L/y) anhydrous ethanol production have been identified. Several common feedstocks (grains, roots and fibers, and sugarcane) and fuels (coal, natural gas, wood, and bagasse) were evaluated throughout each step of generic plant operation, from initial milling and sizing through saccharification, fermentation, distillation, and stillage disposal.

The fermentation, digestion, or combustion phases are not particularly hazardous, although the strong acids and bases used for hydrolysis and pH adjustment should be handled with the same precautions that every industrial solvent deserves. The most serious safety hazard is that of explosion from grain dust or ethanol fume ignition and boiler/steam line overpressurization. Inhalation of ethanol and carbon dioxide vapors may cause intoxication or asphyxiation in unventilated areas, which could be particularly hazardous near equipment controls and agitating vats. Contact with low-pressure process steam would produce scalding burns. Benzene, used in stripping water from ethanol in the final distillation column, is a suspected leukemogen. Substitution of this fluid by alternative liquids is addressed.

1. INTRODUCTION

The development of a viable fuel alcohol industry in the United States is considered by many to be a feasible solution to the problem of maintaining ample domestic supplies of liquid fuels in an unstable world petroleum market. The fact that fermentation and distillation of various sugar and starch feedstocks is an existing and well-understood technology makes ethanol a particularly attractive fuel. Most current emphasis is on distillation of absolute ethanol for blending with gasoline to produce gasohol. The U.S. Department of Energy (DOE) Office of Alcohol Fuels has an interest in evaluating the effects of expanded fuel production on local and regional environments, the work force, and nearby human residents. This and a companion document¹ generically address these issues for commercial-scale [60 to 600×10^6 liters per year (L/y)] facilities.

The scope of the following analysis is necessarily limited by the absence of design plans for a generic facility and identification of a single feedstock-fuel combination. As a result, hazards of several feedstocks and fuels are addressed.

Little job-specific or production-module data necessary for an occupational assessment are available outside the beverage alcohol industry. Thus, only potential problem areas are identified and discussed. No fuel source is completely benign, and ethanol is no exception. Proper attention to sound safety design and industrial hygiene practice will be required by owner-operators in the design, construction, and operation of fuel ethanol facilities.

Facility design and operation is discussed in Sect. 2, followed by descriptions of potential effluents and their control (Sect. 3). The text of these two chapters was originally published in the companion Generic Environmental Assessment Report.¹ Sections 4 and 5 address occupational safety and health considerations, while Sect. 6 does the same for public safety and health. Descriptions and listings of Occupational Safety and Health Administration (OSHA) and U. S. Environmental Protection Agency (USEPA) compliance standards for workplace and environmental pollutants are given in Appendices A and B. Regulatory overlap between states and OSHA is also discussed (Appendix A). A glossary of useful terms is included at the end of this document.

REFERENCES FOR SECTION 1

1. J. L. Elmore, E. D. Waits, F. E. Sharples, D. B. Hunsaker, Jr., S. E. Carnes, M. Schweitzer, and J. F. McBrayer, Generic Environmental Assessment Report for Conventional Fuel Alcohol Plants, ORNL/TM-7993, Oak Ridge, Tenn. (in press).

2. FUEL-ALCOHOL PLANTS

(J. L. Elmore)

The technology for alcohol production from grain and sugar crops has been well established by the beverage industry. Production of fuel alcohol, however, allows a wider variety of feedstocks to be used because taste and absolute purity of the product are no longer important.

Production of fuel alcohol involves (1) feedstock preparation, (2) fermentation, (3) distillation, (4) dehydration, and (5) by-product recovery. Feedstocks may include corn, sugarcane, sugar beets, and other grains and biomass materials. Only corn and sugarcane will be considered in detail in this assessment because they are representative of starch and sugar feedstocks, respectively. Although processing of other feedstocks may produce slightly different residuals, this should not affect the conclusions of this assessment. Also, it has been predicted that corn will be the major feedstock for fuel alcohol production in the near future. The initial steps for processing feedstocks before fermentation differ in some respects. The dilute ethanol (in water) produced by fermentation is concentrated by distillation and then dehydrated with benzene, cyclohexane, ethyl ether, ethylene glycol, gasoline or other hydrocarbons. Coal, bagasse, wood, or natural gas may be used to provide heat for alcohol production and by-product recovery. Requirements and processes for raw-water treatment, cooling towers, wastewater treatment, and alcohol storage and denaturing will differ with types and capacities of plants.

Process options may be coupled in many different ways to produce alcohol. Rather than provide resource requirement and effluent data

for all possible combinations, a base case was chosen consisting of a 60×10^6 L/y (16×10^6 gal/y) plant based on processes predicted to be most important in the near future, i.e., corn dry-milling, conventional distillation, dehydration with benzene, by-product recovery and heat from a coal-fired boiler. The base case plant is assumed to operate 330 days per year. Each major process considered in this assessment is represented by a single module (Fig. 2.1). Modules using other conventional feedstocks, processes, and fuels were developed from the base case using conversion factors.¹

Fluxes of materials shown in all figures and supporting tables in Sections 2 and 3 are for base-case plants producing 60×10^6 L/y of anhydrous ethanol. Fluxes for plants of greater capacities can be calculated as simple proportions of the values given:

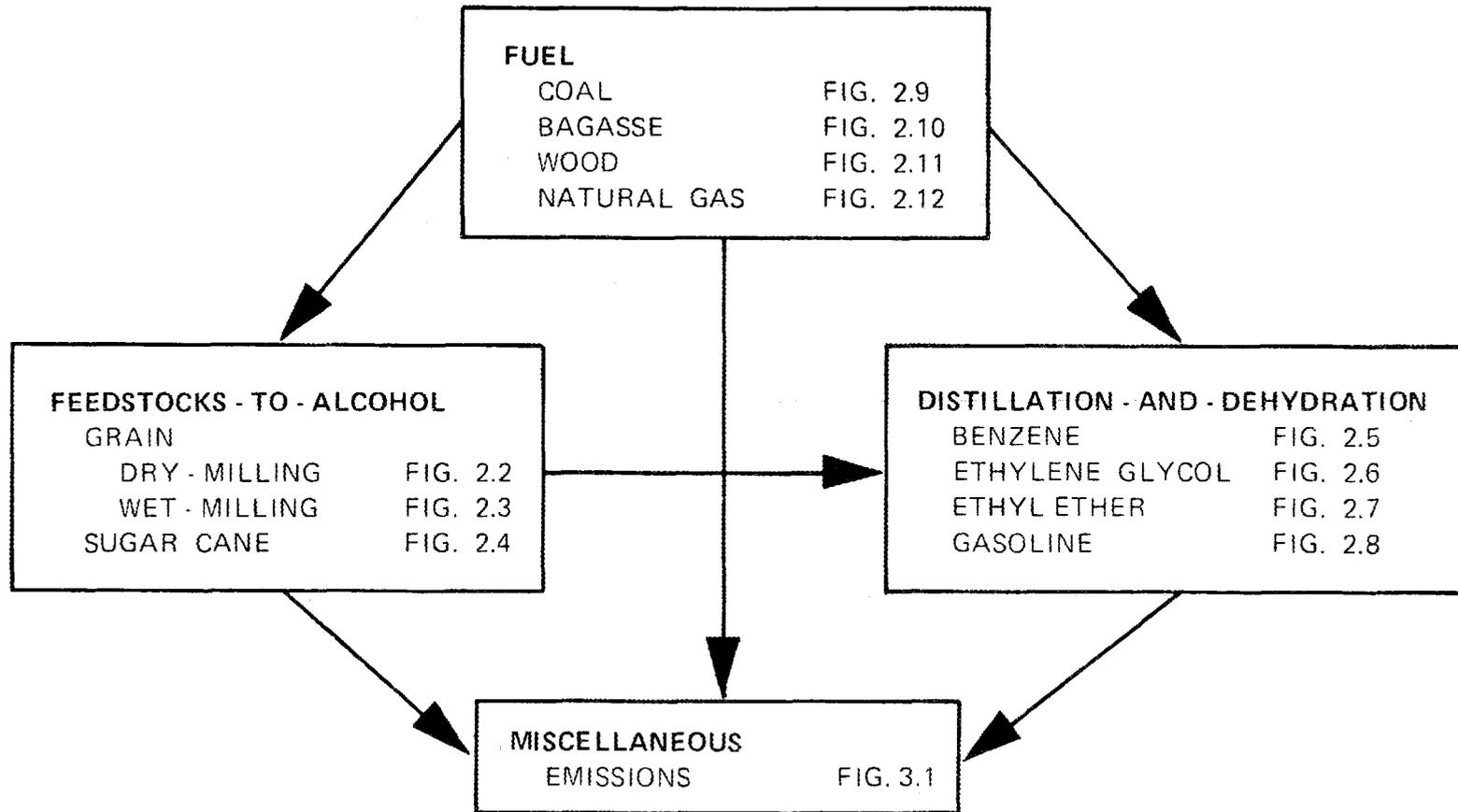
$$\text{Flux value, to be calculated} = \frac{\text{Plant capacity (L/y)}}{60 \times 10^6 \text{ L/y}} \times \text{Flux value given}$$

This linear relationship adequately describes fluxes for plants producing 60×10^6 L/y and greater amounts, but the relationship may not be valid below 60×10^6 L/y.

2.1 FEEDSTOCK PREPARATION, FERMENTATION AND BY-PRODUCT RECOVERY

2.1.1 Plants using grains as feedstocks

The two most common processes for preparing grains for fermentation are dry- and wet-milling. The dry-milling module for producing 60×10^6 L (16×10^6 gal) of ethanol per year from corn is shown in Fig 2.2. Corn is representative of all grains, including grain sorghum.



7

Fig. 2.1. Fuel alcohol plant modules (most conventional fuel alcohol plants can be described by choosing one module from each box, with the miscellaneous emissions module being common to all designs).

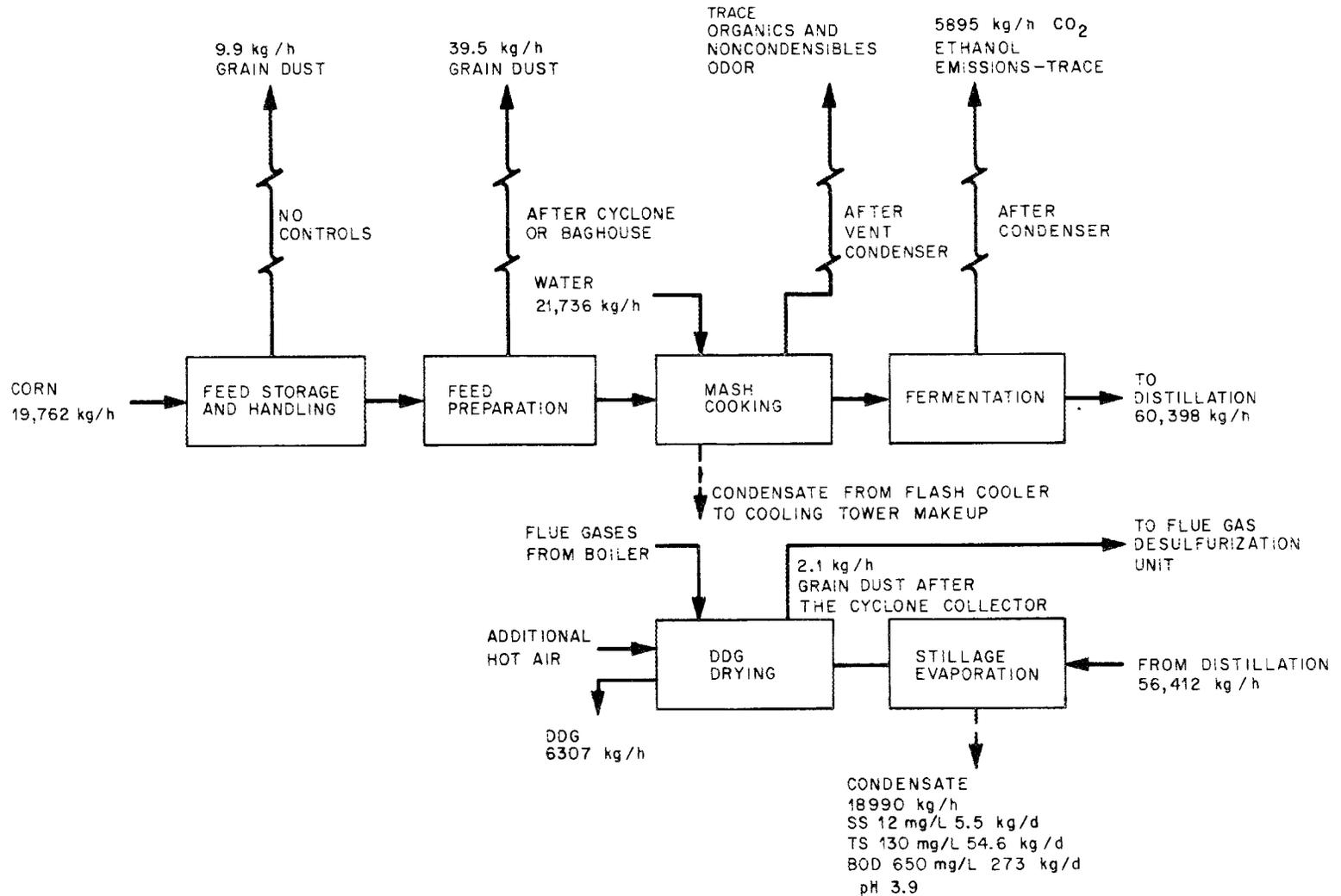


Fig. 2.2. Dry milling, fermentation and DDG drying (fluxes based on 60 million liters/year capacity).

In the dry-milling process, corn kernels are finely ground (often in hammer or roller mills) to expose starch molecules. This material is mixed with water and normally cooked under pressure to solubilize and gelatinize the starch.² After reducing the temperature to about 60°C (140°F), acid or enzymes are added to convert starch to sugar. In preparation for fermentation, the mash is diluted to a 10 to 22% sugar concentration, the pH is adjusted to between 3.0 and 5.0, and the temperature is reduced to 27 to 32°C (80 to 90°F). Then the mash is transferred to fermentation tanks, and yeast of the genus Saccharomyces is added. Yeasts utilize sugar as an energy source; ethanol and carbon dioxide are waste products. The carbon dioxide produced may be vented to the atmosphere or compressed, dried, and sold. After 48 h of fermentation, essentially all of the sugar has been oxidized, and the fermented mash (called beer) is transferred to the beer column. The fermenter is cleaned and sterilized between batches, either with steam or a caustic agent, to prevent contamination by unwanted microorganisms.

The beer, containing 6 to 12% alcohol, is distilled in the beer (stripper) column of a continuous still to separate ethanol and higher molecular weight alcohols and aldehydes (fusel oils) from the remainder of the material (slops or stillage). The high-alcohol fraction (60 to 90% ethanol) of the distillate is distilled further in a rectifying column to produce 95% alcohol; the low-alcohol fraction is redistilled in the beer column with the next batch of beer. Dehydration of the alcohol to produce anhydrous alcohol, necessary for mixing with gasoline for motor fuel, is discussed in Section 2.2.

Stillage is often used as an animal feed. The wet stillage (92 to 94% liquid) can be fed to cattle, but it cannot be stored for long or transported very far. Tank trucks transport the material to feedlots where, in warm weather, it must be consumed by the animals within about 72 h after removal from the still (D. Clark, Jack Daniels Distillery, Lynchberg, TN, personal communication, Feb. 13, 1981). The storage time of stillage can be extended by drying it to form one of several products containing about 9% moisture.³ The multi-step process begins with passing the stillage through screens or centrifuging it to separate solids from liquids. Additional liquid is extracted from the solids by presses that squeeze the material until it contains 60% solids by weight. Distillers dried grains (DDG) are produced by drying these solids in rotary dryers until the moisture content is reduced to 7 to 9% by weight. The liquids from the above processes are sent to evaporators to concentrate the dissolved residues to about 50% solids. These concentrated solubles may be dried with the solids in the rotary dryers to produce distillers dried grains with solubles (DDGS), or they may be dehydrated in drum dryers to 9% moisture to produce distillers dried solubles (DDS).

In the future wet-milling may become an important process for conversion of grain to fuel alcohol because either corn sweeteners or alcohol can be produced, depending on the demand and economics at the time. This complex process is not well known outside of the industry. Unlike dry-milling, which utilizes the entire corn kernel for fermentation, wet-milling (Fig. 2.3) separates all other components from the starch before cooking the mash. The first step entails soaking the

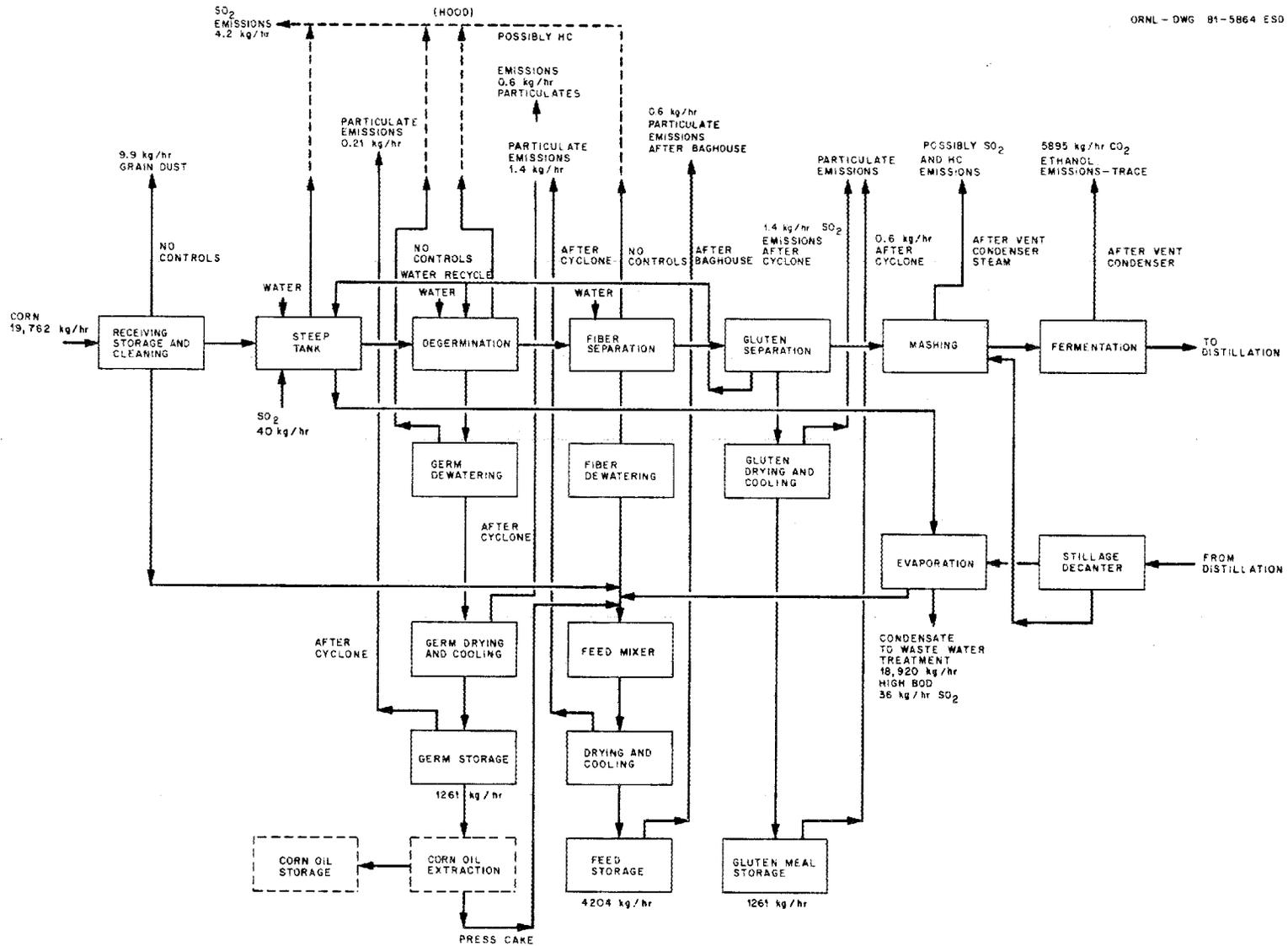


Fig. 2.3. Wet milling, fermentation and stillage handling (fluxes based on 60 million liters/year capacity).

corn kernels in water to which sulfur dioxide (SO_2) is added; the resulting soft and pliable kernels can be more easily manipulated to separate the various components. The sulfur dioxide added to the steep tank is emitted from several of the steps that follow.

