

APPENDIX C

BIOMASS CONVERSION

NREL Notes
Appendix C: Biomass Conversion

The estimates in this appendix represent the inputs and emissions that would result from converting roughly 2,000 tons per day of biomass into ethanol using experimental technology currently under development by DOE. Six ethanol facilities were modeled: one for the year 2000 that converts the organic fractions in MSW and five in the year 2010 that converts energy crops.

The ethanol production facilities produce two products: denatured ethanol and electricity. The inputs and emissions of ethanol production should be allocated between the two products. The proportion of ethanol and electricity (on a Btu value assuming a heat rate of 10400 Btu/kWh) produced by each of the six facilities varies as followed:

<u>Location</u>	<u>% Allocated to Ethanol</u>	<u>% Allocated to Electricity</u>
2000:		
Peoria, IL	87	13
2010:		
Portland, OR	71	29
Tifton, GA	83	17
Lincoln, NE	83	17
Peoria, IL	82	18
Rochester, NY	82	18
2010 Average	80	20

These allocations are not shown in this appendix nor are they accounted for in preceding stages such as feedstock production and transportation described in Appendix A: Energy Crop Production, Storage, and Transportation; and Appendix B: MSW Collection, Transportation, and Separation. However, these allocations are reflected in the fuel cycle analyses reported in *Fuel Cycle Evaluations of Biomass Ethanol and Reformulation Gasoline, Volume I, Summary Report*. The inputs and outputs of biomass energy crop production, storage, transportation, and conversion

are allocated between the two products ultimately produced--ethanol and electricity--based on the allocations shown above. Thus table A, Tables C through G, and Table J, in Volume I, show the fraction of biomass production and transportation that is allocated to each ethanol fuel cycle.

Included in the fuel production stage where ethanol production shown in Table A, Tables C through G, and Table J, in Volume I Summary Report, are the fuel cycle inputs and emissions associated with the gasoline used to denature the ethanol produced in the six locations. The additional inputs and outputs associated with the denaturant are not reported in this appendix.

APPENDIX C:
BIOMASS CONVERSION
TABLE OF CONTENTS

	Page
C.1 Introduction	C-6
C.2 Feedstock Characterization	C-6
C.2.1 Feedstock Selection	C-6
C.2.2 Feedstock Composition	C-11
C.3 Process Description	C-17
C.3.1 Introduction	C-17
C.3.2 Feedstock Handling and Size Reduction	C-18
C.3.3 Prehydrolysis and Neutralization	C-20
C.3.4 Xylose Fermentation	C-21
C.3.5 Cellulase Production	C-22
C.3.6 Simultaneous Saccharification and Fermentation (SSF)	C-23
C.3.7 Ethanol Purification and Solids Separation	C-24
C.3.8 Waste Treatment	C-25
C.3.9 Utilities	C-27
C.4 Inputs, Outputs and Environmental Releases	C-30
C.4.1 Introduction	C-30
C.4.2 Input Requirements	C-30
C.4.3 Outputs Generated by Conversion Facility	C-37
C.4.4 Environmental Releases and Concerns	C-39
C.5. Pre-Operation and Post-Operation Phases	C-65
C.5.1 Pre-Operation Phase	C-65
C.5.2 Post-Operation Phase	C-66
C.6 References	C-67
C.6.1 References	C-67
C.6.2 Bibliography	C-72
C.6.3 Composition Data from the Literature	C-77

LIST OF FIGURES

	Page
C-1 Biomass Conversion Stage - Operating Phase. Map of inputs and effects. . . .	C-84
C-2 Block Flow Diagram, Biomass to Ethanol Process	C-85
C-3 Block Flow Diagram, Feedstock Handling	C-86
C-4 Block Flow Diagram, Prehydrolysis and Neutralization	C-87
C-5 Block Flow Diagram, Xylose Fermentation	C-88
C-6 Block Flow Diagram, Cellulase Production	C-89
C-7 Block Flow Diagram, Simultaneous Saccharification and Fermentation (SSF) .	C-90
C-8 Block Flow Diagram, Ethanol Recovery and Solids Separation	C-91
C-9 Block Flow Diagram, Waste Treatment	C-92
C-10 Block Flow Diagram, Utilities	C-93

LIST OF TABLES

	Page
C-1 Inputs and Outputs	C-7
C-2 Environmental Releases and Concerns	C-8
C-3 Energy Crops Selected for the Biomass-Ethanol Total Energy Cycle Analysis .	C-9
C-4 Annual Average Feedstock Blends	C-10
C-5 Composition of the Cellulose/Organic Fraction Leaving a Typical MSW Separation Facility	C-11
C-6 Average Feedstock Composition for Each Energy Crop	C-13
C-7 Annual Average Blended Feedstock Compositions	C-15
C-8 Simplified Annual Average Blended Biomass Compositions	C-16
C-9 Wood Chipping Requirements	C-19
C-10 Milling Power Requirements	C-19
C-11 Prehydrolysis Design Basis	C-20
C-12 Xylose Fermentation Design Basis	C-22
C-13 Cellulase Production Design Basis	C-22
C-14 SSF Design Basis	C-23
C-15 Ethanol Purification and Recovery Design Basis	C-24
C-16 Material Conversion Factors	C-26
C-17 Wastewater Treatment Design Basis	C-26
C-18 Percentages of Protein, Ash and Soluble Solids Recovered in Solids Stream from Centrifuge	C-28
C-19 Boiler Efficiencies	C-28

LIST OF TABLES (cont'd)

	Page
C-20 Utility Summaries	C-29
C-21 Input Summary for Conversion Process	C-31
C-22 Nutrient Input Summary for Conversion Process	C-35
C-23 Output Summary for Conversion Process	C-38
C-24 Environmental Releases and Concerns Summary for Conversion Process	C-40
C-25 Summary of Air Releases for Case 1	C-41
C-26 Summary of Air Releases for Case 2	C-42
C-27 Summary of Air Releases for Case 3	C-43
C-28 Summary of Air Releases for Case 4	C-44
C-29 Summary of Air Releases for Case 5	C-45
C-30 Summary of Air Releases for Case 6	C-46
C-31 Types of VOC Air Releases	C-47
C-32 Diesel Emission Factors	C-48
C-33 Feedstock Bulk Densities	C-49
C-34 Loader Operating Data	C-50
C-35 Particulate Emissions from Lime Handling	C-52
C-36 Fugitive Emissions from Fermentations	C-53
C-37 Fugitive Emissions from Off-Site Storage Tanks	C-56
C-38 Chemical Composition for All Boiler Fuels	C-58
C-39 Percent Composition of Other Fraction for Each of the Major Feedstocks	C-59

LIST OF TABLES (cont'd)

	Page
C-40 Boiler Emissions	C-60
C-41 Occupational Health and Safety Projection for Ethanol Production from Biomass	C-64
C-42 Wheatgrass Composition Data	C-77
C-43 Willow Composition Data	C-77
C-44 Sycamore Composition Data	C-78
C-45 Sweetgum Composition Data	C-78
C-46 Switchgrass Composition Data	C-79
C-47 Silver Maple Composition Data	C-80
C-48 Sorghum Composition Data	C-80
C-49 Red Alder Composition Data	C-81
C-50 Reed Canary Grass Composition Data	C-81
C-51 Hybrid Cottonwood Composition Data	C-82
C-52 Hybrid Poplar Composition Data	C-82
C-53 Black Locust Composition Data	C-83
C-54 Energy Cane Composition Data	C-83

APPENDIX C

BIOMASS CONVERSION

C.1 Introduction

This Appendix describes the analysis of the conversion stage of the biomass ethanol total energy cycle. Six individual cycles are covered. One energy cycle for the 2000 time frame assumes lignocellulosic biomass is provided from municipal solid waste (MSW). Five cases for the 2010 timeframe are also evaluated where the biomass is a cultivated energy crop. Each of the five cases is intended to describe a particular region of the country. The five regions are Midwest/Lake States, Southeast, Great Plains, Pacific Northwest, and Northeast. Information in this appendix summarizes the work conducted on the first phase of the total energy cycle analysis project and concentrates on the operating phase of the energy cycle. Figure C-1 is a simple block flow diagram of the biomass to ethanol conversion process and a map of the inputs/outputs and environmental releases associated with the process. Table C-1 shows the inputs and outputs addressed in this appendix. Table C-2 shows the environmental releases and concerns addressed in this appendix.

There are four main sections to the body of this Appendix. In Section C.2., Feedstock Characterization, information is provided on the feedstock compositions used as the basis for the conversion plant material and energy balances. Section C.3, Process Description, describes the biomass to ethanol conversion process. In Section C.4, the inventory of inputs, outputs, and environmental releases are discussed and summarized. Section C.5 qualitatively describes the inputs, outputs and environmental releases for the pre-operation and post-operation phases of the conversion stage. References are provided in Section C.6, which also includes composition data from the literature and all figures.

C.2 Feedstock Characterization

The feedstock for each of the six biomass ethanol total energy cycles (TEC) is different. This section describes how the feedstocks were selected, how the compositions were estimated, and some of the assumptions applied to the conversion plant material and energy balance calculations.

C.2.1 Feedstock Selection

C.2.1.1 Biomass from Municipal Solid Waste

The biomass ethanol fuel cycle for the 2000 time frame is based on lignocellulosic material derived from municipal solid waste. The MSW source was assumed to be Chicago and Cook County, Illinois. Appendix B: MSW Collection, Transportation and Separation, describes the technologies required and inputs/outputs and environmental releases of the collection and transportation stages of the waste biomass-ethanol energy cycle.

**Table C-1.
Inputs and Outputs**

	Quantitative	Qualitative
PRIMARY FLOWS		
Pre-Operating Requirements		
Cement		Y
Steel		Y
Plastics		Y
Equipment		Y
Electronics		Y
Asphalt		Y
Aluminum		Y
Fuel		Y
Other Materials		Y
Labor		Y
Construction Wastes		Y
Operating Requirements		
Feedstock	Y	
Electricity	Y	
Chemicals	Y	
Product Slate	Y	
Water Consumption	Y	
Replacement Equipment		Y
Other Materials		Y
Labor	Y	
Solid Wastes		
Hazardous	Y	
Radioactive	Y	
Mixed	Y	
Combustible	Y	
Other	Y	
Post-Operating Requirements		
Cement		Y
Steel		Y
Plastics		Y
Equipment		Y
Electronics		Y
Asphalt		Y
Aluminum		Y
Fuel		Y
Other Materials		Y
Labor		Y
Solid Wastes		Y

**Table C-2.
Environmental Releases and Concerns**

	Quant.	Qual.		Quant.	Qual.
AIR RELEASES			WATER RELEASES		
Criteria Pollutants (CAA)			Agrichemicals		
SO ₂	Y		Fertilizer	Y	
NO _x	Y		Insecticide	Y	
CO	Y		Herbicide	Y	
PM-10	Y		Susp. Solids	Y	
Pb	Y		Oil & Grease		Y
VOC - total	Y		Priority Pollutants		Y
VOC-breakdown	Y		Thermal	Y	
Greenhouse Gases			LAND CONCERNS		
CO ₂	Y		Land Area	Y	
CH ₄		Y	Land Conv.		Y
Others		Y	Soil Productivity		Y
Air Toxics			Erosion	Y	
Acetaldehyde	Y		OTHER CONCERNS		
Formaldehyde	Y		Health/Safety		Y
Other Toxics		Y	Noise		Y
Fertilizer	Y		Odors		Y
Insecticide	Y		Catastrophic Events		Y
Herbicide	Y		Aesthetics		Y
Radionuclides		Y			
Thermal		Y			

Other possible sources of biomass for this near term time frame include agricultural residue, forest product waste, and underutilized forests. MSW was chosen because of its wide spread potential availability and the current problem of limited landfill capacity.

C.2.1.2 Energy Crops

The produced energy crops for the five cases in the 2010 time frame were selected by Oak Ridge National Laboratory. Information on the selection process is provided in Appendix A: Biomass Production, Storage and Transportation. The chosen biomass feedstocks represent likely energy crops that would be grown for a biomass to ethanol industry. These selected feedstocks do not necessarily represent the optimal combination of feedstocks or the entire range of possible energy crops for each region. However, all three classes of cellulosic crops are represented; woody crops, annual herbaceous crops, and perennial herbaceous crops. The selected crops are shown below in Table C-3.

**Table C-3.
Energy Crops Selected for the Biomass-Ethanol Total Energy Cycle Analysis**

Woody Crops	Annual Herbaceous Crops	Perennial Herbaceous Grasses
Black Locust	Sorghum	Reed Canary Grass
Hybrid Poplar		Switchgrass
Red Alder		Wheatgrass
Silver Maple		Energy Cane
Sweetgum		
Sycamore		

Table C-4 shows the annual average feedstock blends for each of the six biomass-ethanol TECs evaluated.

**Table C-4.
Annual Average Feedstock Blends**

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
SOURCE/REGION	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
TIME FRAME	2000	2010	2010	2010	2010	2010
LOCATION	Chicago	Peoria, IL	Tifton, GA	Lincoln, NE	Portland, OR	Rochester, NY
FEEDSTOCK SUMMARY						
Feedstock Blend						
MSW	100%	---	---	---	---	---
Switchgrass	---	39%	44%	60%	---	68%
Reed Canary Grass	---	13%	---	---	---	---
Sorghum	---	10%	---	---	---	---
Energy Cane	---	---	10%	---	---	---
Wheatgrass	---	---	---	40%	---	---
Hybrid Poplar	---	19%	---	---	---	19.2%
Silver Maple	---	11.4%	---	---	---	---
Black Locust	---	7.6%	4.6%	---	---	6.4%
Sweetgum	---	---	23%	---	---	---
Sycamore	---	---	18.4%	---	---	---
Hybrid Cottonwood	---	---	---	---	80%	---
Red Alder	---	---	---	---	20%	---
Willow	---	---	---	---	---	6.4%

C.2.2 Feedstock Composition

C.2.2.1 Composition of Biomass From MSW

The estimated feedstock composition for this case is presented in Table C-5. The basis for the composition is described in Appendix B. The moisture content is assumed to be 30% by weight on a wet basis. The material arrives shredded to a particle size of less than one inch. It is delivered by tractor trailer trucks each with a load capacity of 19.9 dry tons.

Table C-5.
Composition of the Cellulose/Organic Fraction
Leaving a Typical MSW Separation Facility
(Weight %, Dry Basis)

COMPONENTS	PERCENT
Cellulose	45.5
Hemicellulose	8.5
Sugars (and starch) or other carbohydrates	8.5
Protein	3.3
Ash	15.0
Lignin	10.0
Fats and Greases	6.7
Other	2.5
TOTAL	100.0

C.2.2.2 Composition of Energy Crops

The composition of woody crops is very different from the composition of herbaceous crops. First, woody crops will be described followed by herbaceous crops. Table C-6 shows the average compositions for each of the energy crop types listed in Table C-3. These estimated average compositions were based on numerous individual analyses found in the literature and allowance for certain components when data was unavailable. Tables containing these individual analyses from the literature are provided in Section C.6.3.