The germ (embryo) is separated from the other components of the kernel, dewatered, and dried. Corn oil is extracted from the germ; the by-product from this process is combined with by-products from other steps to form corn gluten feed (20-22% protein content). The material left after degermination (called grits) is defibered, and the fiber is dewatered and added to the corn gluten feed mixture. Gluten is separated from the defibered material, dried, and cooled to form an animal feed (called gluten meal) that is 60% protein. The only material left at this point is starch, which is mashed, fermented, and distilled as described for dry-milled corn feedstock. The stillage and steeping liquor from wet-milling is evaporated and added to the moist corn gluten feed to be dried.

2.1.2 Plants using sugarcane feedstock

The flowchart module for sugarcane is shown in Fig. 2.4. Sugarcane, unlike grain, cannot be stored for extended periods of time at high moisture contents, and drying usually causes some loss of sugar. The only proven storage technique is concentration of the extracted sugar solution by evaporation of water to form molasses; this process requires a substantial input of energy. Cane is cleaned before milling to dispose of field mud and other debris. This may be done either dry or by washing. After cleaning, the sugarcane is cut into small sections,

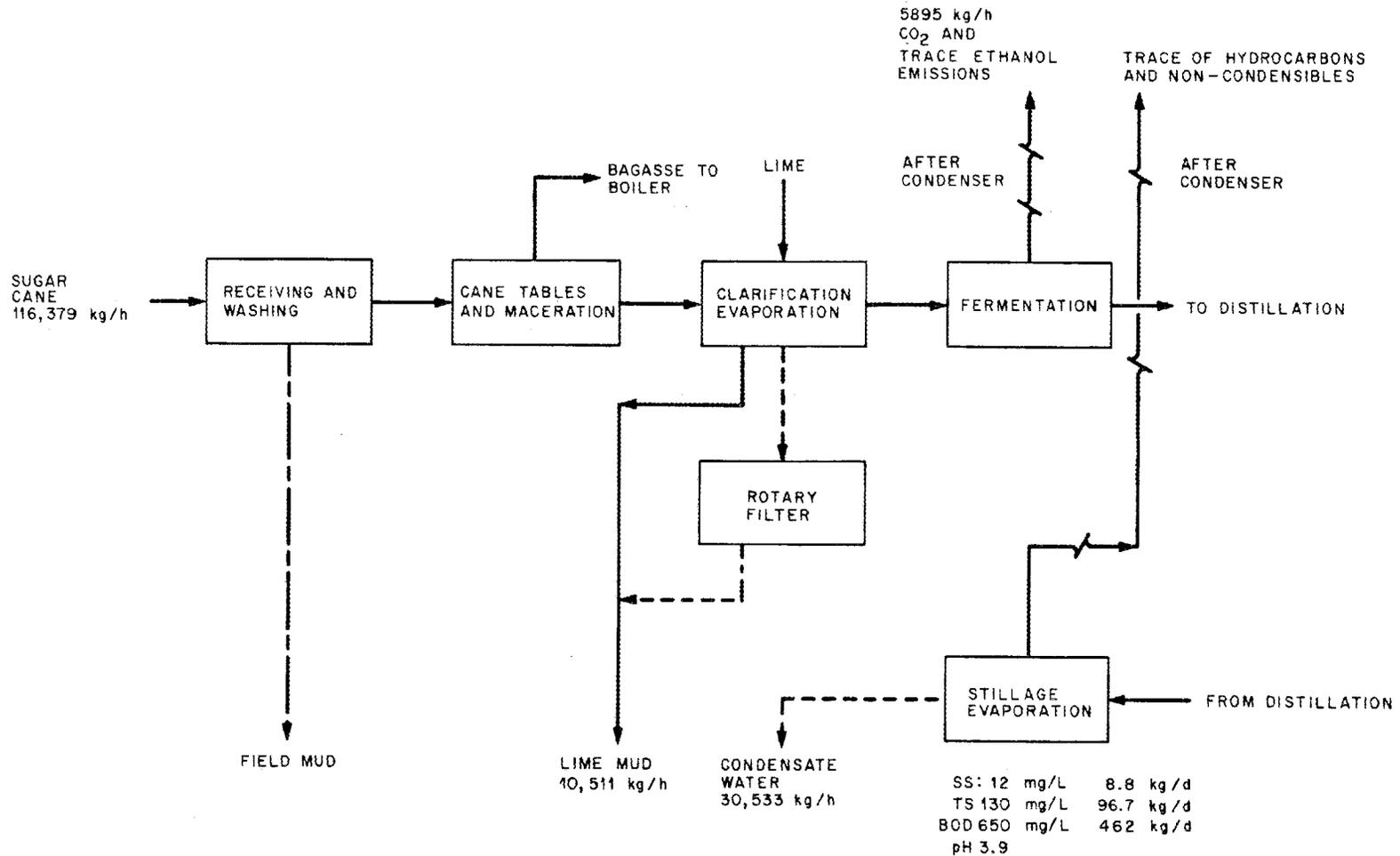


Fig. 2.4. Sugarcane handling, fermentation and stillage evaporation (fluxes based on 60 million liters/year capacity).

shredded mechanically (such as with a hammer-mill shredder), and squeezed through roller presses to extract the sugar juice. All but 5 to 8% of the sugar is removed at this point in the process; an additional 3 to 4% is extracted by pumping the cane particles countercurrent to the flow of juice in a continuous diffuser.⁴ The processed cane (called bagasse), which contains some residual sugar, is passed through rollers; the resulting material is about 50% dry. About 25-30% of the initial sugarcane ends up as bagasse, which normally is burned in boilers to provide process steam or disposed of as a solid waste. The use of bagasse as a fuel is discussed in Section 2.3.1.

The sugar juice is clarified by adding lime (calcium oxide) and evaporated to a 10% sugar concentration. The lime-mud precipitate is separated from wastewater in a rotary filter. Fermentation of the clarified sugar solution and distillation are essentially the same as described for dry-milled corn (Section 2.1.1).

Sugarcane stillage is not considered as good a livestock feed as corn stillage because of its high ash content. A typical Brazilian distillery produces 12 to 13 times more volume of stillage than alcohol.⁵ In Brazil, sugarcane stillage either is used as an animal feed, applied to the land as fertilizer or treated as sewage.^{5,6}

2.2 APPROACHES TO DEHYDRATION AND DENATURATION

2.2.1 Dehydration

The product coming from the distillation columns contains about 5% water and 95% ethanol. Because only anhydrous alcohol can be successfully mixed with gasoline, the water must be extracted. Several solvents

can be used to separate the alcohol-water mixture by azeotropic and extractive distillation. Benzene has been used in the past, but it is a suspected carcinogen. Other chemicals that can be used are cyclohexane, ethylene glycol, ethyl ether and gasoline. Except for gasoline, drying chemicals are used in relatively small quantities because they are recirculated continually in the dehydration systems. The flowchart module for benzene or cyclohexane is shown in Fig. 2.5, for ethylene glycol in Fig. 2.6, for ethyl ether in Fig. 2.7, and for gasoline in Fig. 2.8.

2.2.2 Denaturation

After drying, the alcohol must be denatured to satisfy Federal tax regulations. Addition of gasoline (generally to a 5% concentration) at the plant is the conventional means of complying with this requirement.

2.3 PLANT ENERGY OPTIONS

Data presented in flowsheets for coal (Fig. 2.9), bagasse (Fig. 2.10), wood (Fig. 2.11), and natural gas (Fig. 2.12) were derived from results presented in a study of the Midwest Solvents alcohol plant.⁷ The amount of steam required per hour at this plant was 7.4 kg/L (16.5 lb/gal) of ethanol produced. State-of-the-art-technology would require only about 4.2 kg of steam per liter (35 lb/gal) based on dry or wet-milled corn as feedstock.¹ Conversely, the steam required for a typical sugarcane-based plant would be about 11 kg/L (92 lb/gal) of ethanol.¹ Therefore, producing alcohol from sugarcane is assumed to require 2.6 times more energy than production from corn. The fluxes shown in the fuel-burning modules were derived by multiplying the values in the Midwest Solvents study by appropriate factors.¹

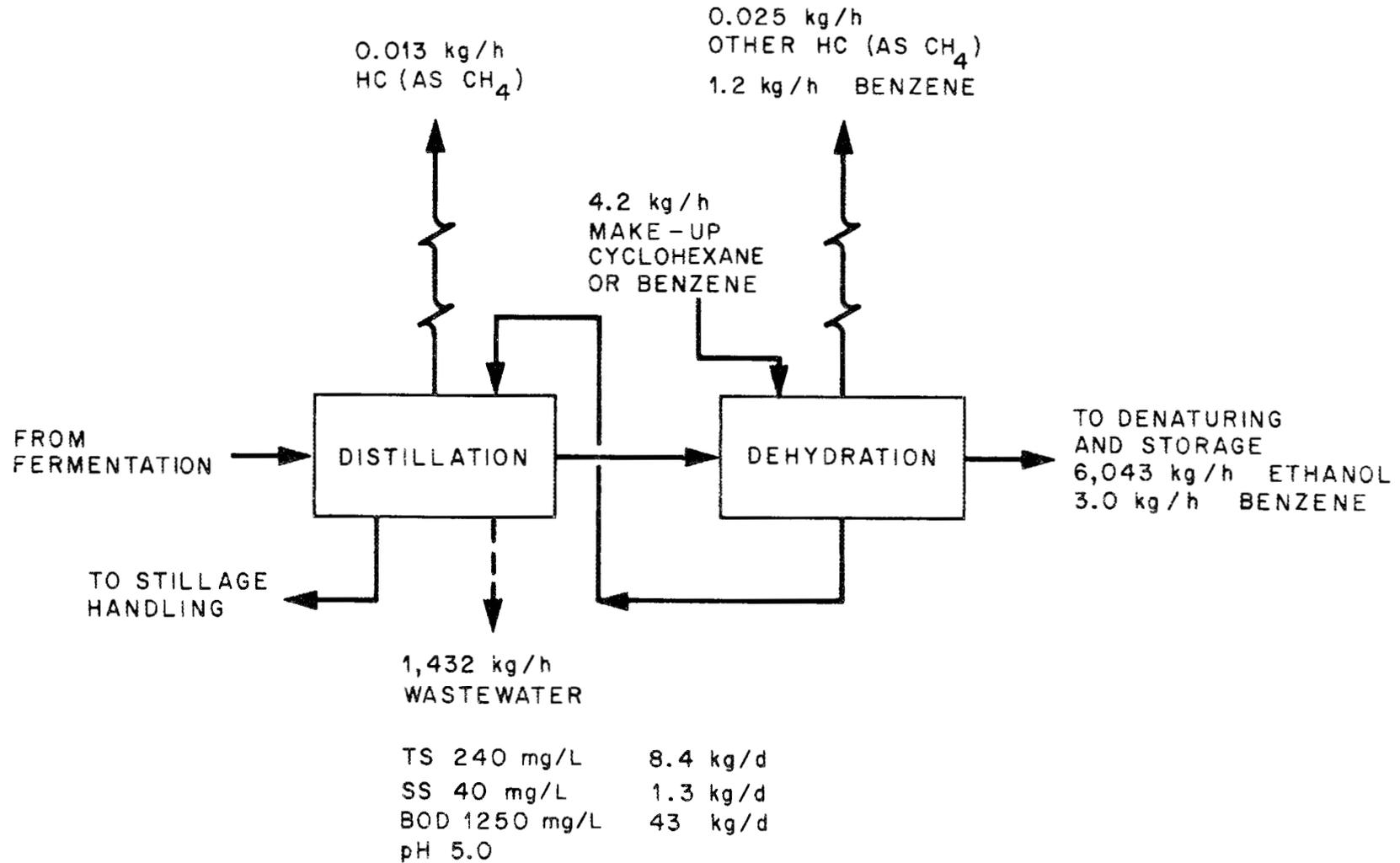


Fig. 2.5. Distillation and benzene dehydration (fluxes based on 60 million liters/year capacity).

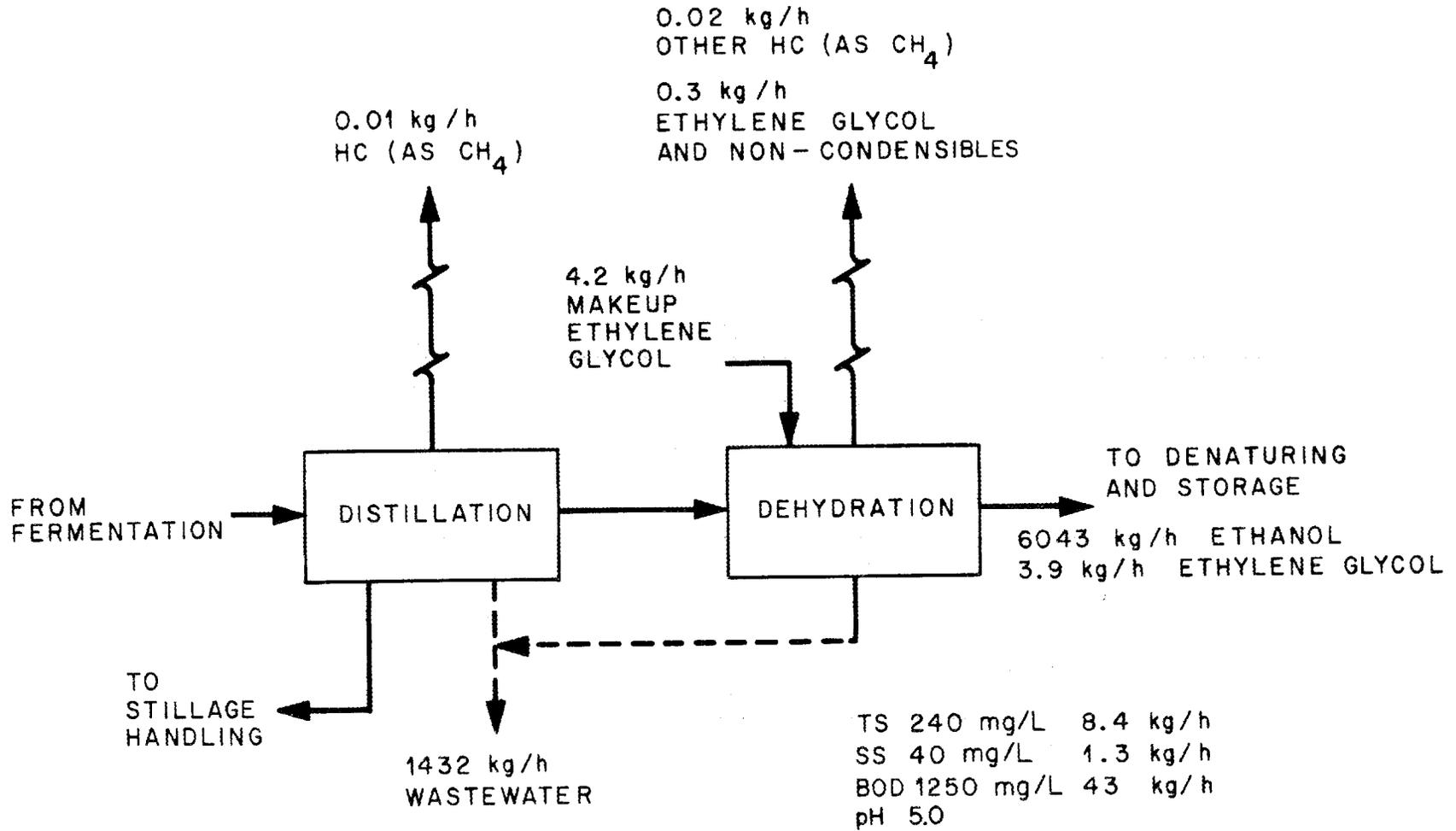


Fig. 2.6. Distillation and ethylene glycol dehydration (fluxes based on 60 million liters/year capacity).

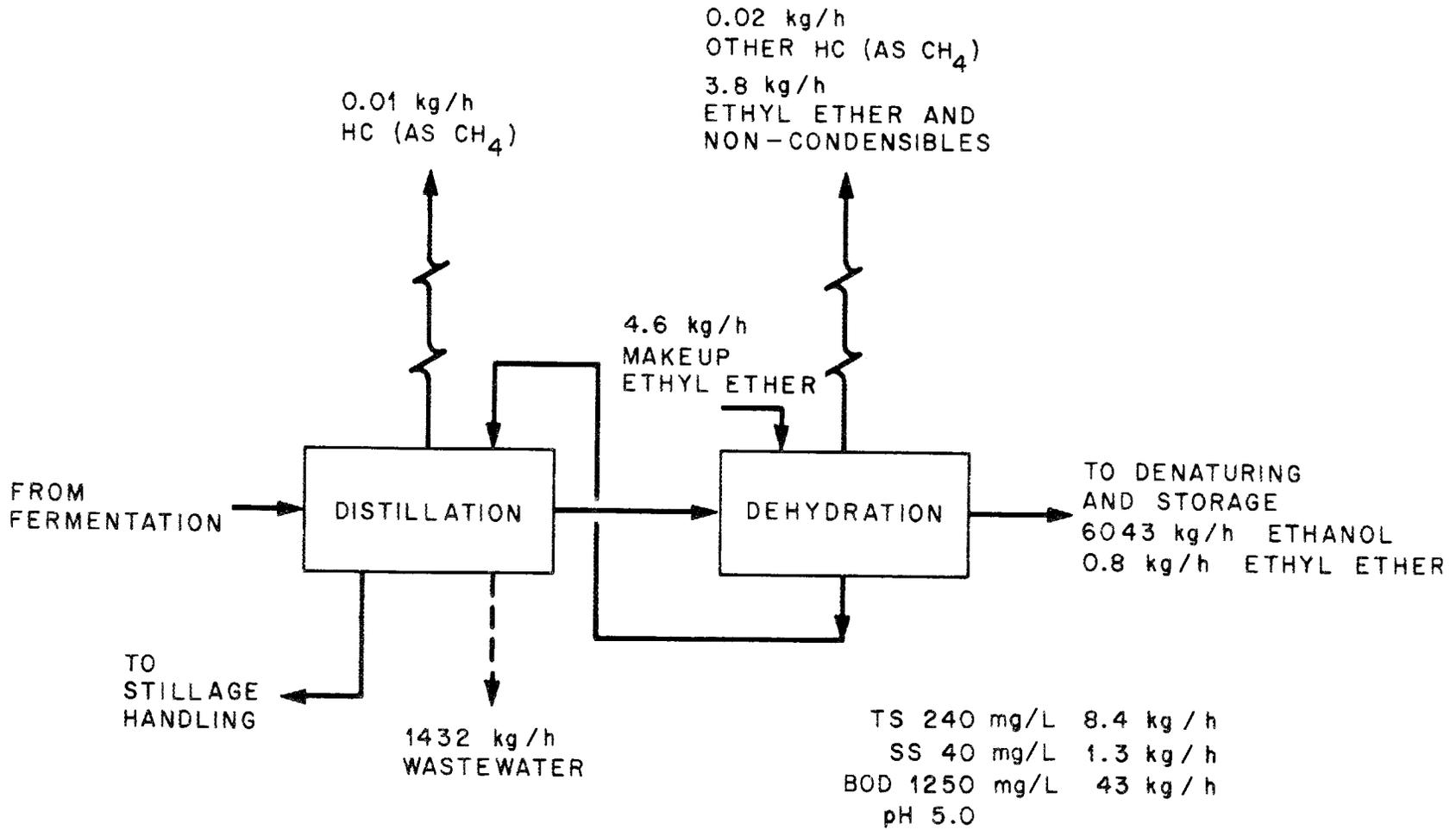


Fig. 2.7. Distillation and ethyl ether dehydration (fluxes based on 60 million liters/year capacity).

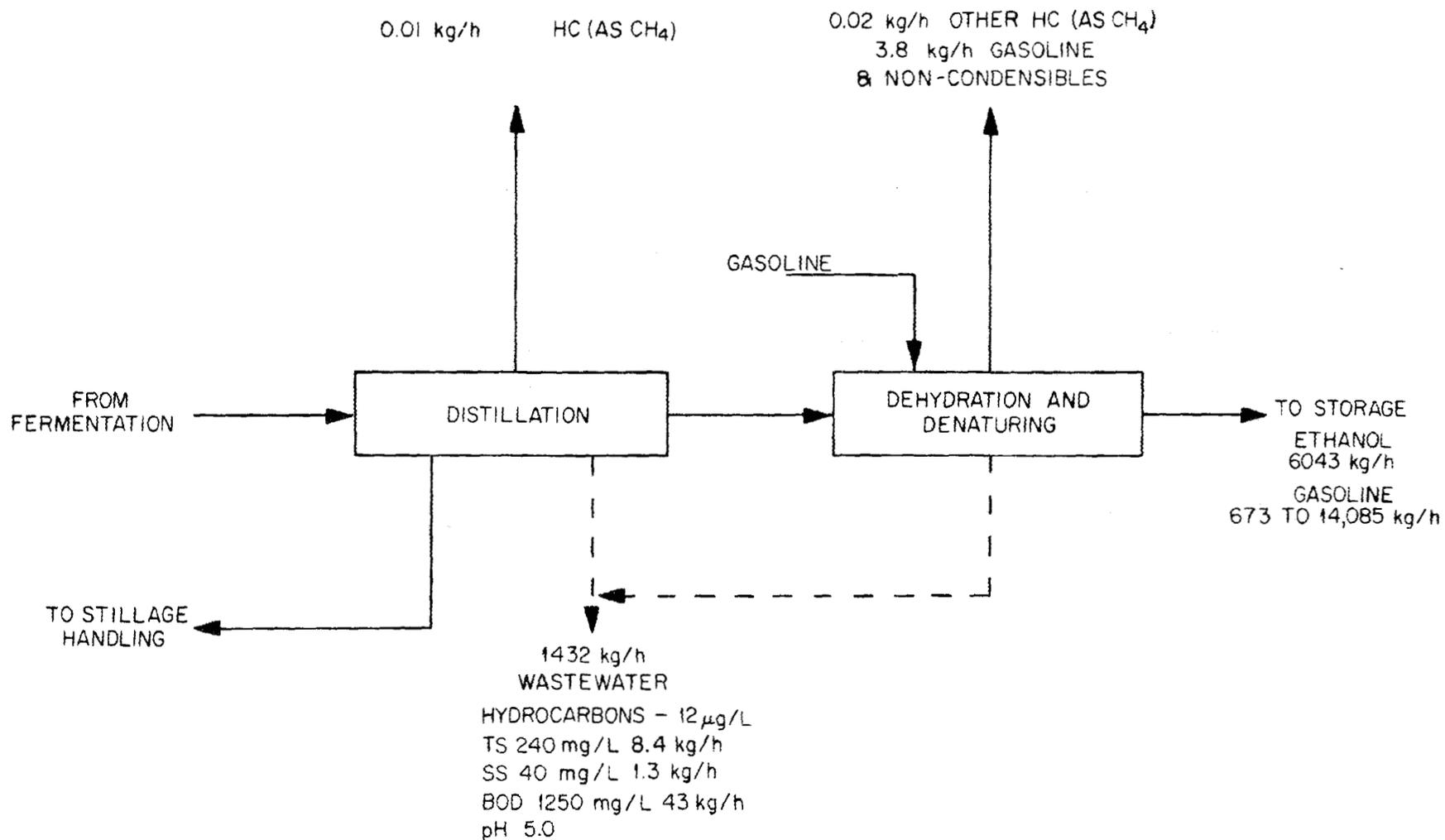


Fig. 2.8. Distillation and gasoline dehydration (fluxes based on 60 million liters/year capacity).

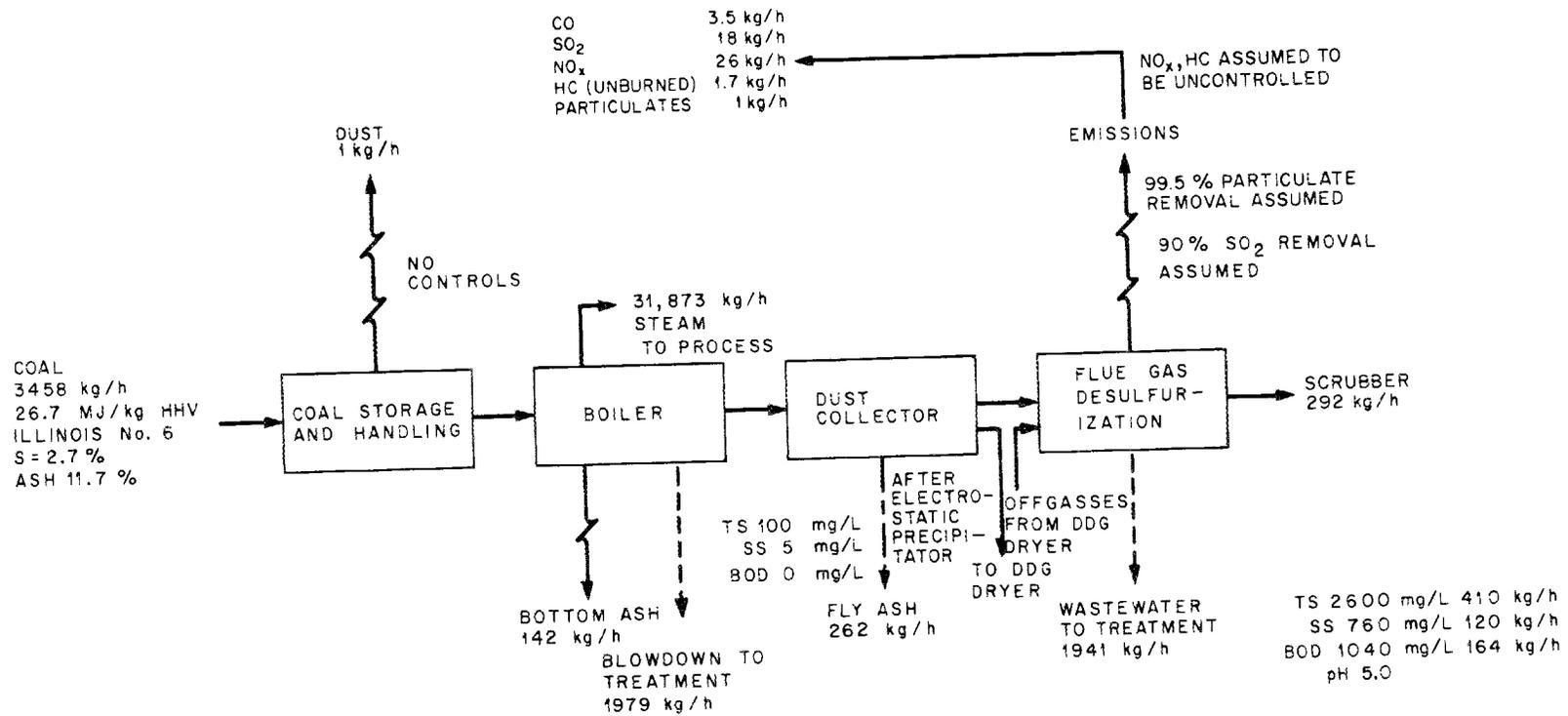


Fig. 2.9. Coal-fired power plant emissions (fluxes based on 60 million liters/year capacity and dry milling of corn).

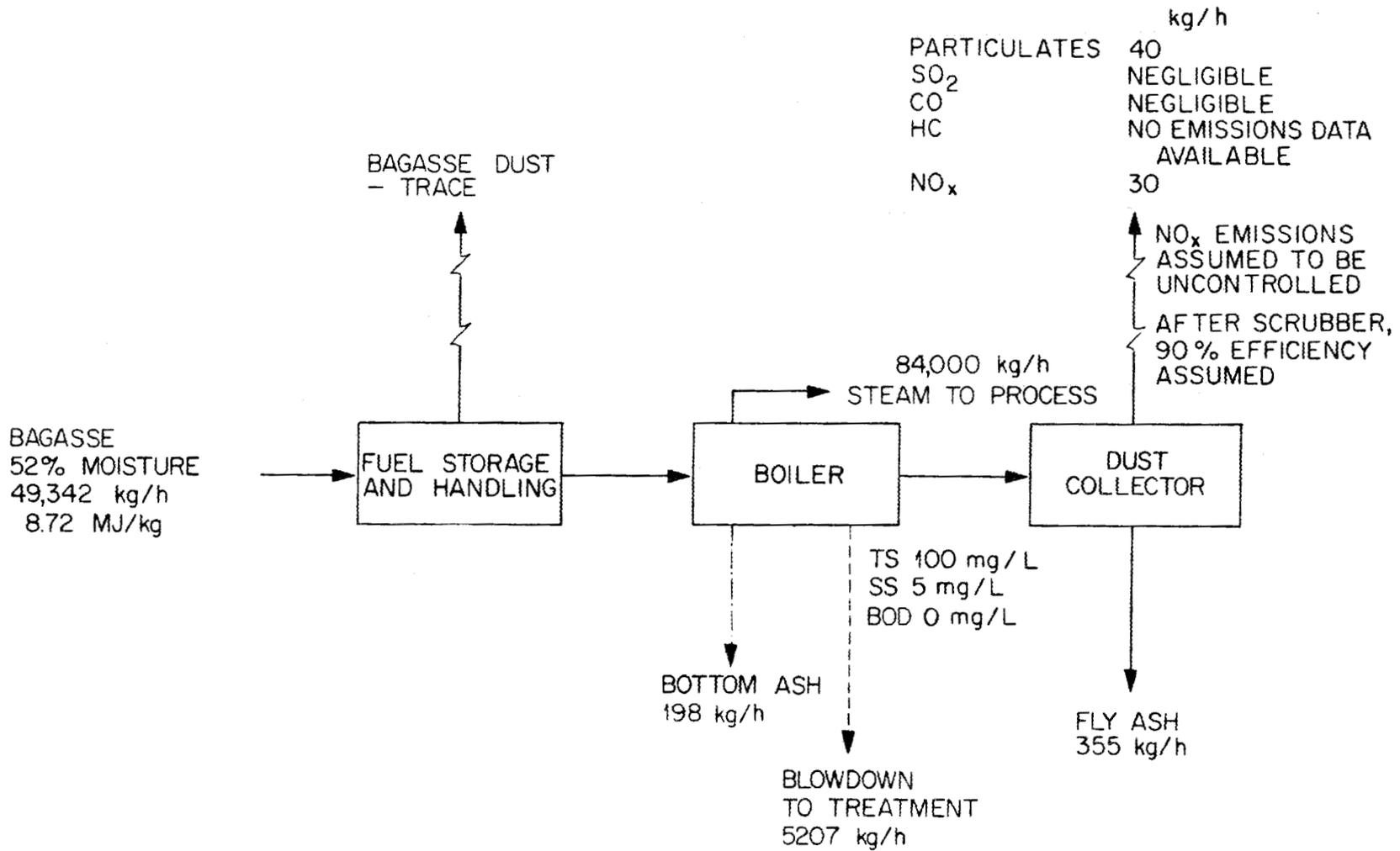


Fig. 2.10. Bagasse-fired boiler emissions (fluxes based on 60 million liters/year capacity).

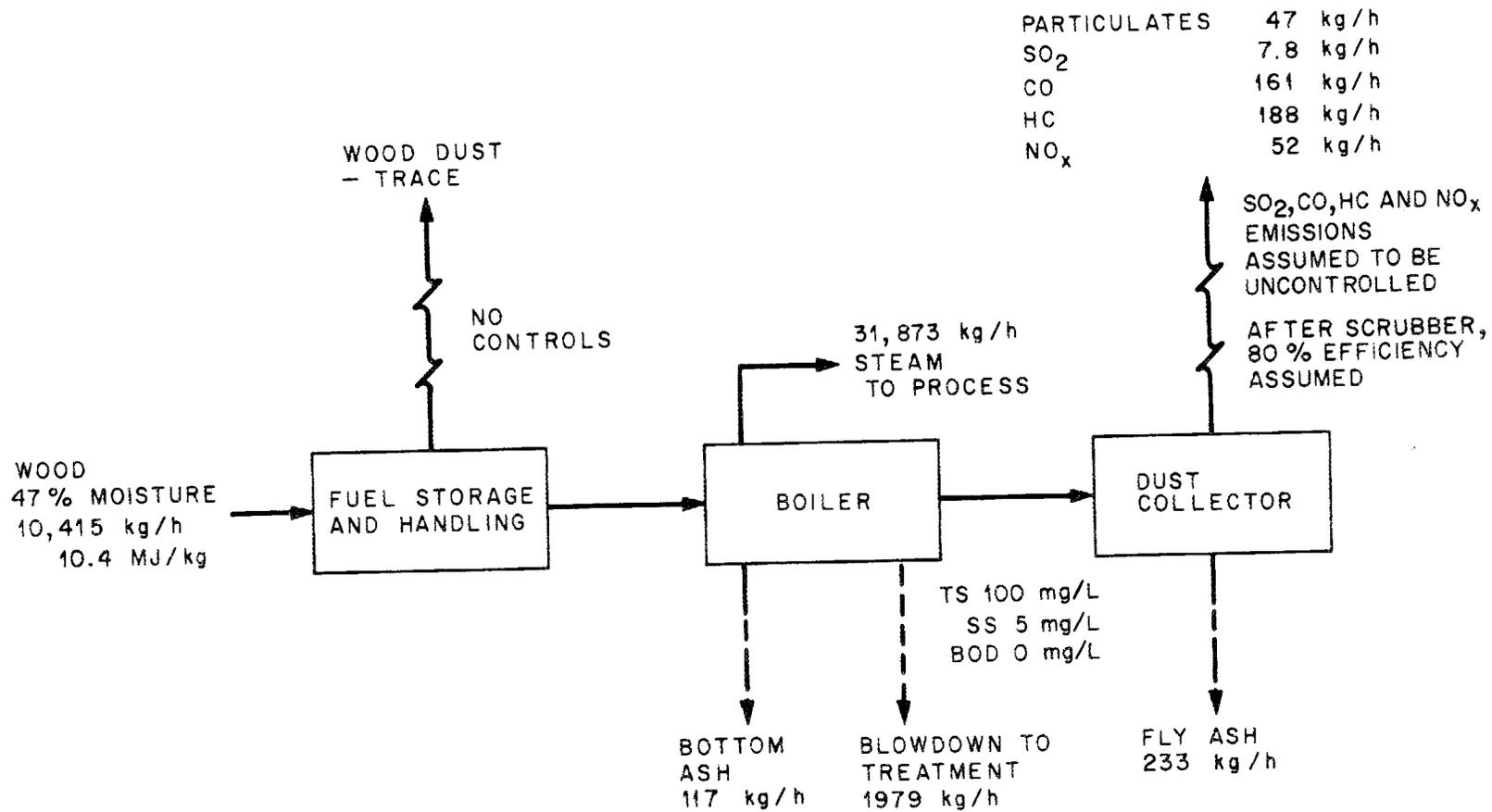


Fig. 2.11. Wood-fired boiler emissions (fluxes based on 60 million liters/year capacity grain dry milling plant).

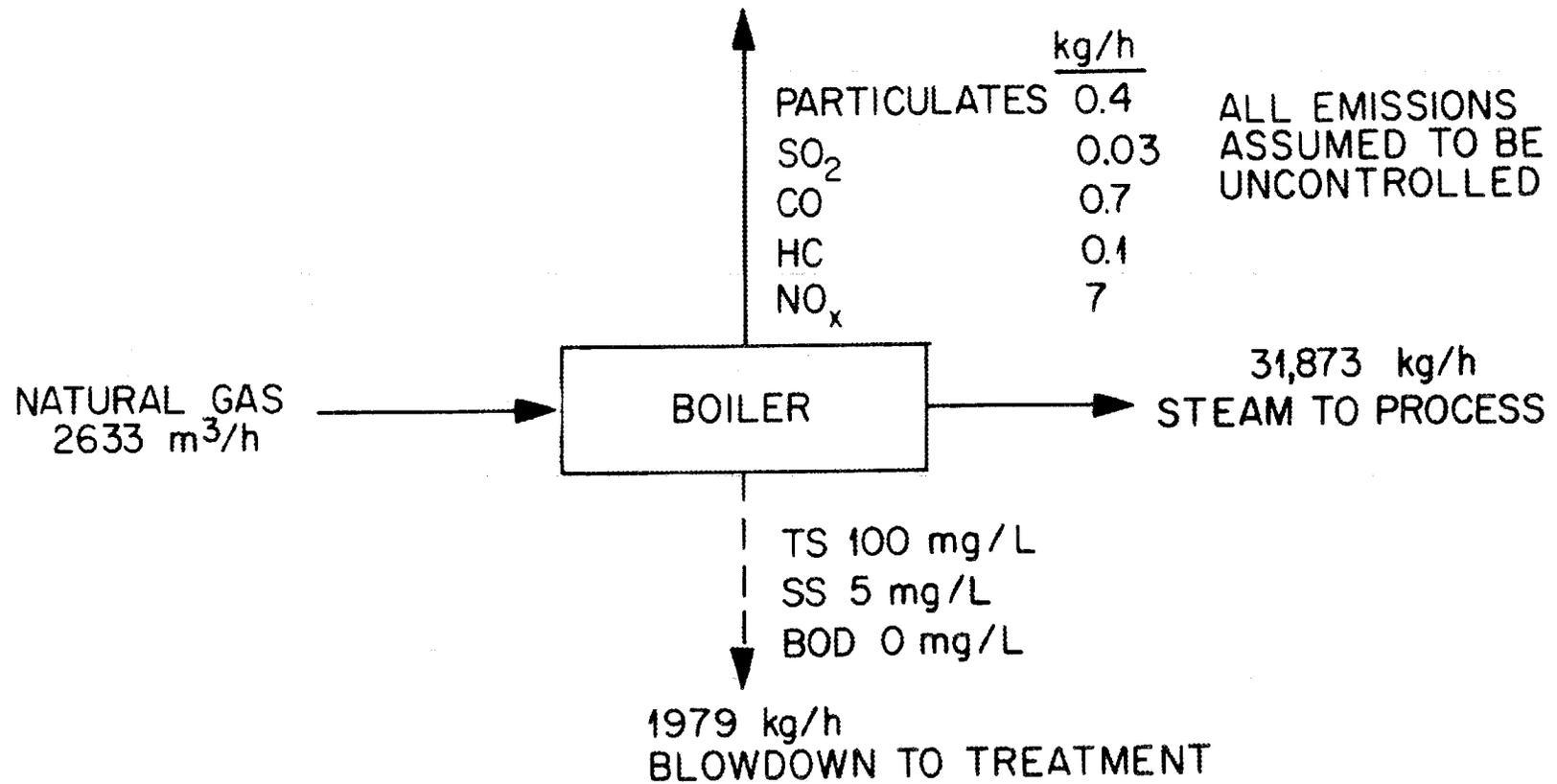


Fig. 2.12. Natural gas-fired boiler emissions (fluxes based on 60 million liter/year capacity grain dry milling plant).

2.3.1 Coal

Coal will probably be the boiler fuel used in most fuel alcohol plants in the near future. Illinois No. 6 coal was used in this assessment to provide source terms because it is a commonly used coal. Other coals obviously will produce different residuals. Illinois No. 6 contains 2.7% sulfur and 11.7% ash and has a heat content of 27 MJ/kg (11,500 Btu/lb). In the base case module (Fig. 2.9), coal will be stored in open piles and fired in boilers to produce process steam for the dry-milling process.

2.3.2 Bagasse

Bagasse is the sugarcane stalk left after the sugar has been extracted. After dewatering, bagasse can be burned to provide the energy needed to produce alcohol from the sugar fraction of the cane. Bagasse will probably be burned only at sugarcane distilleries because transporting it over extended distances is not economically feasible. It is composed of 35 to 45% fiber and 45 to 55% moisture and has as much as 7 to 10% residual sucrose present as combustible material.⁴ The energy content of dry bagasse is 19 to 21 MJ/kg (8000 to 9000 Btu/lb), but without pre-drying it is 9 to 14 MJ/kg (4000 to 6000 Btu/lb). The ash content is relatively low (1.5 to 3%), but soil and silt may become mixed with the bagasse, increasing residue ash and causing slagging problems during combustion. In addition to ash, the dry material contains 45% carbon, 6% hydrogen, and 46% oxygen.⁴ The flowchart module for bagasse is shown in Fig. 2.10.

2.3.3 Wood and other biomass

Wood may be used to produce process heat in some fuel alcohol plants, but its use will be the exception rather than the rule. Like dry bagasse, dry wood has a heat content of 19 to 21 MJ/kg (8000 to 9000 Btu/lb).⁴ Although it can vary somewhat among species, the composition of wood waste products is usually about 50% moisture, 40% volatiles, 10% fixed carbon, and less than 1% ash. Because a large amount of the energy content is in volatiles, wood waste may lose from 10 to 25% of its heating value during the first six months of storage.⁴ The wood flowchart module for the dry-milling base case is shown in Fig. 2.11.

Other forms of combustible biomass would have a flowchart similar to the wood module (Fig. 2.11). Generally, sugar crop residues (e.g., bagasse, sugar beet tops and sweet-sorghum fiber) have structures, combustion behaviors, and analyses similar to wood, whereas grain-crop residues (e.g., corn stalks, rice hulls and straw) have a high ash content with as much as 85% silica in dry material. It is unlikely that any of these sources of biomass will be important fuels for producing alcohol in the near future.