C.2.2.2.1 Woody Crops

Cellulose is a major wood component, making up approximately one half of hardwoods. It can be characterized as a linear high molecular weight polymer, built up exclusively of β -D-glucose. Because of its chemical and physical properties, as well as its supramolecular structure, it can fulfill its function as the main structural component of the plant cell walls. Hemicelluloses are in close association with cellulose in the cell wall. Several different sugars are the main constituents of hemicelluloses. These include the hexoses; glucose, mannose and galactose, and the pentoses; xylose and arabinose. The molecular chains of these sugar polymers are much shorter than in the case of cellulose, having side groups and being branched in some cases. In the hardwoods that are important for biomass to ethanol conversion processes, xylose (or the polymeric form xylan) is the major constituent in the hemicellulose fraction.

Lignin is the third macromolecular wood component. Molecules of lignin are built up quite differently from those of the polysaccharides. They consist of an aromatic system composed of phenylpropane units. Lignin is in an amorphous substance and highly resistant to biological attack. This material goes through the conversion process relatively unchanged and is the major fuel stream, providing the internal energy demands of the process.

In addition to these three major components, there are other minor substances found in wood. These include proteins, small amounts of non-structural carbohydrates, as well as extractive material, primarily resins and turpenes. There are also small amounts of ash, comprised primarily of mineral components in the wood. For the woody crops, if literature data on nitrogen or protein content were unavailable then crude protein was assumed to be 0.5%. Also, non-structural carbohydrates were assumed to be 0.5%.

The woody feedstocks are assumed to arrive at the site as crushed trees in large cylindrical bales and delivered on tractor trailer trucks.

C.2.2.2.2 Herbaceous Crops

Herbaceous biomass composition is very different from woody biomass species. In addition, composition changes greatly as the plant matures. For herbaceous biomass energy crops, mature plants would probably be harvested. The herbaceous species contain cellulose and hemicellulose and lignin as the main structural components. They also contain significant amounts of non-structural carbohydrates. These are primarily starches and fructan. Substantial amounts of crude protein are also generally present in herbaceous species. The remaining fraction, soluble dry matter is described as soluble solids. This component contains tannins and other soluble phenolics, plant pigments, waxes, lipids, soluble minerals and other compounds.

The grasses; switchgrass, wheatgrass and reed canary grass, are assumed to arrive at the conversion facility in large cylindrical bales. The thick stemmed crops, sorghum and energy cane, are assumed to arrive as unconsolidated masses which will be dumped off of trucks into large piles.

Table C-6.
Average Feedstock Composition for Each Energy Crop
(weight %, dry basis)

SPECIES	Black Locust	Energy Cane	Hybrid Cottonwd	Hybrid Poplar	Red Alder	Reed Canary Grass	Silver Maple	Sweet gum	Switch grass	Sycamore	Wheat grass	Willow	Sorghum
Cellulose	46.93	48.00	49.59	48.64	45.54	27.74	46.93	44.56	31.47	46.66	39.00	45.45	28.88
Hemi-Cellulose	19.69	34.00	17.94	16.84	22.15	30.89	20.10	27.64	33.62	23.69	26.00	18.22	27.98
Lignin	23.45	10.00	26.36	24.25	25.78	5.40	25.16	22.34	7.27	24.63	14.00	27.51	5.17
Ash	0.82	3.00	1.96	1.13	0.31	4.20	0.73	0.32	3.77	0.56	7.80	0.00	3.07
Extractives	5.52	1.00	3.15	5.49	3.42	0.00	4.02	4.15	0.00	2.24	1.80	2.14	0.00
NS CHO	0.50	2.00	0.50	0.50	0.50	9.50	0.50	0.50	4.96	0.50	0.00	0.50	18.74
C. Protein	3.08	2.00	0.50	1.88	2.31	9.83	0.50	0.50	4.97	0.72	3.60	0.50	4.03
Soluble Solids	0.00	0.00	0.00	1.27	0.00	12.45	2.06	0.00	13.95	1.02	7.80	5.68	12.12

Notes: 1) NS CHO is non-structural carbohydrate

C.2.2.3 Blended Feedstock Compositions

Blended feedstock compositions on an annual average basis are presented in Table C-7 for the six energy cycle cases evaluated. These compositions are part of the design bases for the individual biomass conversion facility designs. In performing the conversion facility calculations, certain assumptions were made regarding feedstock composition. Cellulose has the structural formula $(C_6H_{10}O_5)_n$. Hemicellulose has the chemical composition $(C_5H_8O_4)_n$. Lignin has the chemical composition $C_6H_{10}(OCH_3)_{1.3}$. Crude protein has the chemical composition $CH_{1.57}O_{0.31}N_{0.29}S_{0.007}$. Non-structural carbohydrates were assumed to have the same chemical composition as cellulose and therefore from a material balance point of view were treated as cellulose. Twenty-five percent of the soluble solids from herbaceous crops were assumed to be some kind of polysaccharide that could be converted to ethanol. This material was assumed to have the same chemical formula as cellulose. Extractives from woody crops and the remaining 75% of the soluble solids from herbaceous crops were assumed to have the composition $CH_{1.48}O_{0.19}$. The extractives and remaining soluble solids were assumed to be unconverted throughout the ethanol fermentation steps, but converted to gas in the waste water treatment system.

Moisture content of the blended feedstocks were based on calculated values, assuming that woody feedstocks and herbaceous perennial grasses contain 25% moisture. Sorghum and energy cane were assumed to contain 233% moisture on a dry basis. These values were determined by Oak Ridge National Laboratory and used in the analysis of the biomass transportation stage of the biomass ethanol fuel cycle. Moisture content of the feedstocks may actually be quite variable. However, this would not seriously change the design or operation of the conversion facility. The major change would be to adjust the amount of process make-up water to maintain a constant fresh water make-up rate. Moisture in the feed is considered a source of fresh water to the facility.

Table C-8 shows the simplified annual average blended biomass compositions that were used as the bases for the conversion plant material and energy balances.

**Table C-7.
Annual Average Blended Feedstock Compositions**

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
SOURCE/REGION	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
AVERAGE COMPOSITION: (weight %, dry basis)						
Cellulose	45.5	36.9	39.7	34.5	48.8	36.7
Hemicellulose	8.5	26.9	29.8	30.6	18.8	28.5
Lignin	10.0	13.3	14.9	9.9	26.2	12.9
Ash	15.0	2.7	2.2	5.4	1.6	2.8
N.S. Carbohydrates	8.5	5.2	2.6	3.0	0.5	3.5
Crude Protein	3.3	4.3	2.8	4.4	0.9	4.0
Extractives	6.7	1.9	1.7	0.7	3.2	1.5
Soluble Solids	2.5	8.8	6.3	11.5	0.0	10.1
% Moisture (dry basis)	45.0	45.8	45.8	25.0	25.0	25.0

**Table C-8.
Simplified Annual Average
Blended Biomass Compositions
(weight %, dry basis)**

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
SOURCE/REGION	MSW	MIDWEST/ LAKE STATES	SOUTHEAST	GREAT PLAINS	PACIFIC NORTHWEST	NORTHEAST
Cellulose	54.00	44.34	43.84	40.32	49.28	42.71
Hemicellulose	8.50	26.91	29.81	30.58	18.78	28.51
Lignin	10.00	13.31	14.94	9.96	26.25	12.86
Ash	15.00	2.68	2.17	5.39	1.64	2.84
Crude Protein	3.30	4.27	2.77	4.43	0.86	3.96
Soluble Solids	9.20	8.48	6.46	9.33	3.20	9.11
% Moisture (wet basis)	31.03	31.40	31.41	20.00	20.00	20.00

C.3 Process Description

C.3.1 Introduction

Figure C-2 is a block diagram which outlines the main process units and flows. Feedstock enters the plant and is stored and processed in the feedstock handling section of the plant. Then, a dilute sulfuric acid pretreatment step is employed to increase the digestibility of the cellulose and hydrolyze the hemicellulosic fraction of the biomass to its component sugars. This material is then processed by the three fermentation steps; xylose fermentation, cellulase production and simultaneous saccharification and fermentation (SSF).

In previous designs (Badger 1984), the xylan component of wood was hydrolyzed to xylose and then converted to furfural. Although a by-product credit was given to furfural, in the long term when ethanol production would be widespread, there would be a glut on the market and the value of this furfural by-product would be questionable. Instead, xylose is converted to ethanol using a genetically engineered *E. coli*.

The cellulase production step produces the enzyme that breaks down cellulose into glucose and which is used in the SSF process. SSF has several advantages over the previous SHF (separate hydrolysis and fermentation) process (Wright 1988). The key advantage is in the reduction in end-product inhibition of the cellulase enzyme complex at high glucose concentrations. This no longer occurs because the glucose that is formed in a SSF reactor is converted very quickly to ethanol and therefore does not build-up in concentration. This lack of inhibition allows for greatly reduced enzyme loading which dramatically cuts the cost of enzyme production. The overall cellulose to ethanol yield is also increased at the same enzyme loading.

Ethanol produced from the fermentation steps is recovered and denatured and sold as fuel grade ethanol. Leftover solids (lignin) is sent to the boiler to provide steam and electricity for the plant. Leftover liquids are further processed in a waste water treatment system.

The following sections give the design basis, a brief description and comments on the potential problems or possibilities for each process section. The design bases presented for most sections of the plant include both "1991" values and future values. In general, the "1991" design conditions are based on data from NREL laboratory work. These reported yields are not the best ever achieved but rather conservative and reproducible values that form a very reasonable basis for a current time frame conceptual design. The yields are not optimum values but rather a snapshot in time reflecting the current state of process development. Improvements are expected as research and development work continues. For the future time frame cases evaluated in this analysis, expected improvements from the current values are itemized in the following descriptions of the various process areas.

The major drawback in the design basis for the current time frame is the lack of actual experimental data from running the process on an integrated basis, i.e. running all the process

steps in series using effluent from one step as the feed to the next step. NREL plans to run an integrated process in the near future to demonstrate that the process will operate as described.

C.3.2 Feedstock Handling and Size Reduction

Design Basis. The compositions of the blended biomass used in the six material balances were presented in Table C-8. The fractions of each individual feedstock in the blends are shown in Table C-4. The feed rate for each case is 2,000 tons of dry feed per day.

Process Description. A block flow diagram is shown in Figure C-3.

Feedstock handling, from delivery at the site to the mill for final size reduction, will be discussed separately for each feedstock type and then the design of a multiple feedstock plant will be discussed. Three cases: Midwest Lake States, Southeast, and the Northeast will need to handle both wood and herbaceous feedstocks.

Wood. Wood is delivered as the whole crushed trees to the plant by truck or rail in the form of compressed bundles. The bundles are dumped into a central receiving area and then lifted by a crane and placed on a belt conveyor and debundled. The belt conveyor feeds the separated logs to the chipper. Chipped wood is conveyed on a belt to a centralized radial stacking conveyor. The radial conveyor makes a circular chip pile that is more easily managed on a "first in, first out" basis. When required, chips are scooped by front end loaders and dumped onto a centralized belt conveyor that delivers the chips to the mill for further size reduction.

Herbaceous (baled). Grass crops are delivered to the central receiving area of the plant as round bales by either truck or rail. The bales are removed by loaders and stacked in a covered storage area (Finassi). Bales are then removed on a "first in, first out" basis by loaders and taken to a central area to be debaled. The broken up material falls onto a belt conveyor and is delivered to the mill for further size reduction.

Cane (unbaled). Sorghum and energy cane are delivered unbaled and are dumped into piles. These piles are managed on a "first in, first out" basis by front-end loaders that deliver the stalks to a centralized belt conveyor which moves the material to the mill for size reduction.

MSW. Shredded MSW is delivered to the plant in bundles by either truck or rail. The feed handling system will be the same as described for the herbaceous and cane crops.

Multiple Feedstocks. A multiple feedstock plant will incorporate separate parallel processing trains for each of the feedstocks as described in the above sections. After milling, the feedstocks can be combined and sent on for further processing. At this point it is assumed that the equipment is sized to handle the expected flowrate for each feedstock. Running the plant on only one train (one feedstock type) at full capacity is possible, but only if the equipment has been sized to handle the maximum flowrate.

The chipping power requirement for wood is estimated at 5.0 kWh/green ton, which is an average from two sources (4.5 kWh/ton - Strehler 1984, 5.5 kWh/ton - Johnson 1989). Table C-9 gives the wood flowrate for each of the cases which use wood as a feedstock and the required chipping power.

**Table C-9.
Wood Chipping Requirements**

CASE	Wood Feed Rate (lb/h)	Chipping Power (kW)
CASE 2 - Midwest/Lake States	84,000	211
CASE 3 - Southeast	132,000	331
CASE 5 - Pacific Northwest	222,000	556
CASE 6 - Northeast	71,000	178

Wood chips, herbaceous grasses, thick stemmed crops and shredded MSW all require size reduction prior to pretreatment. This is accomplished with disc refiners. Milling power requirements are strongly dependent on feedstock type. Table C-10 gives the milling power requirements assumed for this analysis. The "1991" value for wood chips is based on an estimate for milling green, one inch, hardwood chips to a final particle size of 1 to 3 mm (0.04 to 0.12 inches) with a disc refiner. The estimate was provided by Sprout-Bauer, a manufacturer of disc refiners and other equipment used in the pulp and paper industry.

**Table C-10.
Milling Power Requirements (hp hr/dry ton)**

	1991	Future Cases
Wood Chips	128	100
Grasses		40
Energy Cane & Sorghum		20
MSW		50

Comments. Feedstock procurement is a complex operation and will require a dedicated system including production, handling, offsite storage and transportation to the ethanol plant on a large scale. Therefore, the smooth operation of the ethanol plant is dependent on achieving a reliable feedstock delivery system. Feedstock production and transportation technologies are described

in Appendix A: Biomass Production, Storage and Transportation and Appendix B: MSW Collection, Transportation and Separation.

Approximately one-third of the power requirement for the entire plant is used in the size reduction operation. The original NREL design incorporated knife mills. Upon investigation it was found that these mills do not have the capacity required for a reasonable design. Instead of knife mills, disc refiners are used for size reduction. It is important to run trials using this system to verify operation on the different types of feedstock anticipated. Currently this equipment is used primarily on wood chips in the paper and pulp industry.