2.3.4 Natural gas

Some natural gas may be used in fuel-alcohol plants, especially in the drying of the animal feed by-products. The natural gas flowchart module is shown in Fig. 2.12.

2.3.5 Mixed fuels

When considering mixed fuels, the most common mixture would be coal for steam generation and natural gas (or oil) to fire the dryers

for DDG, gluten meal, gluten feed, and corn-germ. As much as about 35% of the fuel might be natural gas (or oil) in these situations.

Use of bagasse is applicable, with few exceptions, only to alcohol plants utilizing raw sugarcane juice and probably only during and for one or two months after active cane harvest. If the alcohol plant is operated at other times, coal probably will be required. Similarly, coal probably would constitute the bulk of the fuel for plants manufacturing alcohol from molasses by-product created by sugar manufacture, or from high-test molasses. High-test molasses is concentrated raw sugarcane juice. In the continental United States, the fuel value provided by bagasse slightly exceeds the heat required to produce alcohol from raw sugarcane juice, providing the alcohol plant only operates for 7 or 8 months. However, if plans call for year-round operation of the plant, the raw juice probably would have to be evaporated to high-test molasses because of preservation and storage-space considerations. Coal would be required for this energy intensive process. If sugar is produced at a plant for sale and the by-product molasses is used as alcohol feedstock, most of the bagasse will have been used to produce the sugar.

In general, the availability of wood near the plant site establishes the maximum size of a wood-fired boiler. Boilers of 100 to 225 Mg (125 to 250 tons) per hour would be realistic in some locations and could adequately serve alcohol plants in the capacity range of 60 to 380×10^6 L (16 to 100×10^6 gal) per year.¹ However, alcohol plant location is more likely to be based on feedstock availability and alcohol and by-product market considerations than accessibility of wood

supply. Currently, consideration of wood-fueled plants would require additional feasibility studies and novel wood-supply negotiations with nonconventional suppliers. It is practical to consider co-firing coal and wood in properly designed burners. Although further study would be required to make a realistic decision, it is likely that only a few plants would be based on wood or mixed wood-coal in the near term. However, there may be a trend to use wood or wood-coal mixtures in future plants.

2.4 RESOURCE REQUIREMENTS

The resource requirements discussed below are based on base-case capacity plants producing 60×10^6 L (16×10^6 gal) of alcohol per year. Requirements for larger plants will be simple multiples of the values presented here. A plant producing 600×10^6 L (160×10^6 gal) per year will use 10 times the amount of resources of one producing 60×10^6 L (16×10^6 gal) per year. This simple linear relationship will not hold for land or for plants smaller than the base case.

2.4.1 Feedstocks

Producing alcohol from corn or other grains, by either dry- or wet-milling, consumes the feedstock at a rate of 19,762 kg/h (22 tons/h). Assuming 330-days production per year, the yearly consumption of corn is 156 Gg (172×10^3 tons). At this rate, about 2.6 kg of corn is required to produce a liter (21.7 lb/gal) of anhydrous alcohol.

The sugarcane feedstock requirement for a base-case size plant is 116,379 kg/h (128 tons/h), or 922 Gg/y (1.0×10^6 tons/y). To produce a liter of alcohol requires 15.4 kg (128 lb/gal) of sugarcane.

Therefore, by weight, about 6 times more sugarcane than corn kernels is required to produce an equivalent amount of alcohol.

2.4.2 Fuel

The fuel requirements for the base-case modules are listed in Table 2.1. The fuel consumption for producing alcohol from corn is about the same whether dry- or wet-milling is used. The sugarcane process requires about 2.6 times more fuel by weight than the corn processes to produce an equal amount of alcohol. About 3 times more wood by weight is needed to produce the same amount of steam as coal. Bagasse would be used only at sugarcane alcohol plants, because transportation of this material over long distances is not economically feasible. The weight of bagasse burned would be 5.4 times that of coal and 1.8 times the amount of wood to produce an equal amount of alcohol from sugarcane.

2.4.3 Land

Widely varying estimates for land requirements exist in the literature. For a complete 190×10^6 L (50×10^6 gal) per year plant based on corn dry-milling, the Raphael Katzen study⁸ indicates that a 15.6 ha area (38.5 acres) having 20 ha (50 acres) for expansion is desirable. Cincinnati Vulcan¹ recommends an area of 3 ha (7 acres) for all portions of the plant except for wastewater treatment, which would require about an additional 2 ha (5 acres) for a total of 5 ha (12 acres). Nevertheless, Cincinnati Vulcan suggests that a total of 14 ha (35 acres) would be preferred. Conversely, purchase of existing sites exceeding 36 ha (90 acres) have been considered for plants having

Table 2.1. Estimated fuel requirements of fuel alcohol plants producing
 60×10^6 L (16×10^6 gal) per year^a

	Corn, dry-milling kg/h (lb/h)	Corn, wet-milling kg/h (lb/h)	Sugarcane, raw juice kg/h (lb/h)
Coal	3,458 (7,624)	3,458 (7,624)	9,100 (20,063)
Bagasse (52% moisture)			49,342 (108,782)
Wood (47% moisture)	10,415 (22,962)	10,415 (22,962)	27,408 (60,426)
Natural gas ^b	2,633 (92,989)	2,633 (92,989)	6,929 (244,708)

^aReference 1.

^bExpressed as m³/h (ft³/h).

capacities of 76 to 114 x 10⁶ L (20 to 30 x 10⁶ gal) per year.¹ For this assessment, a land area of about 12 to 20 ha (30 to 50 acres) is assumed to be sufficient for plant capacities of 60 to 600 x 10⁶ L (16 to 160 x 10⁶ gal) per year, respectively.

The above estimates of required land encompass sufficient area for raw material and fuel receiving and storage, the main process plant, product storage and shipping, the steam plant and its auxiliaries, water treatment, cooling tower, offices and labs, and on-site roads. Area for transmission lines, raw water acquisition and transportation access is not included and may pose additional requirements depending on site-specific needs.

Office and laboratory space would house the quality control, safety, health, and environmental monitoring and testing equipment. A maintenance shop will be necessary to house and maintain various kinds of equipment. The steam plant would include a boiler, cooling tower, generator, water process equipment, and fuel storage and handling facilities. The water system would include a well (or other water source), pumps, motors, water tower, piping to all water use points and wastewater treatment facilities. The main process plant will house equipment for mash preparation, yeast preparation, fermentation, distillation, and dehydration of the alcohol. A grain handling facility that has loading, unloading, weighing, and conveying equipment will be required as will facilities for drying and storage of distillers dried grain (DDG) and for onsite storage of ethanol.⁹

2.4.4 Water

The largest quantity of water used in alcohol production is for cooling purposes. Water of high quality is needed for process water and boiler feed. Miscellaneous uses of water include equipment washing and other sanitary purposes. Water requirements for making alcohol from corn and sugarcane are listed in Table 2.2. An additional capacity of 128 L/s (2000 gpm) will be required for fire protection according to the Insurance Services Organization. Wet-milling uses about half the amount of water that dry-milling requires, whereas producing alcohol from sugarcane requires one third that of grain dry-milling. Recycling in the wet-milling process conserves water. The large amount of water in sugarcane reduces water use when this feedstock is processed.

2.4.5 Employment

This Section summarizes labor requirements for construction and operation of alcohol fuel production facilities having rated outputs of 60×10^6 L (16×10^6 gal) and 600×10^6 L (160×10^6 gal) per year. This analysis assumes a corn, wheat, or milo feedstock in dry-mill plants and does not include requirements for ancillary activities related to the drying of distiller's grain for feed, fructose, corn oil, syrup, and other by-products.

2.4.5.1 Construction labor requirements

The quantity and mix of labor required to construct an alcohol fuel facility vary according to the type of facility and the rated capacity, or output, of the facility. Table 2.3 lists estimates for the total capital and labor costs, total labor requirements, peak period

Table 2.2. Estimated water requirements of fuel alcohol plants producing 60×10^6 L (16×10^6 gal) per year^a

Alcohol plant	L/y (gal/y)	L/s (gpm)
Corn, dry-milling	1.83×10^9 (482×10^6)	64 (1015)
Corn, wet-milling	804×10^6 (213×10^6)	28 (447)
Sugarcane, raw juice	658×10^6 (174×10^6)	23 (366)

^aReference 1.

Table 2.3. Alcohol fuel facility construction estimates^a compared with those for a chemical plant.^b

	Alcohol fuel plant	Chemical plant
60 million liters/year		
Total Capital Costs	\$22.5-45 million	\$40 million ^e
Estimated Labor Costs	\$6.8-9.0 million	NA
Estimated Total Employment	280-375 man years	370 man years
Construction Period	12 months	31 months
Peak Construction Work Force	560 workers	300 workers
600 million liters/year		
Total Capital Costs	\$225-450 million ^c	\$165-330 million ^f
Estimated Labor Costs	\$68-90 million ^c	NA
Estimated Total Employment	2250-3000 man years ^d	1535-2670 man years
Construction Period	NA	46-62 months
Peak Construction Work Force	NA	780-1100 workers

NA - Not Available

^aReference 10.

^bReference 11.

^cLinear extrapolation from ORAU's maximum plant size consideration of 200 million liters per year.

^dExtrapolated from ORAU's maximum plant size consideration of 200 millions liters per year according to the formula:

$$\frac{B \text{ (workforce)}}{A \text{ (workforce)}} = \frac{B \text{ (Capital cost)}^{0.8}}{A \text{ (Capital cost)}}$$

^eProjected Cost of Alcohol Fuel Facility provided by Rafael Katzen Associates. All succeeding figures represent the projected case for a chemical facility of this dollar value.

^fLower figure provided by Rafael Katzen Associates; Upper figure represents staff projection allowing for possible cost overruns. All succeeding figures represent the projected case for a chemical facility of this dollar value.

labor requirements, and duration of the construction period for an alcohol fuel facility with the rated outputs given above and compares these with chemical plants of the same size. These estimates, particularly those for the 600×10^6 L/y plant, should be used very cautiously. The United States has had only limited experience with plants producing as much as 200×10^6 L/y fuel alcohol, and no experience with plants producing 600×10^6 L/y. It is not possible to assess meaningfully what economies of scale result at the larger-sized facility. As experience is acquired in the industry, more accurate forecasts of labor requirements will be possible.

The mix of crafts required to construct an alcohol fuels production facility is likely to be similar to that required for construction of a chemical plant. Table 2.4 presents the craft mix for this industry. The craft mix is not expected to change appreciably as a function of the rated capacity of a plant.

2.4.5.2 Operating Labor Requirements

The number of employees required to operate and maintain alcohol fuel production facilities varies by plant capacity and by type of facility. Employment at large facilities is difficult to assess because wet-milling might be integrated with food-processing capabilities. However, it is estimated that roughly 60 to 125 persons will be required to operate a 60×10^6 L/y facility, and 200 to 275 persons will be needed for a 600×10^6 L/y facility.⁸

Table 2.4. Craft mix for chemical plant construction^a

Craft	Percentage of workforce ^b
Carpenter	18
Laborer	18
Electrician	11
Plumber/pipefitter	10
Bricklayer	8
Iron worker	6
Cement worker	5
Sheet metal	5

^aReference 11.

^bDoes not total 100% because crafts requiring less than 5% of total are not included.

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3. EFFLUENTS AND EFFLUENT CONTROL

(J. L. Elmore)

3.1 LIQUID EFFLUENTS

This Section outlines effluents from the hypothetical plants described in Section 2, and conventional pollution abatement techniques that are likely to be used in the near-term are described.

3.1.1 Process waste streams

The largest volume of liquid effluent from the alcohol production processes described in Section 2 is condensate from stillage drying (Table 3.1). This discharge contains a high concentration of organic material producing a high biochemical oxygen demand (BOD) and an acidic pH (Table 3.2). Wastewater from the distillation/dehydration process is produced in smaller quantities than stillage-drying condensate (Table 3.1), but has about twice the concentration of solids and BOD (Table 3.2).

Boiler blowdown effluent is associated with all forms of fuel listed in Section 2. Blowdown is water that is bled from the system and replaced to prevent concentration of minerals. The dissolved constituents of blowdown are principally minerals, concentrations of which are dependent on the initial composition of the water. The volume is moderate (Table 3.1), and dissolved solids are elevated to a moderate extent (Table 3.2).

Flue-gas desulfurization is a process by which sulfur dioxide is scrubbed from stack emissions, and is usually used when high-sulfur coal is burned. The relatively small amount of wastewater produced from this process is high in solids and is acidic (Table 3.2).

Table 3.1. Estimated flux rates of major liquid effluents from 60×10^6 L (16×10^6 gal) per year fuel alcohol plants.^a

	Corn, dry-milling kg/h (GPM)	Corn, wet-milling kg/h (GPM)	Sugarcane, raw juice kg/h (GPM)
<u>Process effluents</u>			
Stillage drying condensate	18,990 (84)	18,920 (84)	30,533 (135)
Distillation wastewater	1,432 (6.3)	1,432 (6.3)	1,432 (6.3)
<u>Fuel combustion effluents</u>			
Boiler blowdown (all fuels)	1,978 (8.7)	1,978 (8.7)	5,202 (23)
Flue-gas desulfurization wastewater (coal only)	1,941 (8.6)	1,941 (8.6)	5,105 (22.5)
Cooling-tower blowdown	103,660 (457)	42,501 (188)	51,830 (229)
<u>Discharged wastewater</u>			
Wastewater treatment	157,333 (694)	91,253 (402)	118,000 (520)

^aReference 1.

Table 3.2. Estimated water quality of major liquid effluents from 60×10^6 L (16×10^6 gal) per year fuel alcohol plants^a

	Total solids (mg/L)	Suspended solids (mg/L)	Biochemical oxygen demand (mg/L)	Sulfate (mg/L)	pH (units)
<u>Alcohol Process Effluents</u>					
Condensate from stillage drying	130	12	650	<i>b</i>	3.9
Distillation wastewater	240	40	1250	<i>b</i>	5.0
<u>Fuel Combustion Effluents</u>					
Boiler blowdown (all fuels)	100	5	0	<i>b</i>	<i>b</i>
Flue gas desulfurization wastewater (coal only)	2600	120	164	<i>b</i>	5.0
Cooling tower blowdown	800	14	30	520	<i>b</i>
<u>Discharged Wastewater</u>					
Wastewater treatment	313	9	3	52	<i>b</i>

^aReference 1.

^bNo data available.

Miscellaneous sources of wastewater include liquid effluents from cooling-tower blowdown, wastewater treatment and equipment washes (Fig. 3.1). Cooling-tower blowdown produces a large discharge volume (Table 3.1) that is usually high in dissolved solids (Table 3.2), although the concentration of solids depends upon the quality of makeup water and the number of cycles in the tower.

All of the liquid effluent streams will be directed to waste stabilization ponds, where settling will reduce suspended solids and microbial action will reduce the organic content. It is assumed that both primary (mechanical screening and settling) and secondary treatment (biological reduction of organic matter) will be employed. A BOD reduction of as little as 80% would result in effluents from the hypothetical plants with less than 30 mg/L as required by regulations of the Clean Water Act. Waste stabilization ponds can have as high as 95% BOD removal.² A 60×10^6 L/y plant will discharge a quantity of wastewater equivalent to that produced by a town of 10,000 people.

3.1.2 Runoff

Infiltration and runoff from fuel storage piles will be characteristic of the type of fuel. Most types of wood and other biomass give rise to an acidic runoff (Table 3.3). Runoff from coal storage piles also may be acidic with elevated levels of some trace elements (Table 3.4).

Dewatered sludge from flue gas desulfurization (FGD) and raw-water and wastewater treatment, as well as mud, boiler bottom ash, and fly ash collected in the dust collector will have to be discarded. Ponding

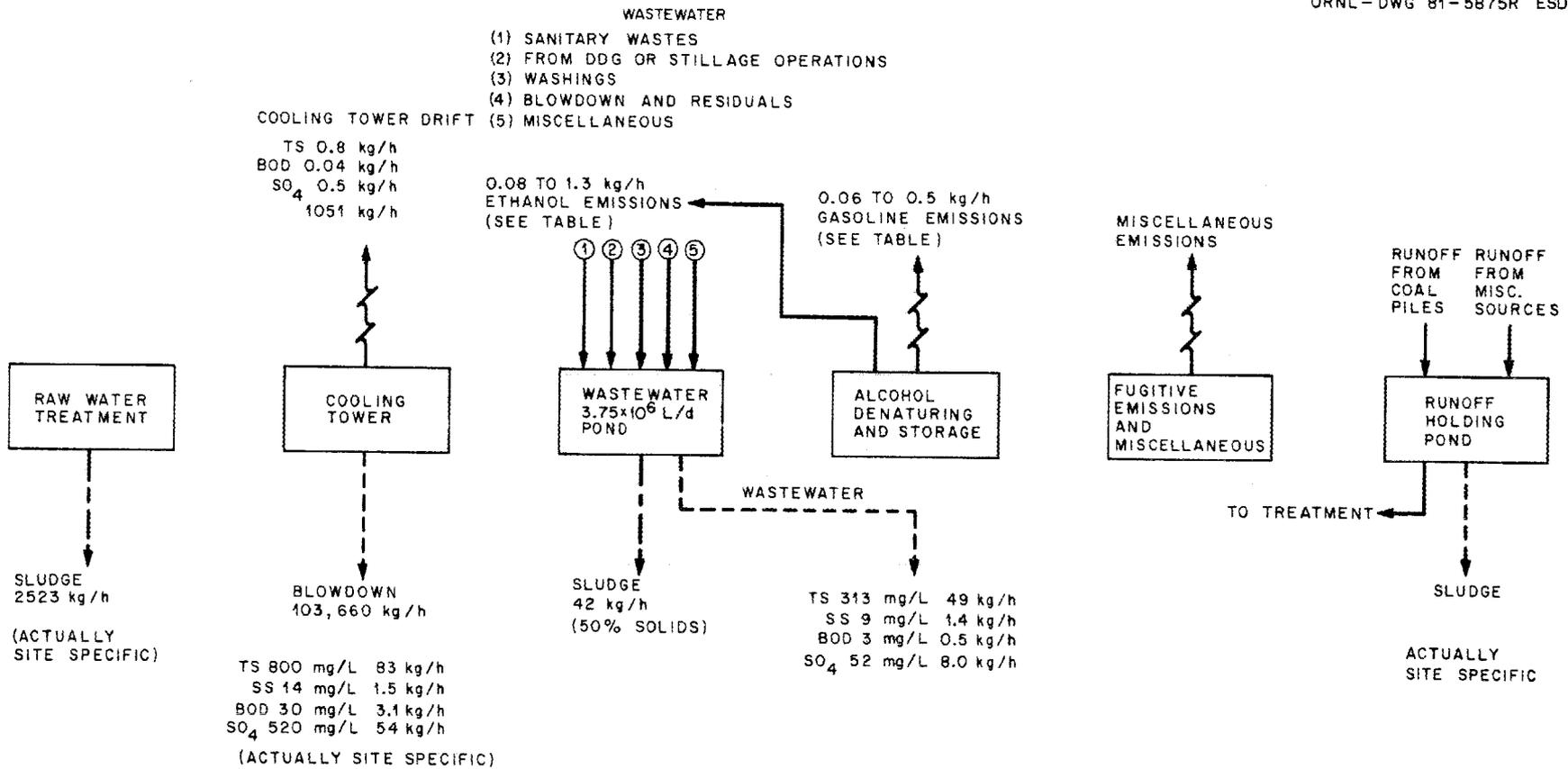


Fig. 3.1. Miscellaneous emissions associated with fuel alcohol production (fluxes based on 60 million liters/year capacity grain dry milling plant).

Table 3.3. pH values for cold water extractions of plant residues^a

Residue type	pH Value ^b
Maple shavings	5.22
Red oak sawdust	4.53
Red oak bark	4.87
Walnut bark	6.03
White oak chips	4.52
White oak bark	5.25
Cottonwood bark	5.58
Corncobs	5.17
Cornstalks	7.49
Hickory shavings	5.63
Mixed hardwood shavings	5.00
Cottonwood shavings	7.38
Sunflower-seed coats	6.90

^aReference 3.

^bEach value is an average of five measurements.

Table 3.4. Representative water quality measurements for coal pile leachate and coal pile drainage
(all values except pH expressed as mg/L)^a

	Coal pile drainage			Western coal leachates
	FEA	Davis and Boegly	TVA plant	
Aluminum	825 - 1,200	48 - 1,200	22.0 - 440	
Arsenic		0.02 - 0.1	0.005 - 0.6	
Barium			0.1	
Cadmium		0.002	0.001 - 0.006	0.05
Cobalt			0.09 - 0.4	
Chromium	0 - 15.7	0.02 - 15.7	0.005 - 0.011	0.05
Copper	1.6 - 3.9	0.2 - 6.1	0.01 - 1.4	0.1 - 0.15
Iron	0.4 - 2.0	0.06 - 93,000	62 - 1,800	0.65 - 12
Mercury			0.0002 - 0.027	
Manganese	90 - 180	3.4 - 72.0	0.88 - 110	0.05 - 0.08
Nickel		0.2 - 2.8	0.24 - 4.5	
Lead		0.2	0.01 - 0.023	0.1
Selenium		0.005 - 0.02	0.001 - 0.03	
Vanadium		1		2
Zinc	0.006 - 12.5	0.006 - 26.0	1.0 - 16	0.15 - 0.23
Sulfate	130 - 20,000	535 - 21,920	870 - 9,600	
Acidity (as CaCO ₃)	10 - 27,800	8.84 - 21,700	270 - 7,100	
Alkalinity (as CaCO ₃)	15 - 80	0 - 36.41		37.5 - 124
Hardness (as CaCO ₃)	130 - 1,850	130 - 1,851	600 - 980	
Total dissolved solids (TDS)	700 - 44,000	720 - 44,050	1,200 - 16,000	490 - 1,720
pH	2.8 - 7.8	2.1 - 6.6	2.3 - 3.1	7.2 - 8.0
Total suspended solids (TSS)	20 - 3,300	22 - 610	8 - 2,500	7.2 - 8.0

^aReference 4.

or landfilling will be the most probable disposal methods for these effluents. Runoff and infiltration from these materials could contaminate surface water and/or groundwater. Heavy metals often constitute a significant portion of the trace cations in some effluents from coal waste disposal (Table 3.5). Silicon, aluminum, and iron are the major elements in coal ash, whereas calcium, potassium, and sodium predominate in wood ash.⁵

3.2 SOLID EFFLUENTS

Solid wastes include muds, ashes, and sludges (Table 3.6). Stillage is not considered a waste in this Section because it is unlikely that a fuel-alcohol plant which did not take advantage of the animal feed by-product would be economically feasible at this time. Some characteristics of stillage are shown in Table 3.7.

If stillage is used, little solid waste would be discharged from the actual alcohol production processes (Table 3.6). In contrast, fuel combustion produces large quantities of solid waste. Boiler bottom ash must be cleaned out periodically. Fly ash, captured by electrostatic precipitators, must be discarded. A gypsum type-sludge ($\text{CaSO} + \text{CaSO}_4$) often is formed from flue-gas desulfurization (FGD). Generally, coal combustion produces a greater quantity of solid wastes than bagasse or wood combustion; use of natural gas produces none. Because the production of alcohol from sugarcane requires about 2.6 times the energy needed for the corn processes, fuel combustion for the sugarcane processes produces larger quantities of solid wastes if the same fuel is used.¹

Table 3.5. Representative water quality measurements for effluents from coal waste disposal (all values except pH expressed as mg/L)^a

	Sludge effluent					
	Ash pond overflow		Simulated leachate		Fixed scrubber sludge	Sludge pond overflow
Aluminum	0.02	- 513	1.4	- 9.8		
Arsenic			0.01	- 0.05		
Cadmium			0.01	- 0.03		
Chromium	negligible	- 0.14		0.02		
Copper	0.005	- 0.06		0.1		
Iron	0.02	- 2.9		0.02		
Mercury	0.0002	- 0.002	0.0015	- 0.0055		
Manganese	0.0002	- 0.10		0.05		
Nickel	0.008	- 0.015		0.015		
Zinc	0.001	- 0.12	0.01	- 0.02		
Sulfate	100	- 300	0	- 344	520	377
Acidity (as CaCO ₃)					5	5
Alkalinity (as CaCO ₃)	30	- 400			80	32
Hardness (as CaCO ₃)	200	- 750	285	- 602	696	484
Total dissolved solids (TDS)	250	- 3,300	68	- 296	1,095	750
pH			10.5	- 11.8	6.7	7.2
Total suspended solids (TSS)	25	- 100	4	- 8	70,780	5

^aReference 4.

Table 3.6. Estimated solid waste effluents from 60×10^6 L (16×10^6 gal) per year fuel alcohol plants^a

	Corn, dry-milling kg/h (lb/h)	Corn, wet-milling kg/h (lb/h)	Sugar Cane, raw juice kg/h (lb/h)
<u>Alcohol Process Effluents</u>			
Lime mud	0	0	10,511 (23,173)
<u>Fuel Combustion Effluents</u>			
Coal			
Bottom ash	142 (312)	142 (312)	373 (821)
Fly ash	262 (576)	262 (576)	689 (1516)
Scrubber sludge	292 (642)	292 (642)	768 (1690)
Bagasse			
Bottom ash			198 (436)
Fly ash			355 (781)
Wood			
Bottom ash	117 (257)	117 (257)	308 (678)
Fly ash	233 (513)	233 (513)	613 (1349)
<u>Miscellaneous Solid Wastes</u>			
Raw water treatment sludge	2,523 (5,562)	1,110 (2,447)	908 (2,002)
Wastewater pond sludge (50% solids)	42 (93)	210 (463)	32 (70)

^aReference 1.

Table 3.7. Composition of distillery stillage (data expressed as mg/L except for pH)^a

Parameter	Bourbon type (Grain)	Molasses (Sugarcane)
pH	4.2	4.5
Total Solids	37,388	71,053
Suspended solids	17,900	40
BOD	26,000	28,700

^aReference 6.

Miscellaneous solid wastes include sludges from treating raw-water, wastewater, and runoff. If water of suitable quality cannot be acquired from a municipal treatment plant, raw water must be treated on the premises, producing a sludge. The quantity of this sludge will vary with the site-specific water quality. Because dry-milling uses more water than the other two processes, greater amounts of sludge from raw-water treatment are produced.

The amount of sludge produced from the wastewater pond is greater for wet-milling than for the other two processes. This occurs because sulfur dioxide, added in the initial step, is emitted in the condensate, and lime is used to precipitate the excess sulfate formed. The amount of sludge formed from the runoff-pond effluent will be site specific.

3.3 ATMOSPHERIC EFFLUENTS

The major sources of air pollution in fuel alcohol plants are fuel alcohol production, fuel combustion to produce process steam or electricity, and storage of alcohol, gasoline, and other volatile hydrocarbons. This Section discusses expected air pollutant emissions from each of these sources; emission rates after the application of typical control devices are emphasized.

3.3.1 Process waste streams

Table 3.8 summarizes estimated major atmospheric effluents from alcohol production at a 60 million liter/y (16 million gallon/y) alcohol fuel plant. The magnitudes of emission rates of various pollutants from the alcohol production process vary with the individual processes; however, some generalizations can be made. Sulfur dioxide (SO_2)

emissions are associated only with the corn wet-milling process because SO_2 is used in this process to acidify the feedstock mixture. The 4.2 kg/h (36.7 ton/y) emission rate is assumed to be uncontrolled.¹ Uncontrolled SO_2 emissions for a 600 million liter/y (160 million gallon/h) plant could be as large as 42 kg/h (370 ton/y), thereby necessitating the application of some type of SO_2 emission control under current air quality laws.

Volatile organic compound (VOC) emissions (which include miscellaneous hydrocarbons and ethanol) from corn and sugarcane fermentation were assumed to be negligible with the use of vent condensers as control devices. The control efficiencies for these devices were assumed to be in excess of 99%, which is feasible using available technology.^{7,8} VOC emissions from distillation and dehydration after using a vent condenser were 0.038 kg/h (0.33 ton/y) for the 60 million liter/y plant. Additional VOC emissions in the form of drying chemicals and denaturants will also result from alcohol production. Expected emissions, after passing through a vent condenser, range from 0.3 kg/h (2.6 tons/y) for ethylene glycol to 3.8 kg/h (33.2 tons/y) for ethyl ether and gasoline for a 60 million liter/y plant. Two factors related to alcohol fuel plant design that affect the emission rates of these chemicals are the quantity used and the volatility of the compounds.¹ Emissions of VOC from leaks of valves, flanges, pump seals, etc. are not included in the above estimates. Based on data collected at petroleum refineries, leaking fittings can emit anywhere from 0.003 kg/h (.003 tons/y) of non-methane hydrocarbons (NMHC) for flanges to 0.44 kg/h (4 tons/y) NMHC for compressor seals.⁹

The corn dry milling process produces more particulate emissions than the other processes; the 49.4 kg/h (431 ton/y) emission rate consists of about 10 kg/h of uncontrolled emissions from corn receiving, storage, and handling, and about 40 kg/h of controlled emissions (cyclone or baghouse) from corn preparation. The corn wet-milling process is estimated to produce about 14.7 kg/h (128 ton/y), 10 kg/h of which are uncontrolled emissions from corn receiving, storage, and cleaning, and 4.7 kg/h of which are controlled emissions (cyclone or baghouse) from germ drying and cooling, germ storage, feed drying and cooling, gluten drying and cooling, and gluten storage.¹ If necessary, cyclones, which are capable of reducing emissions by 95-99%¹⁰, could be installed to reduce emissions from corn preparation.¹¹ The storage and processing of sugarcane is expected to produce negligible amounts of particulates because of the high moisture content of the cane stalk.¹²

Negligible quantities of carbon monoxide (CO) are emitted during any of the alcohol production processes. On the other hand, large quantities of carbon dioxide (CO₂) are emitted from the corn wet and dry-milling and sugarcane processes; each of the processes is estimated to emit 5,895 kg/h (51,465 ton/y) of CO₂. Because CO₂ is not a regulated air pollutant, no control devices were assumed to be installed on CO₂-containing waste streams specifically for reducing CO₂ emissions (vent condensers installed to reduce ethanol emissions may also trap some CO₂). In some instances, recovery of CO₂ for sale as bottled gas or for use in enhanced oil recovery may prove to be economical; under such circumstances, CO₂ emissions may be greatly reduced.

3.3.2 Power plant emissions

Table 3.8 summarizes air pollutant emission rates from combustion of selected fuels to produce process steam for the alcohol production processes considered. The purpose of this Section is to highlight the assumptions on which the fuel combustion emission calculations are based, and to discuss commercially available techniques for producing the lowest (best-case) emissions for each fuel combustion process considered.

The primary sources of information used to calculate the emission rates are the fuel feed rates developed by Otis et al.¹ and air pollutant emission factors developed by the U.S. Environmental Protection Agency.⁸ Dvorak et al.¹³ is used to provide back-up information on emissions from coal combustion. The EPA emission factors are selected because they are used by many local regulatory agencies in evaluating the impacts of new stationary sources, and because factors are available for all fuels of interest in this study. An earlier analysis of the environmental issues associated with biomass energy systems also used these factors.¹⁴

Producing one gallon of fuel alcohol from sugarcane requires about 92 pounds of steam, whereas producing one gallon of fuel alcohol from corn (wet milling or dry milling) requires about 35 pounds of steam. Consequently, sugarcane-based plants produce about 2.6 (92/35) times more air pollutants than do corn-based plants when the same fuel is used.¹ The fuel-combustion emissions in Table 3.8 for alcohol production from sugarcane are calculated by multiplying the emissions from corn-based alcohol production by a factor of 2.6.

Table 3.8. Estimated major atmospheric effluents from 60 x 10⁶ L (16 x 10⁶ gal) per year fuel alcohol plants^{a,b}

	Sulfur Dioxide kg/h (ton/y)	Hydrocarbons kg/h (ton/y)	Particulates or dust kg/h (ton/y)	Carbon Monoxide kg/h (ton/y)	Carbon Dioxide kg/h (ton/y)	Nitrogen Oxides kg/h (ton/y)
<u>Alcohol Production Effluents</u>						
Corn, dry-milling	c	c	49.4 (431)	c	5,895 (51,465)	c
Corn, wet-milling	4.2 (36.7)	c	14.7 (128)	c	5,895 (51,465)	c
Sugarcane, raw juice	c	c	c	c	5,895 (51,465)	c
<u>Distillation and dehydration</u>						
Benzene	c	1.2 (10.8)	c	c	c	c
Ethylene glycol	c	0.3 (2.9)	c	c	c	c
Ethyl ether	c	3.8 (33.5)	c	c	c	c
Gasoline	c	3.8 (33.5)	c	c	c	c
<u>Fuel Combustion Effluents</u>						
<u>Coal</u>						
corn	18 (157)	1.7 (14.8)	2 (17)	3.5 (31)	e	26 (226)
sugarcane	47 (410)	4.5 (39)	5.2 (45)	9.2 (80)	e	68 (592)
Bagasse (sugarcane only)	c	d	40 (346)	c	e	30 (261)
<u>Wood</u>						
corn	7.8 (68)	188 (1,638)	47 (410)	161 (1,403)	e	52 (454)
sugarcane	21 (182)	494 (4,300)	124 (1,080)	423 (3,685)	e	137 (1,196)
<u>Natural gas</u>						
corn	a	a	0.4 (3.5)	0.7 (6.1)		7 (61)
sugarcane	a	0.3 (2.6)	1.1 (9.6)	1.8 (15.7)		18 (157)

^aReference 1.

^bYearly emission based on 24 h/day, 330 day/y operation.

^cNegligible (less than 1.0 ton/y).

^dNo data available.

^eNot calculated.

Sulfur dioxide (SO_2) emissions are expected to be greatest for corn- and sugar-cane based alcohol production using coal combustion, and for sugar-cane based alcohol production using wood combustion. The SO_2 emissions from coal combustion are assumed to be controlled 90% using a scrubber; SO_2 emissions from combustion of the other fuels are assumed to be uncontrolled. The controlled SO_2 emissions from coal combustion are greater than the uncontrolled emissions from combustion of other fuels because the sulfur level in coal is higher than sulfur levels in the other fuels. For example, the coal is assumed to be 2.7% sulfur, whereas the bagasse sulfur level is assumed to be negligible¹² and the wood sulfur level was assumed to be 0.1%.¹⁵ Use of low sulfur (0.6 - 0.7%) coal will reduce controlled (90% assumed) SO_2 emissions from coal combustion at the 60×10^6 L/y plant to 35 Mg/y (38 TPY) for corn-based alcohol production, and 89 Mg/y (99 TPY) for sugarcane-based alcohol production.

Uncontrolled SO_2 emissions of 165 Mg/y (182 TPY) are predicted, using the EPA factors, to result from wood combustion for the production of sugarcane-based alcohol. Use of the EPA emission factors may result in artificially high SO_2 emission estimates because they are based on a high wood sulfur content and a high sulfur-to- SO_2 conversion efficiency. EPA is currently revising the wood combustion emission factors.¹⁶ Research has found that the sulfur content of wood typically ranges from 0.01% to 0.134% by weight and that only about 5% of the fuel sulfur content is typically emitted as SO_2 (the remainder being bound as sulfate in the ash).¹⁵ These two findings significantly lower the expected SO_2 emissions from wood combustion. The new EPA

emission factor for SO_2 emissions from wood combustion is expected to be in the range of 5×10^{-2} kg SO_2/MT wood to 7.5×10^{-2} kg SO_2/MT wood (0.10 to 0.15 lb SO_2/ton wood), which is approximately a factor of ten lower than the current value.¹⁶ Uncontrolled wood-fired boiler SO_2 emissions for sugarcane-based alcohol production (60×10^6 L/y capacity) using the new factor would only be about 16 Mg/y (18 TPY). SO_2 control equipment (90% efficient scrubber) would reduce emissions calculated with the proposed emission factor to 1.6 Mg/y (1.8 TPY) for the 60×10^6 L/y plant.

Hydrocarbon emissions are predicted to be greatest for corn and sugarcane-based alcohol production using wood combustion to provide process steam. The EPA emission factor for hydrocarbon emissions from wood-fired boilers ranges from 1-35 kg/MT. The lower values in the 1-35 kg/MT range are to be used for well-designed and operated boilers.¹⁷ Since no particular boiler has been specified for this study, an average value of 18 kg/MT is used to derive the hydrocarbon emission estimates in Table 3.8. Well designed and operated wood fired boilers would be expected to emit a minimum of approximately 238 TPY and 91 TPY for sugar cane-based and corn-based alcohol production, respectively. Hydrocarbon emissions from sugarcane-based alcohol production using wood combustion to provide process steam would emit large (216 Mg/y) amounts of hydrocarbons even with efficient boilers. These facilities could be subject to the air quality regulatory process, and could be required to install control equipment. One type of control process that could be installed to reduce hydrocarbon emissions is catalytic incineration. This process, when properly applied, designed,

and maintained, can consistently reduce hydrocarbon emissions by 95 percent or more.¹⁸ Controlled hydrocarbon emissions using catalytic incineration would thus be on the order of 11 Mg/y (12 TPY) for sugarcane-based alcohol production for a 60×10^6 L/y facility.

Particulate emissions from sugarcane- and corn-based alcohol production using wood combustion for process steam are estimated to be 982 Mg/y (1080 TPY) and 373 Mg/y (410 TPY), respectively, after reducing emissions 80% using scrubbing. These estimates assume fly ash reinjection, which is typically done in wood-fired boilers in order to improve fuel use efficiency.¹⁷ If no fly ash reinjection is used, emissions from sugarcane-based and corn-based alcohol production would be reduced to 648 Mg/y (720 TPY) and 246 Mg/y (273 TPY), respectively. The EPA emission factor of 22.5 kg TSP/MT wood, which assumes fly ash reinjection, reflects approximately a 4% ash content of the wood with a 2:1 fly ash/bottom ash ratio (although it was not developed with a mass balance approach using these assumptions).¹⁶ The emissions estimate produced from the EPA factor may be artificially high because the ash content of wood can be lower than 4%, and because less particulate matter can become fly ash. Adams¹⁹ reports that typically 15% of the intrinsic ash in wood appears as stack particulate; values can range from 8% to 65% (based on intrinsic ash balance using calcium). Thus, particulate emissions calculated using a mass balance approach could be lower than the estimate produced using the EPA factor. For example, if a wood ash content of 1.8% is assumed (for Birch¹⁵), and if it is assumed that 15% of the ash content of the wood becomes fly ash¹⁹, then uncontrolled particulate emissions would be about 25 Mg/y

(28 TPY) for corn-based alcohol production, and about 66 Mg/y (73 TPY) for sugarcane-based alcohol production. Installation of 80% efficient particulate control equipment would reduce emissions to 5 Mg/y (5.6 TPY) for corn-based plants and 24 Mg/y (14.6 TPY) for sugarcane-based plants.

The EPA factor for CO emissions from wood-fired boilers ranges from 1-30 kg/MT; lower values in the range are to be used for well-designed and operated boilers.¹⁷ Because no particular boiler is specified for this generic study, an average factor of 15.5 kg CO/MT wood is used in the emissions estimates. If efficient boilers are used, uncontrolled CO emissions for corn- and sugarcane-based alcohol production using wood combustion would be 83 Mg/y (91 TPY) and 216 Mg/y (238 TPY) respectively. CO emission can be further reduced by combustion modification or by installation of control equipment. Modifying the combustion process by burning wood in excess air would reduce CO emissions, but it could also increase emissions of nitrogen oxides. Installing control equipment such as thermal incinerators can reduce CO emissions without increasing NO_x emissions²⁰; this process uses an auxiliary fuel (e.g., natural gas) to burn the CO to CO₂. CO control efficiencies in the 60-85% range have been reported for thermal incineration.²¹ Operating costs can be significant for CO thermal incineration²¹ but use of heat recovery may make the process more economically attractive.²⁰ An 85% reduction in CO emissions through thermal incineration would reduce CO emissions (efficient boilers) for the 60 x 10⁶ L plant producing corn-based alcohol to 14 Mg/y (16 TPY) and sugarcane-based alcohol to about 33 Mg/y (36 TPY).

Emissions of uncontrolled nitrogen oxides from fuel combustion are estimated to be significant for all fuels and all processes, with the possible exception of corn-based alcohol production using natural gas. The most proven technology for reducing nitrogen oxides is combustion modification. One combustion modification approach is to design the boiler for staged combustion, in which the main NO_x -forming portion of the furnace is maintained in a cool, oxygen-poor state.¹³ The staged combustion technique is capable of reducing NO_x emission by 50-65%.²² Use of this technique at its maximum control efficiency would reduce NO_x emissions to 35% of the values listed in Table 3.8.

3.3.3 Stored product emissions

Emissions from the liquid fuels storage and denaturing area are not expected to vary directly in proportion to plant capacity¹ (Table 3.9). Underground storage releases fewer emissions than above-ground tanks, but larger size containers usually are not buried. Fixed roof tanks release more emissions than those with floating roofs. More of the stored material escapes from larger size tanks.