A substantial portion of the mechanical energy input to the disc refiners may be converted to thermal energy which would heat up the biomass as it passes through the refiners. No credit for this thermal energy input was taken in the overall energy balance. Steam requirements in the prehydrolysis section could potentially be reduced dramatically.

C.3.3 Prehydrolysis and Neutralization

Design Basis. The values for "1991" yields are based on NREL lab tests. Residence time and temperature have been adjusted to maximize xylan to xylose conversion. The system is not yet optimal. The design conditions for the prehydrolysis step are presented in Table C-11. Although in this study the pretreatment step is included for the MSW case, it may not be required because most of the cellulose has already undergone a chemical pulping treatment.

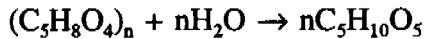
**Table C-11.
Prehydrolysis Design Basis**

	<u>1991</u>	<u>FUTURE CASES</u>
Temperature:	160°C	160°C
Residence Time:	10 minutes	10 minutes
Sulfuric Acid Concentration:	0.85wt%	0.85wt%
Xylan to xylose:	80%	90%
Xylan to furfural:	13%	10%
Xylan unconverted:	7%	0%
Cellulose to glucose:	3%	3%
Cellulose to HMF:	0.1%	0.1%
Cellulose unconverted:	96.9%	96.9%

Process Description. As shown in Figure C-4 (Target 1988), milled feedstock from the disc refiner is fed into a screw feeder that feeds the wood into an impregnator where live steam and dilute sulfuric acid are injected. The residence time is 10 minutes at 100°C. The impregnator discharges the material through a rotary valve to the prehydrolysis reactor operating at the above conditions. Live steam under pressure is injected into this reactor to heat the material up to the reaction temperature under 6 atm pressure. This step opens the wood to expose the cellulose for

future hydrolysis and converts xylan to xylose. The chemical reactions occurring during the pretreatment steps are as follows:

Xylan to Xylose



Xylose to Furfural



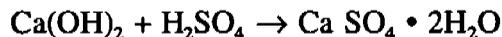
Cellulose to Glucose



Glucose to Hydroxymethyl furfural (HMF)



After pressure let down in a flash tank, the hydrolyzate is neutralized with lime. The neutralization reaction is as follows:



Comments. Most of the work at NREL on the impregnation and prehydrolysis steps was done on a batch reactor with a standard agitator (Torget, 1988). Although some work has been done on continuous prehydrolysis, both units should be run continuously at the process conditions to confirm the batch results. Nevertheless, xylose yields as high as 90 percent have been achieved on the lab scale. While this higher value is currently not constantly reproducible, achieving this value on a regular basis is not unreasonable for the future cases.

C.3.4 Xylose Fermentation

Design Basis. The data for this step is based on NREL lab runs (unpublished data, 5 liter reactors) using purchased xylose. The system used is based on work done at the university of Florida using *E. coli*. The design basis for the xylose fermentation operation is presented in Table C-12 below.

**Table C-12.
Xylose Fermentation Design Basis**

	<u>1991</u>	<u>FUTURE CASES</u>
Xylose available:	95%	100%
Xylose converted:	90%	95%
pH:	7.0	7.0
Temperature:	37°C	37°C

The xylose conversion reaction is as follows:



Process Description. The feed from neutralization enters the xylose fermenters as shown in Figure C-5. The seed fermenters feed cell mass into the main anaerobic xylose fermenters which are large agitated tanks. Temperature is maintained using cooling coils in the tank. Offgas from the fermenters is comprised mainly of CO₂ with water vapor and organic components entrained according to their corresponding vapor pressures and liquid phase concentrations.

Comments. The inclusion of this step is a major advance in the ethanol from biomass process, increasing the ethanol production over earlier designs. The assumption that 100 percent of the xylose is available is optimistic, but yields are high.

C.3.5 Cellulase Production

Design Basis. The data for the design basis is an average of batch data from a variety of literature sources (Sheir-Ness and Montecourt 1984, Tangnu 1981, Hendy 1982, Durand 1988, Watson and Nelligun 1983, Schell 1990, Mohagheghi 1988). The design basis for the cellulase production operation is presented in Table C-13 below.

**Table C-13.
Cellulase Production Design Basis**

	<u>1991</u>	<u>FUTURE</u>
Methods of operation:	Batch	Batch
Temperature:	28°C	28°C
Pressure:	10 psig	10 psig
Cellulase yield:	202 IU/g cellulose	470 IU/g cellulose

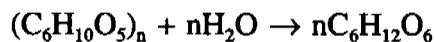
Process Description. As shown in Figure C-6, hydrolyzate is fed to the batch cellulase fermenter. Seed fermenters feed the main fermenter with *T. reesei*. Chilled water is used to cool the fermenters which are large agitated vessels. Offgas from the cellulase fermenters is sent to the low pressure vent system and ultimately to the boiler.

Comments. The average literature values were from laboratory experiments run on pure cellulose substrates. These experiments must be run on pretreated substrates in order to confirm the design basis. NREL will attempt to make improvements in cellulase yield and growth rate.

C.3.6 Simultaneous Saccharification and Fermentation (SSF)

Design Basis. The SSF step is the key step in NREL's process. The 1991 design parameters are based on NREL batch laboratory experiments. The major SSF reactions are as follows:

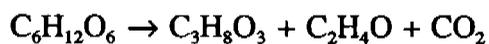
Cellulose to Glucose (Saccharification)



Glucose to Ethanol (Fermentation)



Glucose to Glycerol and Acetaldehyde



The design basis for the SSF unit is described in Table C-14 below.

Table C-14.
SSF Design Basis

	<u>1991</u>	<u>Future Cases</u>
Temperature:	37°C	37°C
Cellulose converted:		
to ethanol:	72.0%	90%
to fusel oils:	0.1%	0.1%
to glycerol and acetaldehyde:	4.9%	4.9%
to the cells:	10.0%	5.0%
Cellulose unconverted:	13.0%	0.0%

Process Description. Figure C-7 presents a block flow diagram for this section. Each tank is agitated using very low power requirements (0.1 HP per 1,000 gals). The low power requirement has been found to provide sufficient agitation for this process (Elander 1988). Cell mass is continuously fed into the fermenter from the SSF seed fermenters. The liquid effluent from the SSF fermenters enters the ethanol recovery section. Offgas from the fermenters is comprised mainly of CO₂ with water vapor and organic components entrained according to their vapor pressures and liquid phase concentrations.

Comments. As in the previous section, the major issue with the NREL lab data is that actual hydrolyzate has not been used in the fermentation.

The yields for the 1991 case are reasonable and reproducible. The major area for process improvement lies in increasing the SSF yield. This is because the yield (72 percent) is relatively low compared to the yields for other process steps and the impact on the cost of production is significant for every percentage point increase in SSF yield. NREL feels confident that improvements in yield will be achieved in the future.

C.3.7 Ethanol Purification and Solids Separation

Design Basis. NREL has not performed any lab experiments on this portion of the process since the unit operations are relatively straightforward. The design basis for the Ethanol Recovery area is presented in Table C-15 below.

**Table C-15.
Ethanol Purification and Recovery Design Basis**

	<u>1991</u>	<u>Future Cases</u>
Recovery Process	Traditional Distillation	Integrated Distillation
Dehydration Process	Azeotropic Distillation	Molecular Sieve
Ethanol Recovery	99.5%	99.9%
Steam Req lb/gal ethanol	25.8	16.5 (2000)
	(Trad. Dist. Only)	15.0 (2010)

Process Description. The traditional recovery process as shown in Figure C-8, consists of a preliminary distillation step, in a beer/rectifying column, to separate the ethanol from the fermentation broth and concentrate it to 95 volume percent. This column is reboiled by low pressure steam, with condensing duty rejected to cooling water. The feed is preheated against the tower bottoms. The overhead product is then dehydrated to 99+ volume percent in a second azeotropic distillation step. This step requires two columns, an anhydrous column and a recovery column. The anhydrous column removes water from the 95 percent ethyl alcohol by azeotropic distillation with a hydrocarbon such as cyclohexane as an entrainer.

For the future cases an integrated distillation unit would be used where the beer/rectifying column is split into two columns. The beer column strips ethanol from the broth and the rectifying column enriches the ethanol to approximately 95%. Splitting the column gives advantages in preheating the feed. In addition, vapor recompression can reduce energy input by using the latent heat of the overhead vapors in the column reboilers.

Vapor phase molecular sieve dehydration is chosen as the most energy efficient absorption method for concentrating the ethanol from the rectifying column to 199+ proof fuel grade ethanol. This process eliminates the need for high temperatures, high pressures and chemicals of any kind.

The steam requirements listed in Table C-15 for the future cases are estimates only based on ranges in the literature. Detailed process simulations have not been made for this area of the plant.

Comments. One of the issues in this process section is the nature of the distillation feed, i.e. the solids content of the feed. The second issue is the relatively low ethanol concentration (5 to 7.5 percent). The low ethanol concentration in the feed is a result of the amount of solids in the stream leaving the neutralization tank and the yield in the ethanol production steps. Increasing the solids concentration entering the fermentation will increase the final ethanol concentration. Here limitations due to fluid flow at higher solids content and the impact of higher ethanol concentrations on the rate and yield have to be explored.

C.3.8 Waste Treatment

Design Basis. The design of this section is based on commercially available technology and was prepared by the company CH2M Hill. It contains three process systems; anaerobic digestion, aerobic digestion and a low pressure vent system.

Following standard wastewater treatment practice, the various components in the stream to anaerobic digestion were converted to parameters typically used for wastewater system design. These factors are given in Table C-16 (Simpkin 1991).

**Table C-16.
Material Conversion Factors (mg/mg)**

Component	TSS	COD	BOD	SO ₄	TDS
Soluble Solids		2.47	1.12		1.00
Ash					1.00
Lignin	1.00				
Protein		1.70	0.40		
Xylose		1.07			
HMF		1.67	0.77		
Furfural		1.67	0.77		
Gypsum (soluble)				0.56	1.00
Gypsum (insoluble)	1.00			0.56	
Cellulase		1.70	0.40		
Glycerol		1.22			
Cell Mass		1.42			

TSS - Total Suspended Solids
 COD - Chemical Oxygen Demand
 BOD - Biological Oxygen Demand
 TDS - Total Dissolved Solids

Based on design data provided by Simpkin (1991), the average conversion for all cases of COD into biogas and H₂S is given below in Table C-17. This data applies to 1991 and all future cases.

The gas produced in anaerobic digestion is sent directly to the boiler as fuel.

**Table C-17.
Wastewater Treatment Design Basis**

	CH ₄ (lb/lb COD)	CO ₂ (lb/lb COD)	H ₂ S (lb/lb SO ₄)
Anaerobic	0.241	0.161	0.252
Aerobic		0.185	

Process Description. As shown in Figure C-9, wastewater enters a holding tank where it is mixed with other streams before flowing to the anaerobic digester. The methane produced supplies a substantial amount of the heat produced in the boiler. The remaining liquid is sent to an aerobic digester. Lignin, insoluble gypsum and cell mass are not converted here. After the digester the liquid is sent to a clarifier where clear water is separated applied to the land or sent to a publicly owned treatment works (POTW) for the MSW case. The bottoms from the clarifier are concentrated by a belt filter press and sent to the boiler for burning in the MSW case and land applied for all of the 2010 time frame cases.

All the vents from the plant are fed into a knockout drum with demister before allowing the vapors to be sent to the boiler. The entrained liquid is sent to the anaerobic digester.

Comments. The design is based on commercially available technology. However, tests should be made of actual material to confirm yields and throughputs.

C.3.9 Utilities

The designs of all of the utility systems are based on commercially available technology.

C.3.9.1 Boiler/Power Cogeneration System

The plant is designed with a boiler/power cogeneration system (Figure C-10), which allows for the coproduction of steam and electricity in a high pressure steam turbine. The steam boiler is a circulating fluidized bed, designed to burn gaseous and solid fuels derived from the various organic waste streams in the process. Methane and lignin account for the bulk of the energy value in the fuel stream fed to the boiler.

The solid fuel stream is obtained by centrifugation, which through the use of a supernatant recycle scheme recover 95 percent of the insoluble solids. Some components in the bottoms stream are partially soluble. These include protein and ash. In addition, research (Keller, 1991) has shown that soluble solids such as waxes and lipids have an affinity for insoluble solids and are actually removed with the insoluble solids. Table C-18 shows the percentages of protein, ash and soluble solids assumed to be recovered with the solids in the six cases. The solids leaving the centrifuge have a water content of 50 percent. Two screws feed the sludge to a special boiler where the solids are burned as fuel.

Table C-18.
Percentages of Protein, Ash and
Soluble Solids Recovered in Solids Stream from Centrifuge

	MSW Case	2010 Cases
Protein	60%	60%
Ash	90%	50%
Soluble Solids	50%	40%

Gaseous fuels are burned directly but wet solids are first sent to a drying system that dries and fluidizes the solids into the boiler using boiler flue gas.

The steam and power generation capacities are sized in accordance with the biomass feed rate. The steam turbine is an extracting type which allows for extraction of 50 psig and 150 psig steam to meet internal process requirements with the balance condensed to maximize turbine output.

The boiler/turbogenerator package was designed by Radian Corporation. The boiler efficiencies (energy extracted as 1500 psi, 950°C steam/ higher heating value of the fuel) are given in Table C-19. These values are higher by 1.0 percentage point for the MSW case (year 2000) and 2.0 percentage points for the other cases (year 2010) over the current technology efficiencies. These are estimated improvements from the boiler vendor (Bell 1991). The electrical power produced by the turbogenerator is calculated from the actual enthalpies of the extracted and letdown steam (Bell 1991). No allowances were made for improvements in turbogenerator efficiencies.

Table C-19.
Boiler Efficiencies (%)

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
Boiler Efficiency	69	75	76	74	77	75

All of the power requirements in the plant are provided by cogenerated power. A summary of electricity produced, consumed and sold for each case is shown in Table C-20.

The bulk of the electricity requirements are for the disc refiner and the air compressors and refrigeration system.

**Table C-20.
Utility Summaries**

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Source/Region	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
Electricity (MW)						
Total Prod.	20.5	27.0	26.3	24.1	42.1	26.8
Consumed	12.1	12.1	12.4	10.4	16.4	12.2
Sold	8.4	14.9	13.9	13.7	25.7	14.6
Steam, lb/hr						
50 psig	160,000	166,000	170,000	160,000	213,000	161,000
150 psig	43,100	78,700	78,700	71,400	67,800	78,700
Cooling Water, gpm	45,000	42,000	41,100	38,000	59,400	40,900
Chilled Water, gpm	1,600	1,030	970	858	1,320	958
Fermentation Air, lb/hr	23,700	17,700	17,000	15,200	22,000	16,800
Make up Water, lb/hr	709,000	656,000	638,000	617,000	891,000	667,000

The proposed process requires 50 psig steam and 150 psig steam. The steam requirements for each case are shown in Table C-20. Steam is used primarily in the impregnator and prehydrolysis reactor in pretreatment and in ethanol purification.