Table 3.9. Emissions from gasoline and denatured alcohol storage^{a,b}

Storage	Annual ethanol capacity 10 ⁶ L (10 ⁶ gal)	Number of tanks	Tank size L(gal)	Underground storage kg/h (lb/h)	Calculated emissions	
					Fixed roof tank kg/h (lb/h)	External floating roof kg/h (lb/h)
Gasoline	57 - 114 (15 - 30)	1	75,708 (20,000)	0.07 - 0.14 (0.15 - 0.30)	0.5 (1.2)	0.24 (0.53)
	114 - 284 (30 - 75)	1	189,270 (50,000)		1.1 - 1.3 (2.4 - 2.8)	0.33 (0.72)
	284 - 568 (75 - 150)	1	378,541 (100,000)		2.4 (5.4)	0.41 (0.90)
Denatured alcohol	57 - 77 (15.0 - 20.4)	1	1,892,706 (500,000)		1.4 - 1.7 (3.1 - 3.7)	0.09 (0.20)
	77 - 154 (20.4 - 40.8)	1	3,785,412 (1,000,000)		2.1 - 3.2 (4.7 - 7.0)	0.12 (0.26)
	154 - 309 (40.8 - 81.6)	2	3,785,412 (1,000,000)		4.3 - 6.4 (9.4 - 14.1)	0.24 (0.53)
	309 - 463 (81.6 - 122.4)	3	3,785,412 (1,000,000)		7.4 - 9.6 (16.4 - 21.2)	0.36 (0.79)
	463 - 568 (122.4 - 150.0)	4	3,785,412 (1,000,000)		10.6 - 12.1 (23.5 - 26.7)	0.48 (1.06)

^aReference 1.

^bBasis: Gasoline, about 5 (4 to 8) days inventory; denatured alcohol: about 10 (7 to 10) days inventory. Calculations assume a Midwest location with an average wind speed of 18 km/h (11 mph), an average temperature of 10.8°C (51.5°F) and an average daily temperature change of 8°C (15°F). Storage in gray tanks.

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4. OCCUPATIONAL SAFETY CONSIDERATIONS

(A. P. Watson and J. G. Smith)

We have been unable to discriminate between facilities of 60×10^6 and 600×10^6 L/y capacity on the basis of available occupational safety and health data. The only difference is the obvious one of size, which would determine the number of workers potentially exposed to accident and health hazards. Note that a large facility might be automated and therefore not necessarily require a large staff. An analysis of scale would require site-specific information.

4.1 FEEDSTOCK HANDLING

All grains, potatoes, or sugarcane must first be crushed or chopped to increase the surface area for later enzyme activity and to increase the ease of handling. Before any size reduction, stones, harvest debris, and any other foreign material that may interfere with succeeding processes must be removed from the feedstock. Stray nails, wire, cans, or other tramp metal are often removed by passing feedstock through a screen or magnetic field. A magnet must be periodically cleaned to prevent clogging of feed lines and passage of tramp metal into the mills.

Grain is usually crushed in hammer mills equipped with classifying screens. Because grain dust is produced, any tramp metal in the feedstock is a potential source of sparking ignition. Grain dust, particularly if allowed to accumulate on machine surfaces and supports, can pose a high explosion risk. For example, grain dust ignition at elevators in Louisiana and Texas claimed 53 lives in December of 1977.¹

Measured work shift dust concentrations in 31 grain elevators of various sizes ranged from 0.18 to 781 mg/m³ (Ref. 2). The greatest mean value, 109 mg/m³, was measured in receiving tunnels, through which all grain must pass. Most grain transfer points (gallery junctions or towers) in those elevators sampled were not equipped with exhaust ventilation, and levels approaching 1000 mg/m³ were measured. As a result, potentially explosive concentrations of dust were probably attained at these sites frequently.² Adequate ventilation of grain transfer points should be a priority at all ethanol fuel facilities.

Other potential ignition sources that must be controlled during grain handling and milling include unsealed electric motors and static charge build-up on conveyors or moving belts.⁴ Use of explosion-proof motors, adequate electrical grounding, and sufficient ventilation should be mandatory during handling and preparation of all grains. Smoking, open flames, and welding should be prohibited in dusty areas.

Grain dust is also known to produce adverse respiratory effects when chronically inhaled.² Several factors are probably involved in producing cough, wheezing, and "grain fever," including: 1) the abrasive quality of small, respirable particles, 2) a constituent of the grain that may elicit allergic reactions, and 3) the presence of fungal spores that could be allergenic.³

Milling is also an inherently noisy operation because of grain impacts within transfer lines and kernel passage through the hammer mill. Prolonged, unprotected exposure poses a hazard of occupational hearing loss. Workplace noise has been analyzed for a number of industries and federal compliance standards for exposure have been established by OSHA (Appendix A). Although no data characterizing noise-

level contours in grain mills are readily available, many beverage distilleries post the mill room as an ear protection site and provide earmuffs or plugs.⁵ Noise emissions below levels causing hearing loss can also reduce speech communication, which may be hazardous near moving equipment.

Tubers, root crops, and cane will all require chopping and shredding to release plant sap and create slurries that can be easily handled. Operation of slicing and crushing equipment pose an amputation hazard, particularly to newly hired personnel, unless mechanical guards and shields are adequately installed and used. "Dead-man" switches would be useful here.

Corn-wet-milling has been proposed as an alternative route of feedstock preparation to produce a greater number and variety of products (see Sect. 2). As delivery, storage, and handling procedures are similar to those for other grains, dust release poses similar hazards of ignition. The steeping/oxidation of whole grain will probably require use of SO_2 in pressurized tanks. Sulfur dioxide is a toxic gas, and eye contact can cause serious injury. (Sulfur dioxide combines with moisture to produce sulfuric acid.) Exposure to concentrations of 6 to 12 ppm in air can irritate the nose and throat, while 20 ppm is the smallest concentration known to be an eye irritant.⁶ The recommended threshold limit value (TLV) is 2 ppm or 5 mg/m^3 air.⁷ Tanks of this material will require careful handling to prevent rupture and acute exposure, and should be stored in chain racks outside the work area. It is a strong oxidant and should be protected from uncontrolled reaction with water or steam.

Storage of corn germ or fiber containing unextracted or residual corn oils may pose a fire hazard. Cornmeal feeds in storage have a high risk of spontaneous ignition; they are also weak allergens and may induce dermatitis or respiratory distress in sensitized individuals.² This potentially allergic population could be identified by a screening skin test at the time of employment. Although the normal industrial hazards of moving machinery, pumps, and heat/steam transfer lines exist, there are no unique sources of occupational injury or disease in corn-wet-milling.

Most fuel ethanol facilities will have feedstock storage bins on site, where grain will be transferred after delivery to the plant gates. Maintenance workers are often required to enter such bins from the top to repair or replace equipment or adjust the conveyor feed system. Walking across the crust of grain to retrieve dropped tools has been known to have tragic consequences when the worker breaks through into voids below. A helpless depth (pinned by grain at the hips) can be reached in 2 to 3 s and suffocation can occur rapidly.⁸ Reaction time would be even shorter if the bin is being emptied at the time. Lifelines attached to a buddy or solid object outside should be an essential piece of equipment for all workers inside grain storage areas.

4.2 FUEL HANDLING

Coal, wood, bagasse, and natural gas have all been considered as fuels to provide process heat and steam within the facility. If coal or wood are used, proper sizing will be required for efficient use by the distillery boiler system. If not delivered as such, these fuels will

require pulverizing or crushing on site. Use of guards and shields will reduce the number of arms and legs that might be fractured or amputated.

Although any coal-handling process generates dust, pulverizing is a particularly localized source. Bituminous coal dust at 49.5 g/m^3 air is explosive under standard test conditions; it is easily ignited and has a high potential for producing a severe explosion,⁹ especially in enclosed situations such as a conveyor tunnel or underground mine. The Mine Safety and Health Administration is developing continuous monitors that will trigger alarms when dangerous dust levels are attained. Safeguards of electrical grounding, explosion-proof motors, and adequate ventilation as previously outlined for grain dust (Sect. 4.1) also apply to coal.

Data available from coal-fired steam plants indicate that auxiliary equipment operators working near noise-generating equipment such as crushers and heavy machinery are at greater risk to occupational hearing loss.^{10,16} Sound pressure levels measured at 3 ft from coal crushers in steam plants are 90 to 100 dBA (decibels measured on an A-weighted scale), while levels measured at the same distance from precipitator rappers and vibrators is 100 to 115 dBA.¹¹ (The maximum permitted value for 8-h exposure is 90 dBA.) Although on a smaller scale in proposed facilities, coal-handling equipment at an ethanol plant is likely to generate high levels of noise (Appendix A). Areas requiring mitigation should be posted and ear protectors made readily available.

Prolonged inhalation of coal dust concentrations exceeding 2 mg/m^3 air can produce irreversible reductions in lung function and capacity.¹² These high concentrations could occur at individual sites adjacent to

the coal crusher during use and the stockpile during handling. Adequate ventilation, reduced exposure times, and use of respirators will reduce the likelihood of respiratory damage (Appendix A).

Wood waste used to fire boilers will likely require trimming to standard lengths before feeding into the furnaces. Operators of saws or milling equipment are usually exposed to excessive noise levels from engines and exhaust systems.¹³ Mitigation is similar to that for coal-handling equipment. Contact with wood and wood dust can produce dermatitis and respiratory ailments in sensitive individuals. Some wood dusts are themselves allergenic (e.g., cedar), while fungal mycelia and spores found on maple trees can produce respiratory difficulty in workers handling maple wood and bark.¹³ Efforts should be made to reduce exposure to dusts with ventilation and respirators and to transfer sensitive individuals to other jobs.

The most serious hazards of wood preparation are the severe accidental injuries caused by falls into conveyors or saws, collisions with forklifts and dropped loads of wood, and muscular strain during manual wood handling.¹³ For 1973 the incidence of recordable injuries in U. S. wood mills was 25 cases per 100 full-time workers; annual lost-workday incidence was 9.8 cases per 100 full-time workers. These rates can be compared with the 1973 annual average for the entire private sector of 11.0 and 3.4 cases per 100 full-time workers, respectively.¹⁴ The ratios are not expected to differ significantly in 1981.

Bagasse is an unconsolidated fuel and will require much handling and storage in large-volume stockpiles on site. Portable cranes are often used to transfer bundles of cane before combustion in boiler

furnaces. Potential occupational hazards (rollovers, crushing, amputation, falls) are those associated with operation of any heavy hydraulic equipment; hard hats and no-skid footwear would be important protective equipment for each crane operator and worker near the loading area.

Use and handling of any fuel gas will require normal industrial precautions against sparking equipment and open flame near feed lines. Precautions to reduce the risk of storage tank or feed line puncture will be necessary to control explosion hazards. Compared with other fuels, gas appears to present the smallest occupational hazard.

4.3 LIQUEFACTION AND SACCHARIFICATION

Heating of the feedstock slurry to temperatures suitable for commercial starch gelatinization and hydrolysis requires operation of boilers and steam transfer lines. Maintenance of proper boiler and line pressurization will be necessary to control the potential for rupture and/or explosion. Most states have their own standards and inspection program (Appendix A). Use of safety valves, adherence to proper boiler procedure, and operation by trained staff [American Society of Mechanical Engineers (ASME) certification] should all be standard practice.⁴ The frequency of scalding and contact burns can be reduced with periodic maintenance of gaskets, insulation of steam lines, and placement of baffles near flanges to direct steam jets away from work stations.⁴

Strong mineral acids are used in undiluted form for acid hydrolysis or may be added to the slurry for pH adjustment before enzyme hydrolysis (acidic spent stillage can also be used for pH adjustment with fewer

safety precautions). In either case, standard industrial safety precautions should be used to prevent skin or eye contact or inhalation of acid droplets. Sulfuric acid, often used for hydrolysis, is a strong oxidant and produces severe chemical burns.⁶ Because the heat of reaction from adding sulfuric acid to slurries can cause fuming or splash, protective clothing should be worn and extreme care should be taken during mixing. Storage should be in resistant containers (never carbon steel) away from materials subject to violent oxidation (e.g., ethylene glycol, metals, and water) and on the ground floor in acid cabinets or detached buildings. Feed lines should also be corrosion-resistant. Deluge showers and eyewash facilities should be available where needed.^{4,6} Strong basic solutions may also be used for pH adjustment or tank cleaning, and similar precautions should be taken during their handling and use.

4.4 FERMENTATION

The principal products of fermentation are carbon dioxide (CO_2) and ethanol. Fermentation tanks may be covered to capture marketable CO_2 for compression. Ethanol vapor can also be recovered for passage through the distillation column. Tank capping greatly reduces the potential risk from CO_2 asphyxiation. Carbon dioxide (vapor density = 1.53) can settle on the floor of a poorly ventilated fermentation room and gradually attain suffocating concentrations upon continual evolution from the open tank(s).⁶ Employees alone on the ground floor of the fermentation area are particularly vulnerable because CO_2 is colorless and relatively odorless. The early symptoms of excessive exposure

(headache, dizziness, and muscle weakness) result in collapse, after which suffocation can occur. A concentration of 3% CO₂ in air can increase blood pressure and pulse rates, while 5% will elevate respiration; 10% is a threat to life.⁸

Beverage distilleries often ferment in open tanks, leaving the dense CO₂ to form a vapor cap over the mash. Large volumes of fresh air flow in this situation would introduce microbial contaminants to the mash. Ventilation is usually adequate for a limited work crew to tend to vats with no difficulty, although CO₂ may build up over weekends or when fans are shut down. Oxygen tanks and masks must be located at key sites in the fermenter room(s) for workers making repairs on the ventilation system and working in high-CO₂ pockets. Carbon dioxide monitors and a buddy system would also be worthwhile precautions.

Under no circumstances should unguarded walkways be constructed above the vat, because workers may easily be overcome by CO₂ or ethanol, fall into the mash, and drown. A useful design feature of the fermentation unit would be to locate the main access area and catwalks approximately 1 m below the lip of each fermentation vat.

Vat cleaning after transfer of the mash to the distillation unit also poses an asphyxiation hazard because dense CO₂ often collects in the vat bottom or the beer well. Adequate ventilation, safety harnesses and ropes, and a buddy system are all good precautions.

No matches, smoking, or welding should be permitted during fermentation. The ignition potential of ethanol vapor is considerable (flash-point is only 13°C).¹⁵

4.5 DISTILLATION

Strained, fermented mash is usually heated for distillation by pressurized steam. Use of this heat source will require precautions against overpressurization and scalding burns (Sect. 4.3).

The release of small amounts of ethanol vapor during distillation is relatively common but maintaining levels below the current OSHA limit of 1000 ppm (8-h time-weighted average) appears to present no great difficulty.⁷ Considered slightly to moderately toxic, the lowest published lethal oral dose of ethanol vapor for humans is approximately 6000 mg/kg body weight.⁶ Vapor concentrations of ethanol ranging from 250 to 1064 ppm are considered safe during the working day.¹⁶ Alcohol has an intense odor and may be practically intolerable at concentrations of 6000 to 9000 ppm in air (114 to 171 g/m³), but acclimatization normally occurs rapidly. Prolonged exposures to high concentrations may produce irritation of the mucous membranes and upper respiratory tract, headache, nervousness, dizziness, tremors, fatigue, nausea, and unconsciousness. If the alcohol concentration in the blood becomes 0.4-0.5% (4,000-5,000 ppm), death may result.¹⁷ The current recommended TLV for ethanol vapor is 1000 ppm.⁷ The greater the amount of alcohol produced, the greater the potential for exposure to hazardous concentrations of alcohol will be. Application of proper precautions as used by currently operating distilleries will considerably reduce the risk of exposure to harmful or lethal concentrations.

The principal industrial safety concern of ethanol vapor is its flammability and explosion potential; therefore, exposure of ethanol to heat and open flame should be avoided. Reaction can be vigorous if

exposed to certain compounds (e.g., acetyl chloride, chlorates and chromates).⁶ Matches, cigarettes, open flames, and unsealed motors should be prohibited in the still house to reduce the hazard of ethanol ignition.

4.6 SUMMARY

All known hazards specific to ethanol facilities are summarized in Table 4.1. Common-sense controls for each problem area are also given. If these precautions are rigorously followed, working conditions in all fuel ethanol plants would be safe and healthful. However, records indicate that major incidents of fatalities and multi-victim accidents in grain handling industries are far from rare. As recently as April, 1981, a grain dust explosion at the Corpus Christi Public Grain Elevator killed 3 and injured 32 individuals.¹⁸ A March, 1979, ignition of flour dust at an Archer Daniels Midland (ADM) mill in Kansas City, Missouri, caused hospitalization of 6 employees suffering from burns and concussion.¹⁹

Other, grain-handling accidents available in OSHA records from January, 1979, through April, 1981, are presented in Table 4.2. These records include all fatalities and multi-victim accidents reported to OSHA for grain mill products (Standard Industrial Category [SIC] 2041), wet-corn-milling (SIC 2046), and distilled liquor beverage-making (SIC 2085).²⁰ Non-disabling, single-victim accidents, which may nevertheless be severe, are not included in the OSHA data. These values indicate that 0.6% of mill and elevator workers investigated suffered

Table 4.1. Potential hazards and their control in fuel-ethanol facilities^a

Hazards	Precautions
1. Overpressurization; explosion of boiler	<ul style="list-style-type: none"> • Regularly maintained/checked safety boiler "pop" valves set to relieve when pressure exceeds the maximum safe pressure of the boiler or delivery lines. • Strict adherence to boiler manufacturer's operating procedure. • If boiler pressure exceeds 20 psi, acquire ASME boiler operator certification. Continuous operator attendance required during boiler operation.
2. Scalding from steam gasket leaks	<ul style="list-style-type: none"> • Place baffles around flanges to direct steam jets away from operating areas. • (Option) Use welded joints in all steam delivery lines.
3. Contact burns from steam lines	<ul style="list-style-type: none"> • Insulate all steam delivery lines.
4. Ignition of ethanol leaks/fumes or grain dust	<ul style="list-style-type: none"> • If electric pump motors are used, use fully enclosed explosion-proof motors. • (Option) Use hydraulic pump drives; main hydraulic pump and reservoir should be physically isolated from ethanol tanks, dehydration section, distillation columns, condenser. • Fully ground all equipment to prevent static electricity build-up. • Never smoke or strike matches around ethanol tanks, dehydration section, distillation columns, condenser. • Never use metal grinders, cutting torches, welders, etc. around systems or equipment containing ethanol. Flush and vent all vessels prior to performing any of these operations.

Table 4.1. (continued)

Hazards	Precautions
5. Handling acids/bases	<ul style="list-style-type: none">• Never breathe the fumes of concentrated acids or bases.• Never store concentrated acids in carbon steel containers.• Mix or dilute acids and bases slowly, allow heat of mixing to dissipate.• Immediate flush skin exposed to acid or base with copious quantities of water.• Wear goggles whenever handling concentrated acids or bases; flush eyes with water and immediately call physician if any gets in eyes.• Do not store acids or bases in overhead work areas or equipment.• Do not carry acids or bases in open buckets.• Select proper materials of construction for all acid or base storage containers, delivery aides, valves, etc.
6. Suffocation	<ul style="list-style-type: none">• Never enter the fermenters, beer well, or stillage tank unless they are properly vented.

^aReference 4.

Table 4.2. Summary of accidents investigated by OSHA^a for SIC 2041;
January, 1979 through April, 1981^{a,b}

Facility type	No. employees	Fatal accidents	Injury accidents	Principal source of injury
Mill	135	0	6	Flour dust explosion.
	10	1	0	Fall; asphyxiation from dust inhalation.
	75	1	0	Caught in unguarded machinery.
	5	0	1	Amputation; caught in unguarded machinery.
	260	0	1	Facial burns; scald.
Elevator	2	1	0	Asphyxiation; caught between equipment.
Total	487	3	8	

^aNo accidents on record for SIC 2046 or SIC 2085.

^bReference 19.

fatalities, while 1.6% were either involved in disabling or multi-victim accidents.

Annual injury incidence rates and lost workdays from all causes for the three SIC codes defined above are summarized for 1978 and 1979 in Table 4.3 by the Bureau of Labor Statistics.²¹ Employees in ethanol-related industries are 111 to 185% as likely to suffer occupational injury than their co-workers in the private sector. In addition, injuries incurred by ethanol workers result in between 15 and 123% more lost workdays than comparable private sector wage-earners. Of the three ethanol categories evaluated, distilled liquor industry workers suffer the greatest number of injuries and workdays lost.