C.3.9.2 Cooling Water System

Cooling water is available from the cooling tower at 90°F. A temperature rise of 27°F has been assumed for the process users. Cooling water requirements are summarized in Table C-20 for each case. The major requirement for cooling water is the condenser in the ethanol recovery system.

C.3.9.3 Chilled Water

Chilled water at 50°F is provided by a chilled water package using propane refrigeration. The chilled water requirements for each case are shown in Table C-20.

Chilled water is used to maximize the condensation of ethanol from streams leaving the anaerobic fermentation tanks. In the cellulase production area, chilled water is used to cool the fermenters and in the utilities chilled water is required for the interstage cooling of the air compressors.

C.3.9.4 Fermentation Air

Fermentation air (45 psig) is required for the seed fermenters in the xylose fermentation and SSF sections and for all of the fermentations in the cellulase production area. The air requirements for the six cases are shown in Table C-20.

C.4 Inputs, Outputs and Environmental Releases

C.4.1 Introduction

This section describes the input requirements, process outputs and environmental releases from the biomass to ethanol conversion facilities for each of the six cases. All annual values presented are based on an annual operating factor of 98% which is equivalent to 8,585 hours per year of onstream time.

C.4.2 Input Requirements

Table C-21 summarizes all of the chemical inputs, fuel inputs, labor inputs and land requirements for the six cases. A brief description of why the inputs are needed and how values were estimated are described below.

**Table C-21.
Input Summary for Conversion Process**

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Source/Region	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
INPUT SUMMARY:						
Chemical Inputs (ton/yr)						
Feedstock (dry)	715,000	715,000	715,000	715,000	715,000	715,000
Sulfuric Acid	12,400	12,400	12,400	12,300	12,300	12,300
Lime	9,140	9,140	9,140	9,080	9,060	9,120
Ammonia	1,990	1,850	1,830	1,660	2,220	1,800
CS Liquor	1,370	807	773	670	1,060	764
Nutrients	395	232	223	193	305	219
Antifoam	86	52	47	43	64	47
Glucose	1,580	1,510	1,470	1,320	1,870	1,450
BFW Chemicals						
Na ₂ PO ₄	0.45	0.59	0.6	0.51	0.83	0.58
Amine	1.34	1.76	1.8	1.52	2.49	1.74
Hydrazine	4.48	5.86	5.99	5.06	8.3	5.8
CW Chemicals						
Silicate	3.87	3.63	3.53	3.26	5.1	3.51
Phosphonate	1.45	1.36	1.32	1.22	1.91	1.32
Polyphosphate	4.84	4.54	4.41	4.08	6.38	4.39
Orthophosphate	4.84	4.54	4.41	4.08	6.38	4.39
Zinc	2.42	2.27	2.21	2.04	3.19	2.2
WWT Chemicals						
Urea	660	1,310	1,330	1,500	790	1,400
Triple Super- Phosphate	270	500	520	590	300	540
Polymer	5.7					
Water (x10 ⁸ gal/yr)	7.30	6.75	6.57	6.35	9.17	6.87
Limestone	1,840	2,280	1,490	2,290	830	2,040

Table C-21.
Input Summary for Conversion Process (Cont'd)

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Source/Region	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
Fuel Inputs (gal/yr)						
Gasoline	3,600,000	4,130,000	4,280,000	4,120,000	3,930,000	4,130,000
Diesel	109,000	219,000	195,000	546,000	109,000	237,000
Labor Inputs (employees)						
Supervisors	10	10	10	10	10	10
Operators	41	41	41	41	41	41
Maintenance	40	40	40	40	40	40

C.4.2.1 Chemical Input Requirements

C.4.2.1.1 Feedstock

The major chemical input required for the conversion plant is the biomass feedstock. Composition of this material is described in Section C.2.2. The conversion plant design was based on a feedstock rate of 2,000 dry tons per day.

C.4.2.1.2 Sulfuric Acid

Sulfuric acid is used in the prehydrolysis step of the conversion process. The rate is determined based on the concentration of sulfuric acid at the outlet of the prehydrolysis reactor. This is set at 0.85%.

This chemical input is required because of the type of the pretreatment process selected for this evaluation. Alternative pretreatment processes would have different chemical input requirements.

C.4.2.1.3 Lime

Lime is used in the neutralization step following prehydrolysis. Here the lime reacts with the sulfuric acid to neutralize the material from the prehydrolysis reactor, prior to fermentation. The quantity of lime required is a function of the sulfuric acid concentration in the stream and the reaction stoichiometry. One mole of lime $\text{Ca}(\text{OH})_2$ reacts with one mole of sulfuric acid, H_2SO_4 . The resulting product is gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.

As with the sulfuric acid, this chemical input is required because of the type of pretreatment and neutralization processes selected for this evaluation. Alternative processes would have different chemical input requirements.

C.4.2.1.4 Ammonia

Ammonia is used in three different places in the process. It is used in xylose fermentation and SSF as a nitrogen source for the growth of the microorganisms. This is the major use of ammonia. A small amount of ammonia is also used in the cellulase production step. Here the ammonia is also used as a nitrogen source for the microorganisms and for pH control of the fermentation. Ammonia is also used in the boiler where it is injected directly into the hot flue gas for the reduction of NO_x . This is a noncatalytic process based on the gas phase reaction between NO_x and ammonia, which produces nitrogen and water.

C.4.2.1.5 Corn Steep Liquor

Corn Steep Liquor (CSL) is used as a source of nutrients for the cellulase production step. CSL is a by-product of the corn wet milling process. It is a concentrate obtained by the evaporation of the water used to soak shelled corn prior to the first stage of milling. It is a major source of

complex organic nitrogen i.e. amino acids, but also contains essential vitamins and minerals. CSL is used at a concentration of 15 g/L (Wilke and Blanch 1985).

C.4.2.1.6 Nutrients

Nutrients are required for the cellulase production step. The required components and their respective concentrations are: $(\text{NH}_4)_2\text{SO}_4$, 1.4 g/L; KH_2PO_4 , 2.0 g/L; $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 0.3 g/L; $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 0.2 g/L; and Tween 80, 0.2 g/L (Wilke and Blanch 1985). The component flow for each case is given in Table C-22.

C.4.2.1.7 Antifoam

The cellulase production fermentation often experiences excessive foam production. Antifoam is added to control this phenomena. It is assumed that the antifoam that would be used in the process, would be corn oil. In the future, this assumption will be evaluated. There are other chemical antifoams available, but there is limited information on how well they work at this time. Whatever antifoam is eventually used will have to be agreeable to the microorganisms in the system.

C.4.2.1.8 Glucose

Glucose is used in the SSF seed fermenters to initiate cell growth. In the final SSF seed fermenter, it is assumed that cellulase enzyme will break down the cellulose to release glucose for the final stage of growth of the yeast to be used in SSF.

C.4.2.1.9 Boiler Feedwater Chemicals

Several different chemicals are required to prepare boiler feedwater before the water is feed to the high pressure boiler. Chemicals used directly to treat the boiler feedwater include hydrazine, which is an oxygen scavenger, amine and phosphate. Phosphate is fed directly to the boiler steam drums.

C.4.2.1.10 Cooling Water Chemicals

The main chemicals used to treat cooling water are a biocide to prevent buildup of algae and other types of microorganisms in the circulating cooling water, and chemicals to inhibit scale formation on heat exchanger surfaces. The chemical additions to the cooling water system are silicate, phosphonate, polyphosphate, orthophosphate, and zinc.

Table C-22.
Nutrient Input Summary for Conversion Process

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Source/Region	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
Nutrient Inputs (ton/yr)						
(NH ₄) ₂ SO ₄	129	76	73	63	99	71
KH ₂ PO ₄	184	108	104	90	142	102
MgSO ₄ ·7H ₂ O	28	16	16	13	21	15
CaCl ₂ ·2H ₂ O	37	22	21	18	28	20
Tween 80	18	11	10	9	14	10

C.4.2.1.11 Waste Water Treatment Chemicals

Nutrients are required for the microorganisms in the waste water treatment system. Urea and triple sugar phosphate are provided as inexpensive forms of nitrogen and phosphorous respectively.

A synthetic water soluble polyelectrolyte is added to the excess sludge from the reactors to aid in dewatering.

C.4.2.1.12 Makeup Water

Makeup water is required in several places in the plant. First there is process water makeup. This is fresh water that is added to the fermenters or seed fermenters throughout the process.

The major water user in the plant is the cooling system. The cooling water is cooled by evaporation of the circulating water stream in the cooling tower. The water lost by evaporation and cooling tower blowdown must be replaced by makeup water. Water use can be reduced by the use of air coolers. This generally results in higher plant capital costs. Operating conditions may also need to be modified since air coolers often cannot cool to as low a temperature as cooling water.

The other requirement for makeup water is to the boiler feed water system to replace boiler blowdown, condensate losses and steam injected directly to the process.

C.4.2.1.13 Limestone

Limestone (CaCO_3) is added to the boiler, a circulating fluidized bed type, to control SO_2 emissions. The quantity used is based on maintaining a Ca:S molar ratio of 2:1. The limestone is converted to calcium oxide (CaO), which reacts with SO_2 to form gypsum (CaSO_4).

C.4.2.2 Fuel Input Requirements

Two types of liquid fuels are required by the conversion plant. These are low-sulfur diesel fuel and gasoline.

C.4.2.2.1 Diesel

Diesel fuel is used by equipment in the plant such as front end loaders and tractors, which are primarily used in the feedstock handling area to move the feedstock from the storage piles to conveyors. Low sulfur diesel fuel (less than 0.05 wt. %) is assumed.

C.4.2.2.2 Gasoline

Gasoline is required in the product storage area to denature the ethanol product. The amount of gasoline used is shown in Table C-21, and is based on a 5.0 volume percent gasoline specification in the final product from the plant.

C.4.2.3 Labor Input Requirements

The operating labor required for the conversion facility is estimated at 41 operators and technicians, 9 foremen and 1 plant supervisor. There will probably be an equal number of skilled or semi-skilled maintenance workers also required.

C.4.2.4 Land Input Requirements

A preliminary layout of the conversion facility shows that approximately 50 acres of flat land would be required for the total plant. This would include the processing facility, an area for feedstock storage, all supporting utilities, offsite product storage, buildings, parking lots and roads.

C.4.3 Outputs Generated by Conversion Facility

Table C-23 summarizes the ethanol, electricity, and solid waste produced in each of the six cases. A brief description of how the values were estimated are described below.

C.4.3.1 Ethanol

The transportation fuel ethanol from the plant is the major product. This ethanol is 199.8+ proof material with 5.0 volume percent gasoline added to it. Table C-23 shows the total fuel production rate as well as a breakdown of the three major components in the fuel; ethanol, gasoline and acetaldehyde.

C.4.3.2 Electricity

Electricity is a secondary product from the plant. Power is generated by the steam turbine connected to an electric generator. The majority of the electricity generated is used internally by plant equipment. Excess electricity is sold to the grid. The amount of electricity produced is determined by the energy balance of the plant and the performance of the boiler and turbogenerator set.

C.4.3.3 Solid Waste

The major solid waste stream from the plant is the ash from the boiler. This ash is comprised of the ash and mineral matter that came into the plant with the feedstock, plus the gypsum produced by the sulfuric acid and lime neutralization reaction and the sulfur dioxide and calcium

Table C-23.
Output Summary for Conversion Process

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
SOURCE/REGION	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific	Northeast
OUTPUT SUMMARY: OUTPUTS						
Denatured Fuel:						
Ethanol (gal/yr)	68,200,000	78,200,000	80,900,000	78,000,000	74,300,000	78,200,000
Gasoline (gal/yr)	3,600,000	4,130,000	4,280,000	4,120,000	3,930,000	4,130,000
Acetaldehyde (ton/yr)	99	82	82	73	90	77
Solid Waste (ton/yr)	130,500	47,300	43,400	66,200	36,200	49,000
Sludge (ton/yr)	N/A	2,420	2,520	1,970	3,720	2,320
Electricity (kWh × 10 ⁶ /yr)	72	128	119	118	220	125

oxide reaction in the boiler. For cases 2-5, the solids are non-hazardous. For the MSW case, the hazards of this material will depend on the degree to which hazardous material is eliminated during upstream processing.

A second solids stream from the plant for cases 2-5 is the sludge produced during waste water treatment operations. The sludge is assumed to be applied to the land used for biomass production.

C.4.4 Environmental Releases and Concerns

C.4.4.1 Air Releases

Emissions to the atmosphere are released throughout the conversion process. This section describes the various emission sources and quantifies the levels of emission of each of the major criteria pollutants, greenhouse gases and air toxics listed in Table C-2, which are relevant to the conversion facility. The approach will be to step through the process and describe the emissions from each area. Table C-24 summarizes the air releases for the six cases. Tables C-25 through C-30 itemize air releases by area of the facility for each case.

The list of volatile organic compounds (VOCs) includes literally hundreds of compounds (Middleton, 1990). In many cases reported VOC emission data does not include a breakdown of specific VOCs but rather is presented as total VOCs. This is the case for most of the emission data for internal combustion engines. Where possible emissions for individual VOCs have been quantified. The individual VOCs of primary importance in a biomass to ethanol conversion facility are listed in Table C-31. Many of the VOCs have not been quantified because there is no data available regarding the quantities of the materials in the process streams. For example, it is well known that higher alcohols such as isobutyl alcohol are produced as byproducts of carbohydrate fermentations for the production of ethanol (Phaff 1966). However, the quantities produced are quite small and variable. Compounds such as these are listed in Table C-31, yet not quantified in this document.

The 1990 amendments of the Clean Air Act completely revised section 112 which had provided for national emission standards for hazardous air pollutants (NESHAPS). Section 112(b)(1) of the Clean Air Act now incorporates a list of 189 substances, or classes of substance, and defines them as hazardous pollutants for the purpose of regulation under section 112. The major hazardous air pollutants, or air toxics, released from the conversion facilities are acetaldehyde and formaldehyde. Acetaldehyde could be released in small quantities in process vent streams as fugitive emissions from the product storage tanks and as a product of incomplete combustion. Formaldehyde is emitted in boiler flue gas as a product of incomplete combustion.

Additional toxic air emissions in the MSW case depend to a large degree on the amount of toxic material, particularly heavy metals, in the sorted feed to the conversion facility. At a minimum, it is expected that some hydrochloric acid and lead compounds will be emitted in the boiler flue gas, due to the presence of chlorine and lead materials respectively, in the MSW feed.

Table C-24.
Environmental Releases and Concerns Summary for Conversion Process

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
SOURCE/REGION	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
AIR RELEASES (ton/yr)						
CO ₂	730,000	823,000	801,000	783,000	891,000	823,000
CO	240	295	299	279	397	298
SO ₂	58.8	73.0	47.6	73.4	26.6	65.2
NO _x	136.7	175.7	174.9	194.6	220.3	176.2
TP	119.0	130.0	131.0	127.0	151.0	130.0
Pb	0.02	n/a	n/a	n/a	n/a	n/a
HCl	47	n/a	n/a	n/a	n/a	n/a
VOC-Total	40.4	50.2	50.3	48.6	66.7	50
Gasoline	1.36	1.36	1.36	1.36	1.36	1.36
Diesel	0.00305	0.00697	0.004	0.00305	0.0038	0.00415
Ethanol	8.7	10	9.5	10.0	10.3	10.0
Acetaldehyde	0.601	0.697	0.644	0.644	0.858	0.687
Formaldehyde	0.396	0.472	0.429	0.429	0.558	0.472
Ammonia	24.9	29.2	28.4	26.6	35.7	29.0
WATER RELEASES	785	756	748	661	948	725
Suspended Solids (ton/yr)	nil	nil	nil	nil	nil	nil
Oil & Grease	942	907	898	793	1137	870
COD	n/a	n/a	n/a	n/a	n/a	n/a
Thermal						
LAND CONCERNS	50	50	50	50	50	50
Land Area (acres)						

**Table C-25.
Summary of Air Releases for Case 1**

	CO ₂ Tons/ Year	CO Tons/ Year	SO ₂ Tons/ Year	NO _x Tons/ Year	TP ¹ Tons/ Year	Gasoline ² Tons/ Year	Diesel Tons/ Year	Ethanol Tons/ Year	VOC Tons/ Year	Air Toxics ³ (Tons/Year)		NH ₃ Tons/ Year
										Acetal- dehyde	Formal- dehyde	
MATERIAL HANDLING Engines Fugitive	1239	6.0	0.04	12.3	1.0 71.5				1.5			
PRETREATMENT Fugitive					0.116							
FERMENTATION Vents Fugitive	236,000							8.05		0.00035		
OFF-SITE TANKS Fugitive						1.36	0.00305	0.662				
ENVIRONMENTAL SYSTEMS Vents	3,810											
UTILITIES Vents	489,000	234	58.8	124.4	47.6				38.9	0.601	0.386	24.9

¹ Total Particulates

² Gasoline and Diesel are VOC's, but have not been included in the VOC column

³ Acetaldehyde and Formaldehyde are VOC's, but have not been included in the VOC column

Additional Releases: 0.020 ton Pb/year, 47.2 ton HCl/year

**Table C-26.
Summary of Air Releases for Case 2**

	CO ₂ Tons/ Year	CO Tons/ Year	SO ₂ Tons/ Year	NO _x Tons/ Year	TP ¹ Tons/ Year	Gasoline ² Tons/ Year	Diesel Tons/ Year	Ethanol Tons/ Year	VOC Tons/ Year	Air Toxics ³ (Tons/Year)		NH ₃ Tons/ Year
										Acetal- dehyde	Formal- dehyde	
MATERIAL HANDLING Engines Fugitive	2,480	12.0	0.08	24.7	2.1 71.5				3.0			
PRETREATMENT Fugitive					.113							
FERMENTATION Vents Fugitive	264,000							9.35		.0003		
OFF-SITE TANKS Fugitive						1.36	0.00675	0.697				
ENVIRONMENTAL SYSTEMS Vents	7,380											
UTILITIES Vents	549,000	283	73.0	151.0	56.7				47.2	0.687	0.472	29.2

¹ Total Particulates

² Gasoline and Diesel are VOC's, but have not been included in the VOC column

³ Acetaldehyde and Formaldehyde are VOC's, but have not been included in the VOC column

**Table C-27.
Summary of Air Releases for Case 3**

	CO ₂ Tons/ Year	CO Tons/ Year	SO ₂ Tons/ Year	NO _x Tons/ Year	TP ¹ Tons/ Year	Gasoline ² Tons/ Year	Diesel Tons/ Year	Ethanol Tons/ Year	VOC Tons/ Year	Air Toxics ³ (Tons/Year)		NH ₃ Tons/ Year
										Acetal- dehyde	Formal- dehyde	
MATERIAL HANDLING Engines Fugitive	2,215	10.7	0.07	22.1	1.9 71.5				2.7			
PRETREATMENT Fugitive					0.054							
FERMENTATION Vents Fugitive	272,000							8.80		0.00035		
OFF-SITE TANKS Fugitive						1.36	0.00400	0.707				
ENVIRONMENTAL SYSTEMS Vents	7,520											
UTILITIES Vents	519,000	287	47.6	152.8	57.5				47.6	0.644	0.429	28.4

¹ Total Particulates

² Gasoline and Diesel are VOC's, but have not been included in the VOC column

³ Acetaldehyde and Formaldehyde are VOC's, but have not been included in the VOC column

Table C-28.
Summary of Air Releases for Case 4

	CO ₂ Tons/ Year	CO Tons/ Year	SO ₂ Tons/ Year	NO _x Tons/ Year	TP ¹ Tons/ Year	Gasoline ² Tons/ Year	Diesel Tons/ Year	Ethanol Tons/ Year	VOC Tons/ Year	Air Toxics ³ (Tons/Year)		NH ₃ Tons/ Year
										Acetal- dehyde	Formal- dehyde	
MATERIAL HANDLING Engines Fugitive	6,183	30.0	0.20	61.6	5.2 71.5				7.4			
PRETREATMENT Fugitive					0.133							
FERMENTATION Vents Fugitive	261,000							9.35		0.00030		
OFF-SITE TANKS Fugitive						1.36	0.00305	0.697				
ENVIRONMENTAL SYSTEMS Vents	8,480											
UTILITIES Vents	507,000	249	73.2	133	50.0				41.2	0.644	0.429	26.6

¹ Total Particulates

² Gasoline and Diesel are VOC's, but have not been included in the VOC column

³ Acetaldehyde and Formaldehyde are VOC's, but have not been included in the VOC column

Table C-29.
Summary of Air Releases for Case 5

	CO ₂	CO	SO ₂	NO _x	TP ¹	Gasoline ²	Diesel	Ethanol	VOC	Air Toxics ³ (Tons/Year)		NH ₃
	Tons/ Year	Tons/ Year	Tons/ Year	Tons/ Year	Tons/ Year	Tons/ Year	Tons/ Year	Tons/ Year	Tons/ Year	Acetal- dehyde	Formal- dehyde	Tons/ Year
MATERIAL HANDLING Engines Fugitive	1,237	6.0	0.04	12.3	1.0 71.5				1.5			
PRETREATMENT Fugitive					0.106							
FERMENTATION Vents Fugitive	254,000							9.60		0.00030		
OFF-SITE TANKS Fugitive						1.36	0.00380	0.684				
ENVIRONMENTAL SYSTEMS Vents	4,510											
UTILITIES Vents	631,000	391	26.6	208	78.1				65.2	0.858	0.558	35.7

¹ Total Particulates

² Gasoline and Diesel are VOC's, but have not been included in the VOC column

³ Acetaldehyde and Formaldehyde are VOC's, but have not been included in the VOC column

Table C-30.
Summary of Air Releases for Case 6

	CO ₂ Tons/ Year	CO Tons/ Year	SO ₂ Tons/ Year	NO _x Tons/ Year	TP ¹ Tons/ Year	Gasoline ² Tons/ Year	Diesel Tons/ Year	Ethanol Tons/ Year	VOC Tons/ Year	Air Toxics ³ (Tons/Year)		NH ₃ Tons/ Year
										Acetal- dehyde	Formal- dehyde	
MATERIAL HANDLING Engines Fugitive	2,688	13.0	0.09	26.8	2.3 71.5				3.2			
PRETREATMENT Fugitive					0.096							
FERMENTATION Vents Fugitive	263,000							9.35		0.00025		
OFF-SITE TANKS Fugitive						1.36	0.00415	0.697				
ENVIRONMENTAL SYSTEMS Vents	7,850											
UTILITIES Vents	549,000	285	65.1	149.4	56.2				46.8	0.687	0.472	29.0

¹ Total Particulates

² Gasoline and Diesel are VOC's, but have not been included in the VOC column

³ Acetaldehyde and Formaldehyde are VOC's, but have not been included in the VOC column

**Table C-31.
Types of VOC Air Releases**

VOC Type	Process Source	Emission Type	Quantifiable
Methane	Anaerobic Digestion	Fugitive	No
Acetaldehyde	Fermentation/Product Storage/Boiler	Vent/Fugitive	Yes
Acetic Acid	Fermentation	Fugitive	No
Formic Acid	Fermentation	Fugitive	No
Propionic Acid	Fermentation	Fugitive	No
Formaldehyde	Boiler	Vent	Yes
2-Furfural	Pretreatment	Fugitive	No
Ethyl Alcohol	Fermentation/Product Storage	Vent/Fugitive	Yes
Isopropyl Alcohol	Fermentation/Product Storage	Fugitive	No
N-butyl Alcohol	Fermentation/Product Storage	Fugitive	No
N-propyl Alcohol	Fermentation/Product Storage	Fugitive	No
S-butyl Alcohol	Fermentation/Product Storage	Fugitive	No
Isobutyl Alcohol	Fermentation/Product Storage	Fugitive	No

Fugitive emissions from this process may occur in the form of particulate emissions from materials handling operations, vapor emissions generated during processing, vapor emissions from storage tanks, spillage, and leakage. Spillage and leakage have not been included in the fugitive emissions estimate. The approach is to develop a fugitive emission estimate using emission factor information from the EPA document, *Compilation of Air Pollutant Emission Factors, Volume I, Stationary Point and Area Sources* (U.S. EPA, 1985).

C.4.4.1.1 Air Releases from Feedstock Handling and Size Reduction Sections

As feedstock enters the conversion facility, it is stored in piles until it is fed to the milling area. The movement of the biomass is accomplished with heavy duty construction equipment such as front end loaders. Emissions from the engines of these vehicles contribute to the air releases from the plant. The fuel used for the year 2000 is assumed to be a low sulfur diesel fuel (less than 0.05 weight%), with a minimum cetane reading of 40. There may be a few alternative fuel trucks probably operating on ethanol (E90), but more than likely it will be a negligible amount and therefore is not considered in the analysis.

Emission rates from vehicles used in the feedstock handling section the plant were determined by estimating the number of vehicle required times the specific emission factors for the vehicle. The emission factors used in this work are given in Table C-32 for the year 2000 (MSW case) and the year 2010 (all other cases) (Humphreys 1991).

**Table C-32.
Diesel Emission Factors**

Pollutant	2000 (g/bhp-h)	2010 (g/bhp-h)
Hydrocarbons	0.80	0.63
CO	3.24	3.89
NO _x	6.66	4.50
Particulates	0.566	0.314

The number of vehicles (loaders) required can be estimated from the vehicle load capacity, the bulk density of the feedstock, the turnaround required to dump each load, and the required feedstock flowrate. The bulk densities for each of the general feedstock components are given in Table C-33 as well as the average bulk densities calculated for each case based on the fractional composition for each case. The actual bulk density depends on water content and was calculated assuming a water content of 50% doubles the bulk density.

**Table C-33.
Feedstock Bulk Densities**

	Bulk Density (dry) (lb/cft)	Source
Wood Chips	10.0	Smook 1989
Herbaceous (baled)	2.0	Wiselogel 1991
Canes (baled)	1.0	Wiselogel 1991
MSW	10.0	Assumed from data in Hasselriis 1984
CASE 1 - MSW	10.0	
CASE 2 - Midwest/Lake States	5.0	
CASE 3 - Southeast	5.6	
CASE 4 - Great Plains	2.0	
CASE 5 - Pacific Northwest	10.0	
CASE 6 - Northeast	4.6	

The rest of the data necessary to determine the number of loaders are given in Table C-34 as well as loader horsepower and fuel consumption. The load is based on using an extra capacity bucket (300 cft) on the loader for scooping wood chips. It is also assumed that a loader can move one round bale of material of 500 cft in the given turnaround time, even though the actual volume will be larger (approx 450 cft).

**Table C-34.
Loader Operating Data**

	Data	Source
Load (cft)	300	Georgia Institute of Technology (GIT 1984)
Turnaround Time (min)	2.0	Assumed
Engine Power Factor (lb fuel/bhp-h) Year 2000	0.46	Humphreys 1991
Year 2010	0.44	Humphreys 1991
Fuel Consumption (lb/h)	54.4	GIT

The emissions are then calculated from fuel consumption, the engine power factor and the appropriate emission factor given in Table C-31. Carbon dioxide and sulfur dioxide production rates were calculated from the fuel consumption rate and the elemental composition for diesel, which is 87.3% C, 12.6% H, 0.04% O, 0.006% N, and 0.22% S (Perry 1984). However, for this study the diesel was assumed to only contain 0.05% S.

Stoichiometric calculations of combustion product rates used the following formula, which is based on the combustion of given weight of a solid or liquid fuel (Strehlow 1991),

$$C_u H_v O_w N_x S_y + \left(u + \frac{v}{4} - \frac{w}{2} + y \right) (O_2 + 3.76 N_2) - u CO_2 + \frac{v}{2} H_2O + y SO_2 + \left[3.76 \left(u + \frac{v}{4} - \frac{w}{2} + y \right) + \frac{x}{2} \right] N_2.$$

The coefficients are molar coefficients based for a known mass of fuel and the elemental composition of the fuel. For example, based on 1.0 kg of diesel fuel, the coefficient u is,

$$u = (1.0 \text{ kg})(0.873) \left(\frac{1000 \text{ g}}{1.0 \text{ kg}} \right) \left(\frac{\text{mole C}}{12 \text{ g C}} \right) = 72.75.$$

Fugitive emissions from the material handling section of the plant are particulate emissions arising from the milling operation. Air emissions due to biomass degradation have been accounted for in the total degradation losses associated with biomass production, harvesting, and handling (Appendix A - Biomass Production, Storage, and Transportation). The emission factor

for a grain milling operation with emission controls is 0.2 lb/ton of feed (U.S. EPA 1985, Table 6.4-6). This number times the total dry feedrate yielded 71.5 tons/year of particulates for each case.

C.4.4.1.2 Air Releases from Pretreatment and Neutralization Section

In the pretreatment section of the conversion facility, the system is totally enclosed. The only emissions anticipated are fugitive emissions due to leaks and spills. Sulfuric acid is added in the pretreatment step, so the concentrated sulfuric acid storage and handling area is one critical area where the process design must contain any leaks and spills.