Recent estimates of manpower required to operate an ethanol fuel facility indicate that between 71 and 83 worker-years would be needed for a 76×10^6 L/y plant, while 182 to 400 worker-years would be needed for a 380×10^6 L/y plant.²² If these values are extrapolated for the range of production analyzed in this assessment, work force size would approximate 56 to 66 worker-years for a 60×10^6 L/y facility and 288 to 632 worker years for a 600×10^6 L/y plant. At 1979 incidence rates for SIC 2085 (Ref. 21) it can be expected that operation of each facility with 60 to 600×10^6 L/y capacity will annually produce between 9.9 and 111.2 accidents resulting in total lost time ranging from 84 to 951 work days.

Table 4.3. Occupational injury and illness rates in ethanol-related industries; 1978 and 1979^a

Industry	Incidence rate per 100 full-time workers			
	Total cases		Lost workdays	
	1978	1979	1978	1979
Grain mill products (SIC 2041)	15.3	16.1	125.8	138.6
Wet corn milling (SIC 2046)	10.4	10.8	73.0	93.2
Distilled liquor (SIC 2085)	16.1	17.6	123.2	150.4
Private sector	9.4	9.5	63.5	67.7

^aReference 20.

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5. OCCUPATIONAL HEALTH CONSIDERATIONS

(J. G. Smith)

5.1 ETHANOL DESICCANTS

Absolute alcohol is required in the blending of gasohol to prevent phase separation. However, an ethanol/water mixture in the still column can only attain 95% purity without the addition of a third liquid to break the constant boiling azeotrope.¹ Numerous compounds have been proposed as desiccants; the most common is benzene. The known health effects are summarized for four such desiccants.

5.1.1 Benzene

Benzene is highly toxic to humans.² Industrial poisoning is most likely to occur by means of vapor inhalation although absorption through the skin may also be toxic.^{3,4} Death from circulatory failure or coma occurs within a few minutes after exposure to high concentrations (20,000 ppm). At concentrations of approximately 2000 ppm, benzene exposure produces toxic effects in about 60 min. Symptoms at this concentration include euphoria, nervous excitation, headache, staggering, and nausea. These symptoms are followed by circulatory and respiratory depression which can result in cardiovascular collapse and/or unconsciousness.⁵ At concentrations of 250 to 500 ppm, symptoms include vertigo, drowsiness, headache, and nausea.^{5,6} Deaths have been reported from exposure to concentrations of 200 ppm or less,⁷ but most deaths have been noted to occur upon prolonged exposure to concentrations above 200 ppm.⁸

In industry, chronic poisoning is more important than acute poisoning.³ Symptoms vary widely among individuals. The onset of poisoning is slow and may include easily masked symptoms such as fatigue, headache, dizziness, nausea, and loss of appetite; loss of weight and weakness are common complaints. Continued exposure may result in pallor, nosebleeds, bleeding gums, excessive or prolonged menstruation, and spots on the skin.³ Blood-forming organs, particularly bone marrow, are especially sensitive to chronic exposure. An initial increase in cell formation is followed by a decrease in the number of red and white blood cells and platelets.⁶ The bone marrow may appear normal, hyperplastic, or hypoblastic.³ Continued exposure may eventually lead to aplastic anemia.⁶ Benzene is a suspected carcinogen in humans,^{8,9} but animal studies have not been supportive of this view.¹⁰ The American Society of Governmental Industrial Hygienists has suggested that benzene may be a cocarcinogen.⁸

Benzene is a known mitotic toxin.^{11,12} Exposure may cause a loss or gain of chromosome segments, whole chromosomes, or chromosome sets. Changes resulting in morphologically aberrant chromosomes may also occur.¹² Although benzene causes chromosome damage, studies have not demonstrated mutagenicity.^{13,14} Most studies have shown that benzene is not a human teratogen, although it may be teratogenic in mice.¹⁵

A self-contained breathing apparatus should be used during prolonged exposure.¹⁶ Benzene is highly flammable³ and should not be used in areas where sparks may occur.¹⁷ Benzene containers should be protected against physical damage and stored outdoors or in detached structures. A standard flammable liquid storage room is needed for indoor storage. Benzene should never be stored near oxidizing agents.¹⁶

5.1.2 Gasoline

Gasoline is considered moderately toxic.² Skin contact can cause drying and defatting,⁴ while acute inhalation or ingestion may cause conjunctivitis; irritation of the nose and throat; headache, dizziness, drowsiness, cough, difficulty in breathing, bronchitis, pneumonia, nausea, vomiting, nervousness, irritability, blurred vision, and confusion.¹⁷ Continued exposure to vapor concentrations of gasoline as low as 110 ppm may cause nervous disorders.¹⁸ A 15-min exposure to 1000 ppm causes drowsiness, dullness, and numbness; a 1-h exposure causes dizziness, confusion, and slight nausea; exposure to 7000 ppm causes intoxication within 5 min. Exposure to concentrations greater than 10,000 ppm is rapidly fatal to most experimental animals.¹⁸

The time and concentration necessary to produce toxic effects depend on the chemical composition of the gasoline; there is no evidence that chronic exposure to low concentrations produces any adverse health effects.⁴ However, adolescents who chronically sniffed high concentrations of gasoline for its narcotic activity have demonstrated many adverse effects.^{19,20} Symptoms of chronic, deliberate exposure include tremors, high blood-lead, confusion, unsteady movement, and hallucinations (auditory and visual). Heavily exposed victims may die from cardiac arrest. Clinical findings indicate that gasoline may be a teratogen.²¹

Gasoline is explosive in the presence of heat or flame.³ Thus, storage areas should be located away from direct sunlight and areas of high fire hazard.¹⁷ Preferred storage is either outdoors or in detached structures, although gasoline may be stored indoors if a standard combustible liquid storage room or cabinet is used.¹⁷ A respiratory hazard

from benzene, common in gasoline formulations, may also exist during blending operations.

5.1.3 Ethyl ether

Ethyl ether is moderately toxic when swallowed but of low toxicity when inhaled.³ Swallowing is generally not a problem because of its disagreeable odor. Eye contact with either the liquid or relatively high atmospheric concentrations causes irritation but no permanent damage.⁴

Nasal irritation begins at a concentration of 200 ppm.²² The lowest oral dose that has been reported lethal to humans is 420 mg/kg body weight.³ A concentration range of 3.6 to 6.5% (36,000 to 65,000 ppm) by volume in air is anesthetic to humans. At a concentration of 7 to 10% (70,000 to 100,000 ppm), respiratory arrest may occur; levels above 10% are fatal.⁴ Loss of consciousness occurs after a 30- to 40-min exposure to an air concentration of 3.5%.²³ Symptoms from acute exposures may include excitement, drowsiness, vomiting, lowering of the pulse and body temperature, and irregular breathing. The after-effects of acute exposure are temporary and may include vomiting, salivation, irritation of the respiratory passages, headaches, and depression or excitation. Repeated exposures by inhalation may cause loss of appetite, exhaustion, headaches, sleepiness, dizziness, excitation, and psychic disturbances.⁴

The extreme flammability and explosiveness of ethyl ether is the greatest problem regarding its industrial use.²³ Ethyl ether should not be exposed to heat, flame, or oxidizing agents.³ The preferred means of

storage is in detached outside buildings. If it must be stored inside, a standard flammable-liquids storage room or cabinet should be used. Static electricity and lighting fixtures may cause explosion and therefore should be controlled.¹⁶ The National Electrical Code defines the area in which ethyl ether is stored as a hazardous location.²³

5.1.4 Ethylene glycol

Toxicity of ethylene glycol is low via skin and mucous membrane exposure and moderate when swallowed.¹⁷ Because the vapor pressure is low, inhalation of ethylene glycol is generally not an industrial hygiene problem unless handled while hot or after violent agitation.^{4,24} Skin irritation is minor unless the victim is exposed to relatively large quantities for prolonged periods.⁴ Although toxicity due to skin contact is low,²⁵ prolonged and repeated contact should be avoided.⁴

The single lethal oral dose of ethylene glycol in humans is approximately 1500 mg/kg body weight.¹⁷ Progressive symptoms of acute exposure include intoxication, vomiting, drowsiness, coma, respiratory failure, convulsions, kidney damage, uremia, and death.²⁶ Intake of a small dose may produce initial symptoms of intoxication, followed by several days without symptoms, after which renal failure may occur.² Severe kidney injury appears to be associated with the intake of repeated small oral doses.⁴

Storage of ethylene glycol should be in resin-coated stainless steel or aluminum containers protected against physical damage. Ethylene glycol is flammable (flash-point at 111°C) and should be protected from fire.^{9,17}

5.1.5 Alternative desiccation

Ethanol is also dried with calcium oxide (CaO) or synthetic zeolites. These materials are commonly known as molecular sieves^{1,27} because they selectively absorb water. Recently, the use of cellulose, starch, and corn have been investigated as ethanol desiccants and found to be more energy efficient than agents such as CaO.²⁷

The use of desiccants such as CaO requires certain precautions. Calcium oxide can react violently with borates, calcium chloride, boron trifluoride, fluorine, hydrogen fluoride, phosphates, chlorine trifluoride, and water.³ Synthetic zeolites can produce inhalable dust, which may be alkaline in contact with moist mucous tissue.³

5.1.6 Assessment of desiccants

Many uncontrolled variables (e.g., spills, equipment failure, etc.) may be involved in handling and using desiccants which make a complete assessment of exposure and hazard potential impossible. However, based on the relative toxicity and amount used of each desiccant, a rough estimate of the potential hazard of handling and using these compounds may be made.

Table 5.1 presents a summary of the current TLVs, toxicities, relative toxicities, estimated quantity used, and the estimated hazard potential of each compound. The hazard potential was estimated by multiplying the relative toxicity of each compound by the amount used for dehydration.²⁸ The compounds with the highest values were considered to have the greatest hazard potential. Relative toxicities were based on the toxicity ratings given by Sax³ as high, medium, and low.

Table 5.1. Proposed threshold limit values (TLV), human toxicities, relative toxicities, estimated quantity used, and estimated hazard potential of potential alcohol desiccants^a

Desiccant	TLV ^b (ppm)	Toxicity (Route of exposure)	Relative toxicity ^c	Amount used (Kg/h) ^d	Hazard potential ^e
Benzene	10	High ^e (Inhalation, skin and oral)	6	4.2	25.2
Gasoline	300 ^f	Moderate ^g (Inhalation and oral) Low ^h (Skin)	3	677.0-14,085	2031.0-42,255.0
Ethyl ether	400	Moderate (Oral) Low (Inhalation and skin)	2	4.6	9.2
Ethylene glycol	100	Moderate (Oral) Low (Skin and inhalation)	2	4.2	8.4

^aInformation not available for calcium oxide or synthetic zeolites.

^bTaken from reference 8.

^cSee text for explanation.

^dFrom Figs. 2.5-2.8.

^eHigh toxicity - Capable of causing death or permanent injury due to the exposures of normal use; incapacitating and poisonous (reference 3).

^fLimited to bulk handling processes (e.g., filling station operations) (reference 8).

^gModerate toxicity - May cause reversible or irreversible changes to exposed tissue, not permanent injury or death (reference 3).

^hLow toxicity - causes readily reversible tissue changes which disappear after exposure stops (reference 3).

Toxicity ratings of high were given a value of 3, moderate ratings a value of 2, and low ratings a value of 1. Because the toxicity of a compound may vary with route of exposure, each possible route of exposure should receive its own relative toxicity ranking – the score of each exposure route would be added to give the total relative toxicity for that compound. For example, benzene is highly toxic by both skin contact and inhalation (Table 5.1); therefore, the relative toxicity would be 6. The relative toxicities of the remaining compounds were also calculated in this manner.

Based upon the estimates of the hazard potential, benzene and gasoline would be the least desirable compounds to use – benzene because of its high toxicity and gasoline because of the large quantity involved. (Large quantities include the amount used for drying, denaturing, and the final product.) Ethyl ether and ethylene glycol appear to be equally hazardous (9.2 and 8.4, respectively) but ethyl ether has a much higher vapor pressure (438.9 mm Hg at 20°C) than ethylene glycol (0.06 mm Hg at 20°C)⁸ and, would, therefore, be potentially more serious as an inhalation hazard.

Although ethylene glycol appears to be the safest compound to use for desiccation, technologies currently exist which could be used for reducing the hazards involved in handling and using any of the potential desiccants (e.g., ventilation systems, appropriate storage containers, etc.). If proper precautions are taken, any of the potential desiccants could be used safely.

5.2 ETHANOL DENATURANTS

Compliance with regulatory provisions of each facility's Federal Bureau of Alcohol, Tobacco, and Firearms permit requires denaturing the final product to make it unfit for human consumption. Specific formulas using methanol, methyl isobutyl ketone, b-hydroxy butyraldehyde and kerosene in various proportions with ethanol are required. Ingestion of any one of these blends produces debilitating symptoms, while accidental inhalation or skin contact can also be toxic. A detailed assessment of each compound follows.

5.2.1 Methanol

Methanol is moderately toxic.² The most likely industrial exposure is by inhalation,¹⁰ but toxic effects also result from ingestion and skin contact.²⁶ Symptoms of acute methanol poisoning may initially resemble ethanol intoxication, followed by a 6- to 24-h delay before additional symptoms appear. These symptoms may include headache, fatigue, nausea, vomiting, visual impairment or complete blindness, shortness of breath, delirium, acidosis, convulsions, circulatory collapse, coma, respiratory failure, and death.^{10,26} The lowest reported lethal dose for humans is 340 mg/kg.⁹ Under industrial conditions, with varying concentration and duration of exposure, symptoms may include irritation of all mucous membranes, headache, roaring in the ears, fatigue, insomnia, trembling, dizziness, unsteady gait, difficulty in breathing, nausea, abdominal pain, constipation, dilated pupils, clouded vision, blindness, eczema, and dermatitis.⁴ The detrimental effects of methanol on the eye are well documented.²⁹

Methanol does not possess odors or irritating properties suitable to warn of impending overexposure; the threshold of detection by scent or irritation is approximately 2000 ppm.³⁰ Therefore, precautions should be taken to avoid methanol inhalation. Methanol is flammable and moderately explosive³¹ (flash point of 11°C) and should never be exposed to heat, flame, or oxidants.³ Detached storage is recommended.

5.2.2 Methyl isobutyl ketone

Methyl isobutyl ketone is moderately toxic when inhaled or swallowed.³ The most likely routes of industrial exposure are inhalation or skin and eye contact.⁴ Exposure to 200 ppm causes eye irritation, while exposure to 100 ppm can be irritating if no acclimatization has occurred.³² A high concentration of methyl isobutyl ketone lowers body temperature and respiratory and pulse rates.¹⁶ Unconsciousness quickly follows. Because this compound is rapidly eliminated from the body, no long-term pathological changes are expected.⁴

Methyl isobutyl ketone is moderately explosive and flammable, requiring detached outside storage or use of flammable liquid storage cabinets.^{3,16} It should not be exposed to heat, flames, or oxidizing/reducing agents.³

5.2.3 Aldol

When swallowed, aldol (β -hydroxy butyraldehyde) is moderately toxic.³ Aldol has been therapeutically used as a hypnotic and sedative.²⁶ The oral LD₅₀ for rats is 2180 mg/kg body weight.⁹ Although no

human data are available, caution should be taken when handling aldol because animal studies indicate potential human toxicity.

Aldol is flammable when exposed to heat or flame. When heated to decomposition, aldol decomposes to crotonaldehyde (highly toxic) and water. Exposure to oxidizing agents should be avoided.³

5.2.4 Kerosene

Kerosene is moderately toxic when swallowed or inhaled¹⁷ with an estimated human lethal dose of 0.5 to 5 g/kg body weight.² The lowest published human lethal dose is 500 mg/kg body weight.⁹ Symptoms of kerosene inhalation may include headache, excitement, dizziness, confusion, bronchitis, nausea, anemia, and polyneuritis. Symptoms following ingestion may include mouth and throat irritations, nausea and vomiting, drowsiness, rapid or irregular heartbeat, shallow respiration, cyanosis, pneumonia, proteinuria, and convulsions.¹⁷ Prolonged or repeated skin contact causes drying and dermatitis.⁴

Kerosene is flammable and can be explosive. Exposure to heat, open flames, and oxidizing materials should be avoided.³ Kerosene is preferably stored in outdoor or detached buildings, although standard combustible-liquid storage room or cabinets are also suitable.¹⁷

5.2.5 Assessment of denaturants

Alcohol for fuel use may be denatured using three possible combinations of compounds: (1) add 5 gallons of methanol to each 100 gallons of ethanol; (2) add 2.5 gallons of methyl isobutyl ketone, 0.125 gallon

of pyronate, 0.50 gallon aldol, and 1 gallon of either kerosene or gasoline to each 100 gallons of ethanol; or (3) add 4 gallons of methyl isobutyl ketone and 1 gallon of either kerosene or gasoline.¹ As with desiccants, many uncontrolled variables are involved in handling and using these denaturants; thus, a complete assessment of the exposure and hazard potential of these compounds is not possible, but a rough estimate of the potential hazard of each compound may be made.

A summary of the current TLVs, toxicities, relative toxicities, estimated quantity used, and the estimated hazard potential of each discussed denaturant is presented in Table 5.2. The relative toxicities and estimated hazard potentials of the denaturants were determined using the same procedure as was used for the desiccants (see Sect. 5.1.6). A comparable estimate of the potential hazards of aldol and pyronate was not possible due to the lack of toxicity data.

Methanol (Table 5.2) appears to present the greatest hazard potential (20.0), followed by methyl isobutyl ketone (12.0 or 7.5) due to the greater volumes required. The handling and use of kerosene (3.0) or gasoline (3.0) would present the least hazard.

Because these compounds are used either together or alone for denaturing alcohol, their hazard potentials should be considered cumulative. Based upon the three previously discussed possible combinations used for denaturing alcohol, the first combination (methanol only) would be the most hazardous (total hazard potential of 20) while the third combination (methyl isobutyl ketone and kerosene, or gasoline) would be somewhat less hazardous (total hazard potential of 15). A total hazard potential for the second combination is not possible due to the lack of

Table 5.2. Proposed threshold limit values (TLV), human toxicities, relative toxicities, estimated quantity used, and estimated hazard potential of the potential alcohol denaturants

Denaturant	TLV ^a (ppm)	Toxicity (Route of exposure)	Relative toxicity ^b	Amount used (gal/100 gal ethanol) ^c	Hazard potential ^d
Methanol	200	Moderate ^d (Inhalation, oral and skin)	4	5	20.0
Methyl isobutyl ketone	100	Moderate (Inhalation and oral) Low ^f (Skin)	3	2.5 ^e 4.0	7.5 12.0
Aldol	Not available	Moderate (Oral)	<i>g</i>	0.5	<i>g</i>
Kerosene	<i>h</i>	Moderate (Oral and inhalation) Low (Skin)	3	1.0	3.0
Gasoline	300 ⁱ	Moderate (Inhalation and oral) Low (Skin)	3	1.0	3.0
Pyronate	Not available	No data	<i>g</i>	0.125	<i>g</i>

^aTaken from reference 8.

^bSee Sect. 5.1.6 for explanation.

^cFrom Appendix B of reference 1.

^dModerate toxicity - May cause reversible or irreversible changes to exposed tissue, not permanent injury or death (reference 3).

^eAmount used depends upon combination of other denaturants used.

^fLow toxicity - causes readily reversible tissue changes which disappear after exposure stops (reference 3).

^gEstimation of relative toxicity and exposure potential were not possible due to lack of toxicity data.

^hA single TLV cannot be determined for kerosene because of its variable chemical composition.

ⁱLimited to bulk handling processes (e.g., filling station operations) (reference 8).

toxicity data. If the conventional means of dehydration was used (addition of 5 gallons of gasoline to each 100 gallons of alcohol,²⁸ the hazard potential of handling gasoline would increase fivefold (total hazard potential of 15). Thus, the use of gasoline as a denaturant would be equally hazardous to the third denaturant combination but somewhat less hazardous than using methanol alone.

Technology currently exists which can help reduce the hazards associated with the handling and use of these compounds. Therefore, any of the possible denaturants could be safely used if the proper precautions and equipment were implemented.

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6. PUBLIC HEALTH AND SAFETY CONSIDERATIONS

(A. P. Watson)

6.1 ATMOSPHERIC RELEASES

The major public health concern of ethanol fuel plant operation is that of combustion product releases from fuels used to fire on-site boilers. The sole use of coal without flue gas desulfurization could release significant quantities of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x), thus inducing local violations of (EPA's) Prevention of Significant Deterioration standards. The use of wood or bagasse could also release quantities of NO_x in addition to particulates. Local meteorology, flue stack configuration and fuel quality will all determine if existing standards for total suspended particulates (TSP), SO_2 , and NO_x will be exceeded. Releases of criteria pollutants have been estimated for various plant designs using each of the 4 major fuels.¹ Scaling factors provided by Battelle Columbus Laboratories² are used in this analysis to estimate emission rates (Table 6.1) for facilities producing 60×10^6 to 600×10^6 L/y.