Fugitive emissions from prehydrolysis are limited to the lime handling system. Particulate emissions are generated during the process of unloading the lime from the railcar to the lime pit. The rest of the lime handling system contains controls (e.g. cyclones on the storage bins), which are assumed to limit the emissions to near zero values.

The particulates generated during the unloading process are calculated using the following equation (U.S. EPA 1985),

$$E = k(0.0032) \frac{\left(\frac{u}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}},$$

where E = emission factor (lb/ton),

k = particle size multiplier = 0.74 (U.S EPA 1985, worst case),

u = mean wind speed (mph), (Wind Energy Resource Atlas 1980),

M = material moisture content = 0.7% (U.S. EPA 1985, crushed limestone).

The mean wind speed, emission factor and particulates released are given below in Table C-35.

Table C-35.
Particulate Emissions From Lime Handling

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
u (mph)	10.0	9.8	5.6	11.2	9.4	10.3
E (lb/ton)	0.025	0.025	0.012	0.029	0.023	0.021
Particulates (ton/yr)	0.166	0.113	0.054	0.133	0.106	0.096

C.4.4.1.3 Air Releases from Fermentation Sections

In the fermentation area of the facility, there are several different types of fermentation operations that occur. There are aerobic fermentations for the production of the microorganisms used in the main anaerobic fermentations. There is also the aerobic fermentation for the production of cellulase enzyme. Fermentation air is supplied to the aerobic fermenters and the unused oxygen, nitrogen and any entrained organic compounds are vented out the top of the aerobic fermenters. These vents are collected in a header system and sent directly to the boiler where the organic portions are destroyed and the oxygen is used in combustion.

The production of carbon dioxide in the aerobic fermentations was estimated strictly from sugar consumption in each of the fermentations as determined from the material balances. Where cellulose or xylan was converted, the appropriate conversion factors (1.11 g glucose/g cellulose, 1.14 g xylose/g xylan) were applied. The only other data required is the yield (g CO₂/g sugar consumed). Assuming the elemental composition given for yeast cells (50.8% C, 7.2% H, 31.6% O, 10.4% N, Atkinson 1983) and that the only products from sugar metabolism are cells (at a yield of 0.5 g cells/g glucose), carbon dioxide and water, the CO₂ yield from stoichiometry is 0.42. In another example from Atkinson, the CO₂ yield is 0.60 for aerobic growth of yeast on glucose (again 0.5 g cells/g glucose). Given this wide variability, this study assumed a CO₂ yield of 0.5 for aerobic yeast growth. Little or no data is available on elemental composition or cell yield for *T. reesei* growth and cellulase production or *E. coli* growth on xylose. Therefore, the CO₂ yield for each of these systems was also assumed to be 0.5.

In the anaerobic fermentations, CO₂ is the major product that is vented from the fermenters. Reaction stoichiometry for the anaerobic fermentations are presented in Sections C.3.4 and C.3.6. These gaseous vent streams are chilled to recover ethanol, then are scrubbed in a water scrubber with fresh water and then sent through a carbon bed for final volatile organic carbon removal. The scrubber water is recycled to the front end of the plant and the carbon beds are periodically regenerated.

In some cases it may be possible to sell the CO₂ from the fermenters as a co-product. However, any sizeable ethanol fuel program would probably quickly saturate any local demands for CO₂ and therefore it is assumed that it would be vented.

Fugitive emissions from the fermentation area are primarily due to ethanol and acetaldehyde entrainment in the carbon dioxide vent stream. U.S. EPA document AP-42 (Section 6.5) provides emission factor information for fermentation processes that is limited to primarily ethanol. An ethanol emission factor of 4.79 lbs per 1000 gals (or 1.45 lb/ton) produced is shown for wine fermentations. Acetaldehyde emissions were estimated by ratioing the acetaldehyde and ethanol production rates and multiplying times the ethanol emission rate. Because the vent stream is chilled to condense the volatiles and further scrubbed, the emissions are assumed to be reduced by 95%. The emissions of ethanol and acetaldehyde are given below in Table C-36. Acetaldehyde emissions are negligible compared to boiler acetaldehyde emissions.

**Table C-36.
Fugitive Emissions from Fermentations**

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Ethanol (ton/yr)	8.05	9.35	8.80	9.35	9.60	9.35
Acetalde- hyde (ton/yr)	0.00035	0.00030	0.00035	0.0003	0.0003	0.00025

C.4.4.1.4 Air Releases from Ethanol Recovery Section

The ethanol recovery process is a totally enclosed system. In ethanol recovery, the ethanol is first recovered as an azeotropic product. Light ends such as acetaldehyde are recovered overhead in the distillation column as a vapor stream. This overhead vapor is sent directly to the boiler as a waste fuel stream.

The azeotropic ethanol is dehydrated by molecular sieve. Regeneration gas containing ethanol and water is cooled and the ethanol and water condensed and recycled to the distillation column. Uncondensed gases are sent directly to the boiler.

The main emissions from the distillation area are fugitive in nature and due to leaks from piping and equipment and accidental spills.

C.4.4.1.5 Atmospheric Releases from Offsite Storage Tanks

The ethanol product is stored and blended with gasoline as a denaturant in large product storage tanks. Gasoline, diesel fuel, and ammonia are also stored in suitable storage tanks. All of these tanks are internal floating roof tanks which minimize evaporative losses. Major atmospheric emissions from this area will be tank losses, piping leaks and accidental spills.

Fugitive emissions losses from the off-site storage tanks were estimated using emission losses for floating roof tanks (U.S. EPA 1985). The ethanol, gasoline and diesel storage are assumed to be internal floating roof tanks having the following losses,

$$L_T = L_R + L_W + L_F,$$

where L_T = total loss (lb/yr),

L_R = rim seal loss,

L_W = withdrawal loss,

L_F = deck fitting loss.

The equations for each loss term are given below,

$$L_R = K_1 V^* P^* D M_v K_c,$$

$$P^* = \frac{\frac{P}{P_a}}{\left[1 + \left(1 - \frac{P}{P_a} \right)^{0.5} \right]^2},$$

$$L_w = \frac{0.934QCW_L}{D} \left[1 + \frac{N_c F_c}{D} \right],$$

$$L_F = F_F P^* M_v K_c,$$

where K_s = seal factor = 3.0 (single liquid mounted seal),

n = seal related wind speed exponent = 0.0 (for internal floating roof tanks),

P = vapor pressure at storage temperature (psi),
 = 6.2 for gasoline (U.S EPA 1985, Table 4.3-2),
 = 0.009 for diesel (U.S EPA 1985, Table 4.3-2),
 = 0.90 for ethanol (U.S EPA 1985, Table 4.3-2),

P_a = atmospheric pressure, assumed 14.7 psi for all cases,

D = tank diameter (ft),

M_v = vapor molecular weight (lb/lb-mole),
 = 66 for gasoline (U.S. EPA 1985, Table 4.3-2),
 = 103 for diesel (U.S. EPA 1985, Table 4.3-2),
 = 46 for ethanol (U.S. EPA 1985, Table 4.3-2),

K_c = product factor = 1.0 for all liquids (U.S. EPA 1985),

Q = throughput (bbl yr),

C = shell clingage factor = 0.0015 for all liquids, good tank condition (U.S. EPA 1985, Table 4.3-5),

W_L = liquid density (lb/gal),

N_c = number of columns = 1.0 for all cases (U.S. EPA 1985, Table 4.3-6),

F_c = effective column diameter = 1.0 ft (U.S. EPA 1985),

- F_F = total deck fitting loss factor (lb-moles/yr),
- = 210 for gasoline (U.S. EPA 1985, Figure 4.3.-10),
- = 164 for diesel (U.S. EPA 1985, Figure 4.3.-10),
- = 394 for ethanol (U.S. EPA 1985, Figure 4.3.-10).

The total losses for each case are given below in Table C-37.

Table C-37.
Fugitive Emissions from Off-Site Storage Tanks

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Gasoline (ton/yr)	1.36	1.36	1.36	1.36	1.36	1.36
Diesel (ton/yr)	0.00305	0.00675	0.00400	0.00305	0.00380	0.00415
Ethanol (ton/yr)	0.662	0.697	0.707	0.697	0.684	0.697

C.4.4.1.6 Air Releases from Environmental Systems

In the environmental systems area of the plant, there are two major processing steps. First, there is the vent collection system. All of the low pressure vents from the process are collected and passed through a liquid knock out drum upstream of a vent gas blower. The blower elevates the pressure of the vent stream to a high enough pressure to send it to the boiler. The only major vent streams not processed through the low pressure vent system are the CO₂ streams from the anaerobic xylose fermentation and the anaerobic simultaneous saccharification and fermentation reactors. Any liquids knocked out in the liquid knock out drum are sent to waste water treatment.

The second major area in environmental systems is wastewater treatment. The liquid waste streams from the low pressure vent knock out drum, the wet solids from the solid separation equipment and a condensed vent stream from the ethanol recovery area are all fed to the wastewater treatment system. The blended material is cooled and fed to the anaerobic reactor. Here the majority of the organic material is converted to biogas, a mixture of carbon dioxide and methane. This gas is sent to the boiler as a gaseous fuel. Material from the anaerobic reactor is further processed in an aerobic reactor. Here the majority of the remaining organic material is converted to CO₂. The gaseous vent stream from the aerobic reactor is sent to the boiler. Therefore, any of the volatile organic carbon materials or dissolved hydrogen sulfide is all contained and combusted in the boiler.

Fugitive atmospheric emissions from the environmental systems would be due to leaks in equipment and piping and accidental spills.

C.4.4.1.7 Air Releases from Utility Systems

In the utility section of the plant, there are several utility systems that release atmospheric emissions.

The major carbon dioxide release comes from the boiler. This is where all the gaseous, liquid and solid waste fuel streams are burned. Products of incomplete combustion in the boiler will include carbon monoxide, particulates, and VOCs. Sulfur in the solid waste stream, as well as H₂S from the anaerobic and aerobic digestion of wastewater will contribute to SO₂ in the boiler flue gas. Limestone is added to the boiler to reduce SO₂ emissions. Enough limestone (CaCO₃) is added to achieve a Ca:S molar ratio of 2:1. Ninety percent SO₂ reduction was assumed. Nitrogen oxides are produced from nitrogen associated in the solid fuel. This is partially derived from the nitrogen in the crude protein. In addition, thermal NO_x production is expected. Ammonia (NH₃) is injected into the hot flue gas to reduce NO_x emissions. The NH₃ reacts with the NO_x in the flue gas to produce nitrogen and water. Ammonia is supplied at a rate of 1.1 pounds per pound of NO_x reduced. Eighty percent NO_x reduction is assumed. Unreacted ammonia in the flue gas is estimated at a concentration of 20 ppmv. Lead and other air toxics may be present in the boiler flue gas for the municipal solid waste case. These would be due to the presence of heavy metals and other materials in the original solid waste stream fed to the conversion facility. For this analysis the only air toxics estimated are lead and hydrochloric acid for the MSW case.

The composition of each of the fuels entering the boiler are given below in Table C-38. This information is needed to calculate flue gas composition. The others fraction is assumed to be terpenes, phenolic acids, and fats and waxes. The exact composition of this material is unknown and extremely variable, therefore, the following simplified composition shown below in Table C-39 was assumed (Johnson 1991).

The average composition of the "others" fraction for all three feedstocks is approximately the same, and in order to simplify the calculation, an average composition was used for all three feedstocks giving an elemental formula of CH_{1.48}O_{0.19}.

The composition of the flue gas is given in Table C-40 as determined in part by Radian Corporation (Ron Bell 1991). Radian Corporation estimated uncontrolled SO₂ and NO_x emissions. SO₂ control with limestone addition was assumed to reduce uncontrolled SO₂ by 90 percent. NO_x control by ammonia injection into the hot flue gas was assumed to reduce uncontrolled NO_x by 80 percent. The Pb and HCl emissions from MSW were estimated as 0.000247 lb HCl/lb dry fuel and 0.0000001 lb Pb/lb dry fuel (Baker and Paouncic 1990). Particulate emissions are in the range of 0.009 to 0.012 gr/scft, well below most state regulations (i.e. Pennsylvania Standard - 0.08 gr/dscf, Baker and Paouncic 1990).

**Table C-38.
Chemical Composition for All Boiler Fuels (weight %)**

Component	C	H	O	N	S	Source/Comments
Cells	50.8	7.2	31.6	10.4		Atkinson 1983
Protein	52.7	6.9	21.7	17.7	1.0	ASME 1987 (as gliadin, a vegetable protein)
Cellulose	44.5	6.2	49.3			Tillman 1991
Xylan	45.5	6.0	48.5			Tillman 1991
Lignin	77.8	8.7	13.5			Tillman 1991
Cellulase	52.7	6.9	21.7	17.7	1.0	assumed the same as protein
Fusel Oils	64.9	13.5	21.6			assumed all butanol
Others	72.5	8.9	18.6			Johnson 1991

Table C-39.
Percent Composition of Other Fraction for Each of the Major Feedstocks

	<u>Terpenes</u> α -pinene $C_{10}H_{16}$	<u>Phenolic Acids</u> Ferulic acid $C_{10}H_{10}O_4$	<u>Fats and Waxes</u> Linoleic acid $C_{17}H_{32}CO_2H$
Wood	36	36	28
Grass Crops		50	50
MSW			100

Table C-40.
Boiler Emissions (lb/h)

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
SOURCE/REGION	MSW	Midwest/ Lake States	Southeast	Great Plains	Pacific Northwest	Northeast
CO ₂	114,000	128,000	121,000	118,000	147,000	128,000
CO	54.4	66.0	66.8	58.1	91.1	66.4
SO ₂	13.7	17.0	11.1	17.1	62.0	15.2
NO _x	29.0	35.2	35.6	31.0	48.6	34.8
PM-10	10.9	13.2	13.4	11.6	18.2	13.1
Pb	0.00445	0.0	0.0	0.0	0.0	0.0
HCL	11	0.0	0.0	0.0	0.0	0.0
VOC	9.07	11.0	11.1	9.69	15.2	10.9
Acetaldehyde	0.14	0.16	0.15	0.15	0.20	0.16
Formaldehyde	0.09	0.11	0.10	0.10	0.13	0.11
Ammonia	5.8	6.8	6.6	6.2	8.3	6.8

Fugitive emissions from the boiler system include leaks from equipment and piping and accidental spills of the solid or liquid waste fuel streams. In addition, vent gas from the solids dryer upstream of the boiler is exhausted to the atmosphere after scrubbing and adsorption in a carbon bed.

The cooling tower exhausts primarily water vapor to the atmosphere. While this is not considered a release with significant environmental consequences, it is the major thermal release from the conversion facility to the atmosphere. If there are leaks from the process system into the cooling water at the various water cooled heat exchangers throughout the process, then organic materials such as VOC's may be entrained in the cooling water and then exhausted to the atmosphere at the cooling tower. This type of emission is minimized by proper equipment maintenance and cooling water monitoring.

In the chilled water unit a propane refrigeration system is used to reduce the water temperature. Fugitive propane emissions in the form of leaks or spills from refrigeration system equipment and piping are the only source of environmental atmospheric releases from the chilled water system.

The other utility systems include fermentation air, process water, and instrument and plant air. No atmospheric releases are anticipated from any of these remaining utility supply areas.

C.4.4.2 Water Releases

All water released from the conversion facility is treated by a wastewater treatment system to reduce COD, BOD, and suspended and dissolved solids. A large fraction of the wastewater is blowdown from the cooling water and boiler system. The goal of the current design is to increase water quality to the point where it can be land applied or discharged to a publicly owned treatment works (POTW). The goal of future designs will be to eliminate all water discharges by treatment and recycle of the treated water.

Treated waste water from the conversion facility will contain dissolved solids and some unconverted organic material. The dissolved solids include minerals from the biomass feedstock, nutrients added for microbial growth and maintenance, and soluble gypsum. The organic material is primarily lignin, which is very resistant to microbial degradation.

For the MSW case in the year 2000, it is assumed that the treated effluent from the waste water treatment system with discharge limits of 600 mg per liter COD and 300 mg per liter BOD will be discharged to a (POTW). The citing of the MSW plant will likely be near an urban area so that discharge to a POTW would be possible. This will result in an indirect release of effluent to a surface water.

It is likely that the effluent from the POTW will discharge water with a suspended solids content of 30 mg/l or less. Consequently, the suspended solids contributed by the ethanol production wastewater would be at most 47 tons/yr. The POTW effluent should contain little or no oil and grease or priority pollutants that were contributed by the ethanol production wastewater. The

ethanol production wastewater may contain a small amount of color that should not be an environmental problem for the discharge of the wastewater. The ethanol production wastewater will have an elevated temperature (about 30°C) by the time it reaches the POTW. Depending on the total flow of the POTW, this may or may not raise the temperature of the POTW effluent.

For the cases in the 2010 timeframe, it was assumed that both the treated wastewater and the sludge would be applied to the land used to grow the biomass. It is not likely that there will be POTWs near the ethanol production facilities to accept the effluent, so that the effluent must be either land applied or discharged to a surface water. Large quantities of land that the biomass crops are grown on should be available for land application. Sludge application to the land the biomass crops are grown on is also suggested. The organic matter and nutrients in the sludge will serve as soil enhancers.

The amount of land required for land application is controlled by the nitrogen uptake of the biomass crops. No more nitrogen can be added to the land than is taken up by the crops. It is estimated that a high of 9,200 ac to a low of 5,000 ac will be needed to balance the nitrogen uptake of the crops to that applied in sludge. Acreage estimates for the five biomass production cases range from 95,000 to 161,000 acres.

It is likely that there will be three months out of each year in many parts of the country that effluent and sludge cannot be land applied due to frozen ground or excess rain fall. Consequently, a storage lagoon will be provided to store the effluent and sludge. Alternatives to land application include an evaporation pond or evaporation system where the dissolved solids are concentrated and ultimately disposed of as salts in a landfill. Finally, a National Pollutant Discharge Elimination System (NPDES) permit could allow discharge of the treated waste water to surface waters. However, the future goal will be to eliminate all wastewater discharges by maximizing internal water treatment and reuse.

C.4.4.3 Land Concerns

C.4.4.3.1 Soil Productivity

The land application of the wastewater treatment effluent and sludge for the 2010 timeframe cases will add TDS and nitrogen to the soil. The TDS may leach into the groundwater, but it should not result in an environmental problem unless there is little dilution in the groundwater system and the groundwater is used for drinking or irrigation. The nitrogen in the sludge could leach from the soil to the groundwater if the application rates are not controlled to match the uptake by the crops.

The goal for future plants will be to eliminate all wastewater discharges.

C.4.4.3.2 Erosion

Some erosion is likely to occur during the construction of the conversion facility. With good construction practices, this should be minimal and typical of any construction. Once the facility is completed there will be little or no erosion. Some erosion may occur due to the land application of the waste water treatment effluent and sludge for the cases in the 2010 timeframe. With a proper design and good management practices, minimal erosion should take place.

C.4.4.4 Other Concerns

C.4.4.4.1 Occupational Health and Safety

Standard health and safety design considerations and operational practices will have to be followed for the conversion facility. The occupational health and safety hazards of biomass conversion to ethanol are predominantly due to the nature of the chemicals handled at the facility. The biomass feedstock as well as the ethanol product are flammable materials which can be sources of catastrophic fires and/or explosions. Physical contact with or inhalation of toxic compounds such as ammonia, sulfuric acid, furfural, acetaldehyde and hydrogen sulfide could cause serious injury or death. These compounds can exist in process feed streams, products, waste and process streams and can be released during process upsets and maintenance operations. Other occupational safety hazards include exposure to high temperatures, noise, corrosive materials and accidents.

Some of the primary areas of concern are listed below.

- Feedstock Handling: Operation of large mobile equipment
- Feedstock Size Reduction: Dust emissions and dust explosions, noise
- Sulfuric Acid Storage and Handling: Physical contact with or inhalation of concentrated acid
- Pretreatment Reactors: Physical contact with or inhalation of furfural or other toxic compounds
- Ammonia Storage and Handling: Physical contact with or inhalation of concentrated ammonia, explosions
- Ethanol Recovery: High temperatures, physical contact with potentially high concentrations of organic acids
- Product Storage: Fires and explosions, physical contact with or inhalation of concentrated ethanol and/or gasoline
- Boiler: High temperatures, high pressures, fires and explosions
- High Pressure Steam System: High temperatures, high pressures
- Biogas Handling System: Inhalation of hydrogen sulfide
- Pure Oxygen System (for Aerobic Digestion): Explosions and fires

Selected information from the 1988 Bureau of Labor report (U.S. Department of Labor 1990) on occupational injuries illnesses and fatalities is presented in Table C-41. The report gives data

for all industries by Standard Industrial Code (SIC). The industries listed in Table C-41 have some similarities with the conceptual biomass-to-ethanol industry and so it may be possible in the future to make occupational health and safety projections from the data on these existing industries. Wet corn milling plants convert corn into a slate of products including high fructose corn syrup, ethanol, corn oil, gluten feed and gluten meal. Pulp mills convert wood into pulp which is subsequently made into paper products. This is similar to the feedstock handling and pretreatment operations, particularly for woody feedstocks. Electric services includes operation of power plants. The high pressure boiler and turbogenerator operations are very similar to what is found in coal fired power plants.

**Table C-41.
Occupational Health and Safety Projection for
Ethanol Production from Biomass**

Industry	SIC Code	Injury and Illness Rate per 100 Full-Time Workers	Lost Workdays Cases per 100 Full-Time Workers	Fatalities per 100,000 Full-Time Workers ¹
Wet Corn Milling	2046	12.6	3.4	3.6
Pulp Mills	261	13.3	4.9	3.6
Electric Services	491	6.2	2.8	3.6

¹ Values based on work-related fatalities in private sector manufacturing industries, reported for 1988.

C.4.4.4.2 Noise

Some noise will be released from the conversion facilities. Most of the noise will come from rotating equipment, such as the disk refiners in feedstock size reduction area, blowers, pumps and centrifuges. The trucks delivering biomass and the front end loaders used in the feedstock handling area will also release noise. Methods are available to effectively control the noise if it is a concern at the location of the production facility, thus it may be assumed that methods will be employed so that the standards controlling noise emissions will not be violated.

C.4.4.4.3 Odors

With proper design and operations, odors released from the conversion facility should be minimized. The facility design includes the use of vent gas treating methods that will effectively control odors and all the gaseous streams released to the atmosphere. The area of the plant most

susceptible to releasing odors is in the feedstock storage and handling area. This will be minimized by limiting the supply of feedstock stored at the site. The most problematic feedstock is probably the biomass derived from municipal solid waste. Design and operation of the feedstock handling area for this case will be similar to those for MSW separation facilities and refuse derived fuel operations.

C.4.4.4.4 Catastrophic Events

The only area of the facility that could cause a catastrophic event, is the product storage area. The energy density of the ethanol product blended with gasoline, combined with the quantity stored in reasonably sized product storage tanks, allows for the possibility of a major fire. Design of the product storage area will be consistent with recommended practices governing design of fuel storage systems in the oil refining industry.

C.4.4.4.5 Aesthetics

The conversion facility will impact the aesthetics of the area since it will change the native land use. The aesthetic impacts will be variable depending on the amount of money that is spent to minimize them. It is assumed that conventional efforts will be made to improve the aesthetics of the site, thus the site will visually look like a conversion facility, but through landscaping and appropriate architectural design of buildings it will look acceptable to the average person.

C.5. Pre-Operation and Post-Operation Phases

The information presented in sections C.2. through C.4. of this appendix concentrated on the operating phase of the conversion stage life cycle. This section will identify the inputs, outputs and environmental releases associated with the pre-operation and post-operation phases of the conversion stage life cycle.

C.5.1 Pre-Operation Phase

The activities in the pre-operation phase include research and development, planning, facility design and construction. Research and development, planning and facility design are generally labor intensive processes with relatively small environmental outputs or releases. The major material inputs, outputs and releases during this phase are those associated with construction of the facility.

The primary inputs required to construct a conversion facility include: 1) concrete for foundations and pads, 2) steel for structural support, 3) various types of process equipment including tanks, heat exchangers, pumps, compressors, reactors, material handling equipment, and packaged systems, 4) bulk materials such as pipe, valves, insulation and paint, 5) electrical systems, 6) construction equipment, 7) fuel and electricity to operate the construction equipment, and 7) construction labor.

The primary output from the construction activity is the completed facility. Environmental emissions include air emissions resulting from operation of construction equipment, most of which would probably be powered by diesel engines. The emissions from labor used to construct the facility will include liquid and solid wastes generated at the construction site. Solid waste will result from garbage and construction debris. Some soil erosion is likely to occur. However, with good construction practices, this should be minimal and typical of any construction project.

C.5.2 Post-Operation Phase

The post-operational phase includes removing the facility from service, disassembling the facility and reclaiming the land the plant occupied. Removing the plant from service includes emptying and cleaning equipment such that it can be disassembled safely. Disassembly usually involves either scrapping the materials for recycling purposes, salvaging equipment for some other use, or disposing of waste material in a landfill. Land reclamation could involve removing any toxic or hazardous materials, cleaning up contaminated soil, top soil application and reestablishment of vegetation to reduce soil erosion.

In order to remove the facility from service, several inputs will be required. Labor is a major input because all of the activities in the post-operation are labor intensive. Heavy equipment required for disassembly will probably be powered by diesel fuel. Additional processing facilities may be needed to destroy hazardous or toxic wastes, or to clean up contaminated soil. These activities also required fuel and labor.

The primary outputs of the post-operation phase are 1) reclaimed land suitable for a new use, 2) recycled materials, and 3) salvaged equipment. There are possible air, liquid and solid waste emissions resulting from emptying and cleaning out equipment and piping in the plant. Air emissions will result from operation of the heavy equipment used in disassembly. Solid wastes generated may be substantial depending on how much of the construction materials and equipment can be recycled or salvaged.

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C.6.1 References

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C.6.3 Composition Data from the Literature

Table C-42.
Wheatgrass Composition Data (weight %, dry basis)

Reference	U.S.- Canadian Table of Feed Composition
Cellulose	39.00
Hemicellulose	26.00
Lignin	14.00
Ash	7.80
Extractives	1.80
NS CHO	
N	3.60
Other	7.80

Table C-43.
Willow Composition Data (weight %, dry basis)

Reference	Anderson and Zsuffa,82	Petterson, 1984	Sennerby- Forsee,88	Krigstin, 1985	Fengal and Wegener, 1989
Cellulose			46.00	38.94	
Hemicellulose					17.00
Lignin	30.50	21.00		21.85	25.40
Ash					
Extractives					2.00
NS CHO					
N					
Other					5.30

Table C-44.
Sycamore Composition Data (weight %, dry basis)

Reference	Dinus, 1990	Dinus, 1990	Frederick, 1982	Torget, 1991	Fengel and Wegener 1989
Cellulose	43.00			44.00	50.70
Hemicellulose	27.20			17.80	24.90
Lignin	24.00	21.00		22.80	29.10
Ash				0.50	0.6
Extractives	2.20	0.80		3.60	
NS CHO					
N					
Other					1.00

Table C-45.
Sweetgum Composition Data (weight %, dry basis)

Reference	Dinus, 1990	Pettersen 1984	Karchesy & Koch	Torget, 1990	Dinus 1990
Cellulose		46.00	42.10	49.50	44.40
Hemicellulose			30.55	23.50	30.60
Lignin	20.00	21.00	24.05	21.80	22.80
Ash			0.25	0.40	
Extractives	1.50		3.50		7.70
NS CHO					
N					
Other					

Table C-46.
Switchgrass Composition Data (weight %, dry basis)

Reference	Wright, 1988	Wright, 1989	Parrish, 19890	Cherney, 1990	Bransby 1990	Bransby 1990
Cellulose	33.00	30.00	38.00	29.20		
Hemicellulose	37.00	35.00	32.90	34.20		
Lignin	4.60	5.90	9.50	6.60	9.40	9.10
Ash	3.50	5.50		1.20	4.10	5.20
Extractives						
NS CHO	5.80	4.30		5.30		
N	0.80	0.50		1.01	0.90	0.90
Other	10.70	15.9		16.70		

Table C-47.
Silver Maple Composition Data (weight %, dry basis)

Reference	Petterson 1988	Walawender 1988	Torget 1991	Agblevor 1991	Dinus 1990
Cellulose	42.00	41.70	45.90		
Hemicellulose		18.00	17.10		20.40
Lignin	21.00	26.40	20.80	20.90	
Ash		0.95	0.40		
Extractives			3.90		3.50
NS CHO					
N					
Other (sugars)			1.90		

Table C-48.
Sorghum Composition Data (weight %, dry basis)

Reference	Cherney			Wright					Cher- ney 1990
	89, 88, 87	88	87	88	88	88	89	89	
Cellulose	26.40	28.20	26.20	30.30	29.00	31.00	25.00	24.00	35.10
Hemicellulose	25.80	26.90	22.20	27.00	31.00	32.00	27.00	25.00	30.3
Lignin	5.00	5.40	4.80	2.70	4.00	5.00	4.90	6.50	7.4
Ash				2.70	3.00	3.50	3.50	3.90	1.5
Extractives									
NS CHO	17.10	19.00	22.50	16.70	16.80	17.20	24.60	24.30	7.40
N	0.49	0.59	0.52	0.40	0.80	0.50	0.70	0.70	1.00
Other				18.1	11.20	8.20	10.70	12.50	10.70