Ethanol vapors may also be vented during fermentation and distillation or lost during transfer to storage and tank trucks. However, an efficient, well-managed facility cannot afford to lose its principal product. Ethanol vapor release is not considered to be a major public health concern.³

Coal storage piles represent local uncontrolled sources of the criteria pollutants carbon monoxide (CO), hydrocarbons, and particulate matter (as fugitive dust). However, at distances of 50 m from an

Table 6.1. Estimated release^a of atmospheric pollutants at ethanol production^b facilities according to fuel and feedstock used (kg/h)

Pollutant	Coal		Wood		Natural gas	Bagasse
	Corn	Sugarcane	Corn	Sugarcane	Corn	Sugarcane
SO ₂	19-185	49-488	8-78	21-207	0-0.2	21-207
TSP ^e	<i>d</i>	<i>d</i>	62-615	164-1628	0.6-6.2	164-1628
NO _x ^e	29-291	76-770	53-521	139-1377	9.5-95	139-1377
Hydrocarbons ^f	5-47	13-125	53-1157	308-3060	0.1-1.2	139-1377

^aBased on release rates from Radian¹ and multiplication factors calculated by Battelle Columbus Laboratories (reference 2).

^bWith a production of 60×10^6 to 600×10^6 L/y.

^cTotal suspended particulates.

^dNot significant.

^eNitrogen oxides.

^fHydrocarbons (unburned in case of coal but as methane for all other fuels).

average coal pile, measured concentrations of CO and hydrocarbons do not exceed ambient air standards.⁴ The quantity of dust redistributed from coal storage piles is a function of wind speed, coal particle size, coal moisture content, and mitigative measures taken to reduce fugitive release. The dust emission rate has been estimated to equal 610 kg/y from a representative bituminous coal pile containing 95,000 metric tons to a height of 5.8 m and exposed to a 4 m/s average annual wind.¹ This release is not considered to have any near-term health impacts.

6.2 STILLAGE DISPOSAL

Liquid effluent is usually acidic ($\text{pH} \leq 4.0$) and may contain heavy metals leached from valves, piping, tanks, and distillation columns.⁵ Samples collected from two midwestern on-farm ethanol fuel plants indicate that neither the metal nor biocide content of effluent currently exceeds standards of the Resource Conservation and Recovery Act.⁵ However, commercial-scale facilities should have complete waste-water treatment units or contract to supply local cattlemen with stillage waste as a feed supplement. In any case, the risk of contaminating local surface waters and groundwaters should be minimized by plant operation. As these materials also possess a high oxygen demand, uncontrolled release into local waters may reduce their potability by altering taste or odor.

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APPENDIX A

REGULATORY COMPLIANCE: OCCUPATIONAL

REGULATORY COMPLIANCE: OCCUPATIONAL

A.1 INTRODUCTION

The Occupational Safety and Health Act of 1970 (84 Stat 1593) was passed to provide safe and healthy working conditions for the U.S. workforce. The majority of U.S. workers are protected by provisions of the Act, with the exception of those working for certain states and municipalities or in industries already covered by other federal agencies (such as the Mine Safety and Health Administration). The federal agency responsible for establishing and enforcing standards promulgated for the Act is the Occupational Safety and Health Administration (OSHA).¹

Employers who retain one or more agricultural workers must comply with workplace standards, although members of a farmer-employer's family are not defined as employees under the Act and would not count as "agricultural workers." This provision would be directly pertinent to single-family operation of an ethanol fuel facility, which is not likely to be of commercial size. The operator of a single business employing 10 or fewer workers must still meet OSHA criteria but is exempt from many OSHA bookkeeping requirements. For businesses employing more than 10 workers, records of job-related injury accidents and illnesses are required to be maintained and periodically sent to OSHA. These records are evaluated by both OSHA and the National Institute for Occupational Safety and Health (NIOSH) to understand causes of occupational accidents and disease and develop mitigation procedures.¹

The Act transfers jurisdiction to each state submitting (for federal approval) a job safety and health program as effective as that established by OSHA. The state submission may be more stringent but cannot be weaker than the Act. Current (1980) approved states and territories are Alaska, Arizona, California, Hawaii, Indiana, Iowa, Kentucky, Maryland, Michigan, Minnesota, Nevada, New Mexico, North Carolina, Oregon, Puerto Rico, South Carolina, Tennessee, Utah, Vermont, Virginia, Virgin Islands, Washington, and Wyoming. Employers in the remaining nonapproved states, territories, or protectorates must meet federal job safety and health criteria unless a state has specific regulations not covered by OSHA. A common example is boiler and grain elevator inspections, for which state rather than OSHA regulations exist. Variations in state codes for boilers and grain elevators were not evaluated for this assessment.¹

Another special concern is exposure to particular hazards, such as carcinogens. All such exposures are regulated by OSHA rather than the states. Benzene, a dehydrating agent in the final distillation column of an absolute ethanol facility, falls into this category. In general, provisions of the Act apply to all states, because approved programs must meet minimum standards of the Act.

A.2 NOISE

Noise has been defined as a disorderly mixture of tones at many frequencies.² The resulting sound is often measured in decibels on a weighted scale (A) to simulate the tones and frequencies to which the human ear is sensitive. A worker may be exposed to many sources of

noise (Fig. A.1). Uncontrolled exposure to excessive sound levels can result in hearing loss.

In August 1971, OSHA first published regulations controlling occupational noise exposure.³ Section (b) of the OSHA noise standard is summarized in Table A.1. When workers are subjected to sound exceeding OSHA limits (Table A.1), the following actions shall be taken: (1) feasible administrative and engineering controls shall be used to reduce noise levels, and (2) if these controls are not adequate, personal protective equipment shall be provided, and an effective hearing conservation program shall be administered. Exposure to impulsive or impact noise should not exceed 40 dB peak sound pressure level.

This standard was based on the then-current recommendations of the American Conference of Governmental Industrial Hygienists.⁴ Because the standard was statistically derived, compliance was never meant to create a zero risk of occupational hearing loss. Instead, it was to provide protection for a majority of workers. The great range of individual susceptibility in the exposed population requires development and implementation of an adequate hearing conservation program in the workplace. Recently published revised recommendations reduce the sound levels for each exposure duration by 5 dBA from the existing standard (Table A.1).⁴

Stronger standards have been considered by the U.S. Department of Labor for several years, and were addressed at length in administrative hearings in 1975.⁵ At that time, compliance with more stringent regulations was urged by labor representatives on the grounds that significant hearing loss still occurs at the higher exposure level. This position is supported by findings in steel foundries, where hearing loss among

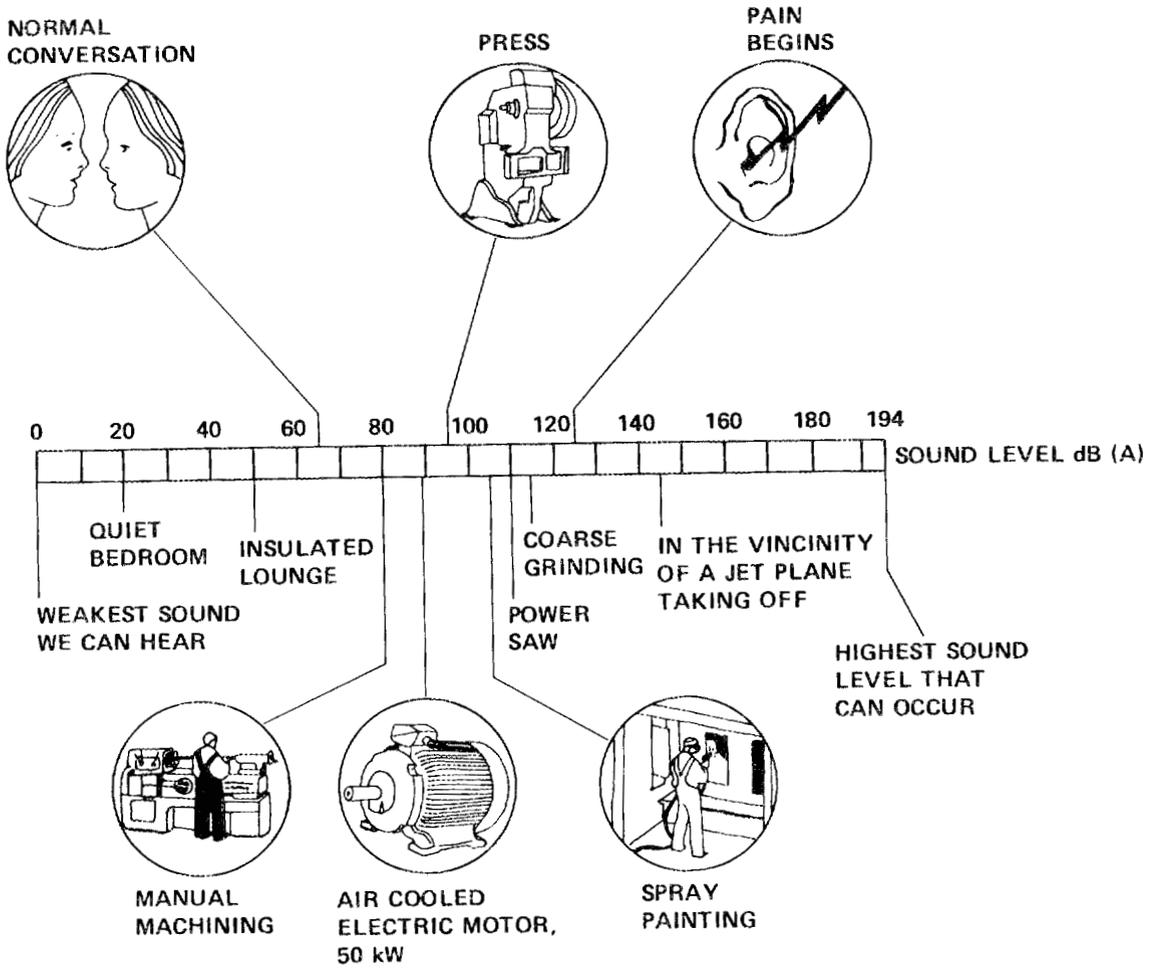


Fig. A.1. Comparison of normally-encountered sound levels (Witt, 1980).

Table A.1. Permissible workplace noise exposures^a

Sound level duration per day (h)	Slow response (dBA)
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or less	115

^aReference 3.

workers exposed to 90 dBA was 18.5% greater than that experienced at 85 dBA (workers between 50 and 65 years old).⁶ To reduce the potential for hearing impairment even further, some labor leaders have recommended further tightening of the limit to 75 dBA for 8-h daily exposure.⁶ Occupational noise standards were to be revised by OSHA in 1980 to reflect revised ACGIH recommendations.⁷ New regulations have not yet been published in the Federal Register. Noise releases even below maximum federal standards can interfere with speech communication to create potential accident hazard.

Sustained exposure to excessive noise levels is not expected to be a major hazard during operation of a fuel ethanol facility. However, certain tasks, such as grain milling, coal crushing and steam/ pressure line maintenance and repair could cause occupational hearing loss if reasonable safeguards are not used.

A.3 PARTICULATE MATTER

Inhalation of coal dust in high concentrations produces fibrotic scar tissue in lungs.⁸ However, elevated concentrations are likely to exist only in contained environments where ventilation is inadequate for extended periods. The existing occupational standard of 2 mg/m^3 coal dust⁴ was originally established by the Federal Coal Mine Health and Safety Act of 1969 (PL 91-173) for respirable dust in an effort to reduce black lung incidence during underground mining. The United Mine Workers of America and NIOSH are actively seeking consideration of a 1-mg/m^3 standard to further reduce the probability of disease induction in young miners. Although conditions in coal mines do not compare with

those in the proposed facility, unprotected employees may be exposed to hazardous concentrations of coal dust in confined locations under special working conditions. Increased ventilation can reduce these concentrations to acceptable levels.

Another dust to which employees may be exposed while working near coal-handling equipment is free silica. The recommended TLV is based on the percentage quartz in the coal. Inhalation of these abrasive particles in high concentrations can rapidly produce lung damage and silicosis.⁸

Of greater significance is the potential for dust explosions during coal and grain handling, especially if particles are allowed to accumulate close to sources of static charge build-up (conveyors, blowers, dry crushing and grinding equipment) or unsealed motors. Proper grounding, sealing, installation, and use of all electrical equipment to reduce fire and explosion risk is standardized in the National Electric Code and was adopted by OSHA in 1979 (29 CFR, 1910.309). Hazardous areas are classified according to the nature of the operation and atmospheric concentration of dust (29 CFR, 1910.309). To further reduce the risk of ignition, some system for removal of tramp metal from grain shipments should be installed at the grain receiving areas. Screens, magnets, or other equipment items are required on facilities constructed after 1973.

A.4 AIR CONTAMINANTS

A number of potentially hazardous compounds may be used during the drying and denaturing processes of ethanol production. Protection of employees against over-exposure to these materials is required by the

Occupational Safety and Health Act. The 8-h time weighted average limit (in ppm) for some of the substances used in drying and denaturing ethanol are as follows: benzene, 10; ethyl ether, 400; methyl isobutyl ketone, 100; and methanol, 200.⁹ The maximum acceptable ceiling concentration for benzene is 25 ppm, and the maximum peak above this ceiling is 50 ppm, with a maximum duration of 10 min.⁹ A TLV of 100 ppm has been proposed for ethylene glycol. Because gasoline and kerosene consist of a mixture of hydrocarbons, the concentrations of the component hydrocarbons may vary considerably. Thus, it is not possible to set an exposure limit on them.¹⁰ In addition to the denaturants and drying agents, exposure limits have also been established for ethanol. The current 8-h time-weighted average is 1000 ppm.⁹

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APPENDIX B

REGULATORY COMPLIANCE: PUBLIC

REGULATORY COMPLIANCE: PUBLIC

Combustion product emissions from a commercial ethanol fuel facility will be required to comply with the National Ambient Air Quality Standards (NAAQS) established by the EPA under authority of the Clean Air Act of 1977 (PL 95-95). The primary (protection of public health) standards of compounds most likely to be released by a distillery are summarized in Table B.1. Also included are increments that may not be exceeded if prevention of significant air quality deterioration (PSD) is to be maintained. Airsheds in the U.S. have been ordered into one of three classifications based on existing ambient air quality, with Class I being pristine (national parks and wilderness areas), Class II being in compliance but polluted, and Class III out of compliance. Potential PSD violations will need to be evaluated on a site-specific basis. Incremental changes in local air quality from any atmospheric release is dependent on local meteorology, plume temperature and composition, and stack configuration. Use of high-ash and/or high-sulfur coal without adequate particulate or SO₂ control could easily produce violations of the NAAQS.

The major public health concerns regarding ash, stillage, and scrubber sludge disposal are potential deterioration of drinking water quality through aquifer contamination, food chain transport of toxic materials via crop use of disposal sites, and inhalation exposure to fugitive dusts from unstabilized waste piles. If approved, the practice of sludge or stillage dumping at landfills and abandoned quarries will be prohibited from contaminating local aquifers beyond the outermost perimeter of the waste disposal site by provisions of the Solid Waste

Table B-1. Federal atmospheric pollution control standards for selected combustion products

Pollutant	NAAQS ^a ($\mu\text{g}/\text{m}^3$)	PSD ^b increment ($\mu\text{g}/\text{m}^3$)		
		Class I	Class II	Class III
TSP ^c				
Annual average	75	5	19	37
24-h average	260	10	37	75
SO ₂				
Annual average	80	2	20	40
24-h average ^d	365	5	91	182
3-h average ^d	--	25	512	700
NO ₂ , annual	100	--	--	--

^aNational ambient air quality standards.

^bPrevention of significant deterioration.

^cTotal suspended particulates.

^dNot to be exceeded more than once in a calendar year.

Disposal Act (40 CFR 257).¹ Stringent conditions govern variances to extend the boundary of contamination. The potential for groundwater deterioration would have to be evaluated with the use of monitoring wells both before and after development of the site as a waste disposal area. The level of pollution allowed is based on both National Interim Primary Drinking Water Standards (for several inorganic and organic chemicals, coliforms, and radionuclides) and the National Secondary Drinking Water Regulations (for chlorine, color, copper, foaming agents, iron, manganese, odor, pH, sulfate, total dissolved solids, and zinc) (40 CFR 257).² These latter materials are not toxic to ingest, but may make water unpotable by altering its odor, color, or taste. High levels of sulfate are laxative in humans. In the absence of data on chemical composition of potential leachate liquors and hydrogeological characterization of potential sites, no specific drinking water hazards can be identified. However, this assessment recommends the use of swelling clay seals and careful monitoring by use of wells to the water table.

If an open land disposal site is to be used later for agriculture, specific procedures must be followed to ensure against future incorporation of toxic materials into food crops or products of foraging animals (40 CFR 257).¹ This concern is particularly pertinent for cadmium. If the sludge is allowed to dry and is not stabilized by vegetation, asphaltic coatings, or physical barriers, fugitive dusts may produce local problems. Suspended particles are likely to be fine and may pose an inhalation hazard similar to that discussed for airborne combustion products.

No special handling precautions for ash and sludge are suggested by this analysis, because, effective November 19, 1980, "fly ash waste, bottom ash waste, slag waste, and flue-gas emission control waste generated primarily from primarily from the combustion of coal or other fossil fuels" have been classified as "solid wastes which are not hazardous" under the Resource Conservation and Recovery Act of 1976 (40 CFR 260).³ However, the EPA reserves the right to reclassify these wastes if further data warrant reclassification.

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GLOSSARY

- Absolute Alcohol - pure alcohol; 100% alcohol.
- Acidosis - a pathologic condition resulting from accumulation of acid in, or loss of base from, the body.
- Aplastic anemia - a deficiency in red blood cells and hemoglobin due to a reduction in production of these elements by the bone marrow.
- Cocarcinogen - a compound which by itself does not cause cancer but, when given with a weak-cancer causing agent, increases that agent's carcinogenicity.
- Conjunctivitis - inflammation of the membrane that lines the eyelids.
- Cyanosis - a bluish discoloration of the skin and mucous membranes due to lack of oxygen in the blood.
- High toxicity - capable of causing death or permanent injury due to the exposures of normal use; incapacitating and poisonous (ref. 12).
- Hyperplastic - increase in number of cells in a tissue or organ whereby the bulk of the part or organ is increased.
- Hypoplastic - underdevelopment of tissue or organ usually due to a decrease in the number of cells.
- Low toxicity - causes readily reversible tissue changes which disappear after exposure stops (ref. 12).
- LD₅₀ - dose lethal to 50% of the exposed population.
- Mitotic toxin - a compound which interferes with the normal process of cell division.
- Moderate toxicity - may cause reversible or irreversible changes to exposed tissue, but not permanent injury or death (ref. 12).
- Mutagenicity - the capability of a compound to cause a relatively permanent change in hereditary material.
- Polyneuritis - simultaneous inflammation of many peripheral nerves.
- Proteinuria - the presence of an excess of serum proteins in the urine.
- Teratogen - a compound which causes birth defects.

TLV - threshold limit value.

Uremia - accumulation in the blood, usually in severe kidney disease, of constituents normally eliminated in the urine; produces a severe toxic condition.

LIST OF ABBREVIATIONS

BOD -biochemical oxygen demand
Btu -British thermal unit
°C - degrees Celsius
CaCO₃ - calcium carbonate
CaSO₃ - calcium sulfite
CaSO₄ - calcium sulfate
CH₄ - methane
CO - carbon monoxide
CO₂ - carbon dioxide
d - day
DDG - distillers dried grains
DDGS - distillers dried grains with solubles
DDS - distillers dried solubles
EPA - Environmental Protection Agency
°F - degrees Fahrenheit
FGD - flue-gas desulfurization
ft - foot
gal - gallon
Gg - gigagram
gpm - gallons per minute
h - hour
ha - hectare
HC - hydrocarbons
kg - kilogram

L - liter

lb - pound

m - meter

μ g - microgram

Mg - megagram

mg - milligram

MJ - megajoule

MT - metric ton

NMHC - non-methane hydrocarbons

NO_x - nitrogen oxides

pH - the symbol for the logarithm of the reciprocal of hydrogen ion concentration in gram atoms per liter

s - second

SO₂ - sulfur dioxide

SO₄ - sulfate

SS - suspended solids

TPY - tons per year

TS - total solids

TSP - total suspended particulate

VOC - volatile organic compound

y - year

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