Table C-49.
Red Alder Composition Data (weight %, dry basis)

Reference	Bollen	Pettersen 1984	Dinus 1990
Cellulose		44.00	
Hemicellulose		20.00	22.80
Lignin		24.00	23.90
Ash		0.30	1.60
Extractives		5.00	
NS CHO			
N	0.37		
Other			

Table C-50.
Reed Canary Grass Composition Data (weight %, dry basis)

Reference	Johnson, 1990	Wright, 1991	Agblevor, 1991
Cellulose	23.70	31.80	
Hemicellulose	30.30	31.50	
Lignin	5.20	5.60	
Ash	3.00	5.40	
Extractives			
NS CHO	10.90	8.10	
N	12.00	7.50	10.00
Other (sugars)	14.80	10.10	

Table C-51.
Hybrid Cottonwood Composition Data (weight %, dry basis)

Reference	Olson, 1985	Pettersen 1984	Walender 1988	Dinus 1990
Cellulose	51.10	47.00	44.00	47.00
Hemicellulose			15.70	18.50
Lignin		23.00	29.60	22.80
Ash		0.40	1.81	3.4
Extractives				
NS CHO				
N			0.04	
Other				

Table C-52.
Hybrid Poplar Composition Data (weight %, dry basis)

Reference	Blankenhorn, 1985	Dickson, 1974	Agblevor, 1991	Torget, 1990	Torget, 1990
Cellulose	43.00		40.00	48.60	51.80
Hemicellulose	15.60		22.00	14.60	11.30
Lignin	24.70	21.30	24.00	21.80	22.50
Ash	1.75		1.20	0.7	0.60
Extractives	9.10		3.00	4.50	4.10
NS CHO					
N			0.30		
Other				1.10	1.30

Table C-53.
Black Locust Composition Data (weight %, dry basis)

Reference	ASME, 1987	Walawender, 1988	Agblevor, 1991	Torget, 1991	Fengel and Wegener 1989
Cellulose		45.90	45.00	49.40	50.10
Hemicellulose		17.60	21.00	17.60	23.70
Lignin		24.70	24.70	21.50	20.60
Ash		1.61		0.60	0.30
Extractives				3.80	7.40
NS CHO					
N	0.57				
Other					

Table C-54.
Energy Cane Composition Data (weight %, dry basis)

Reference	Wright, 1991				
Cellulose	48				
Hemicellulose	34				
Lignin	10				
Ash	3				
Extractives	1				
NS CHO	2				
N	2				
Other	0				

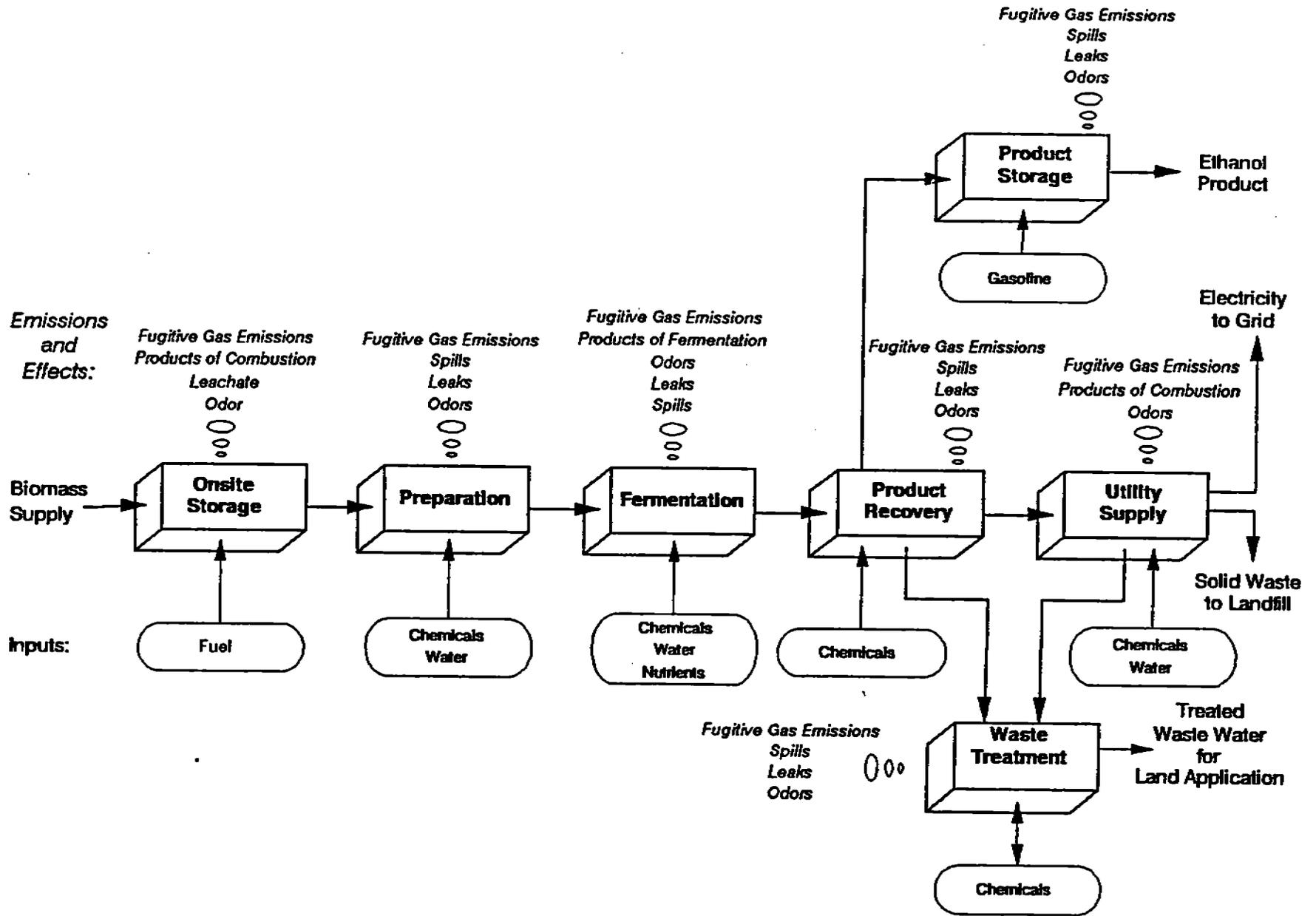


Figure C-1. Biomass Conversion Stage - Operating Phase. Map of inputs and effects.

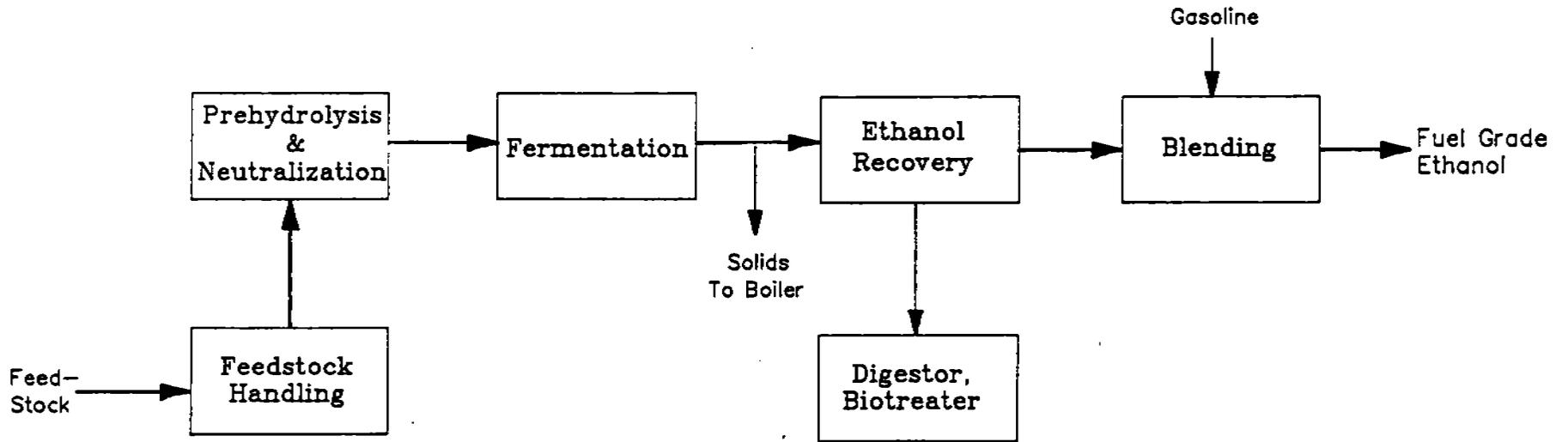


Figure C-2. Block Flow Diagram, Biomass to Ethanol Process.

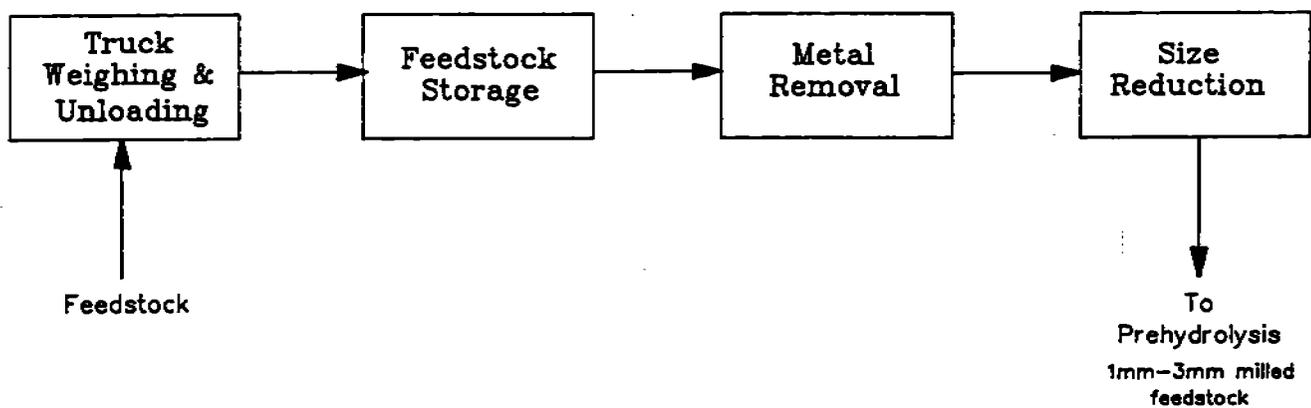


Figure C-3. Block Flow Diagram, Feedstock Handling.

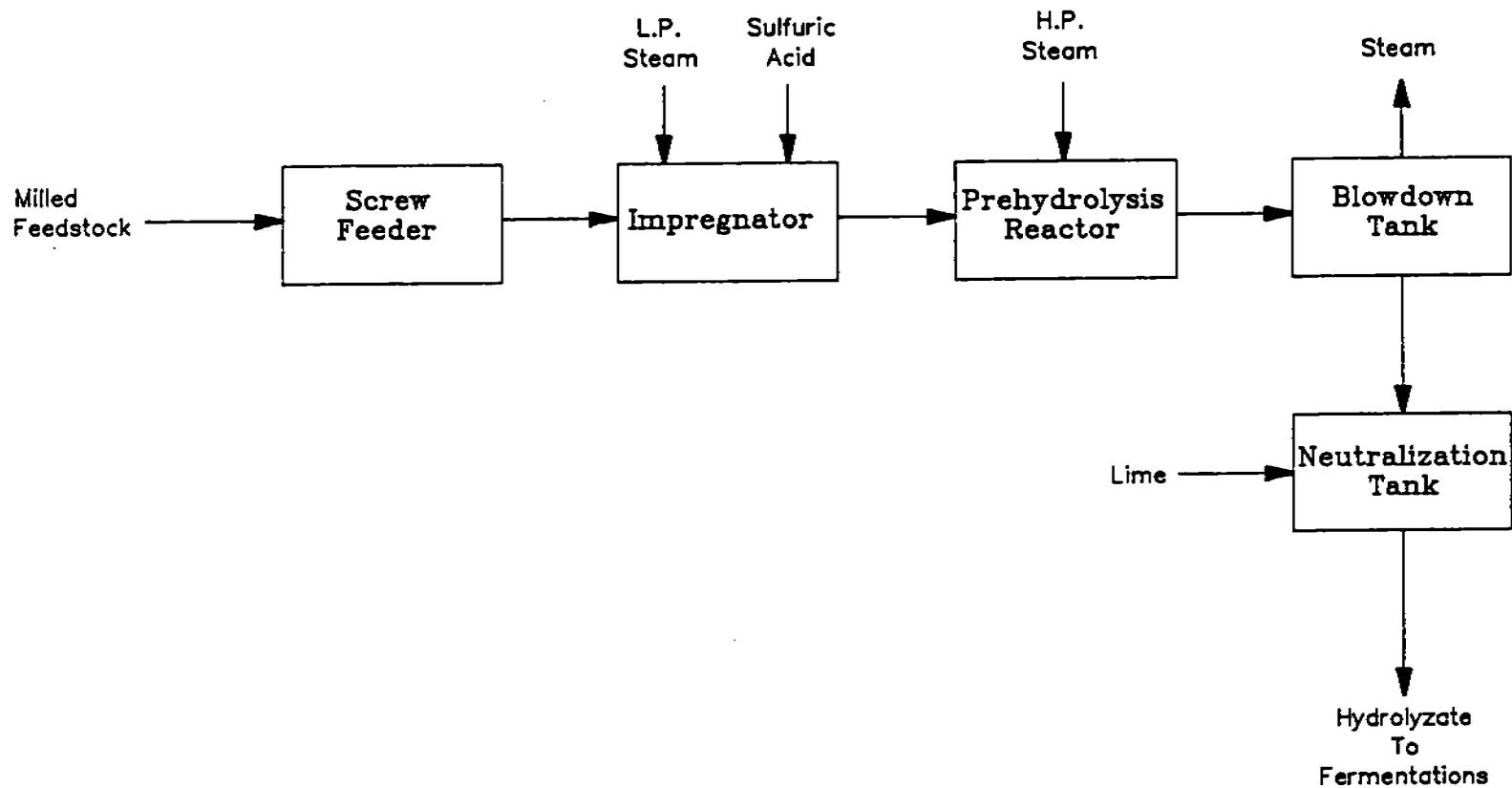


Figure C-4. Block Flow Diagram, Prehydrolysis and Neutralization.

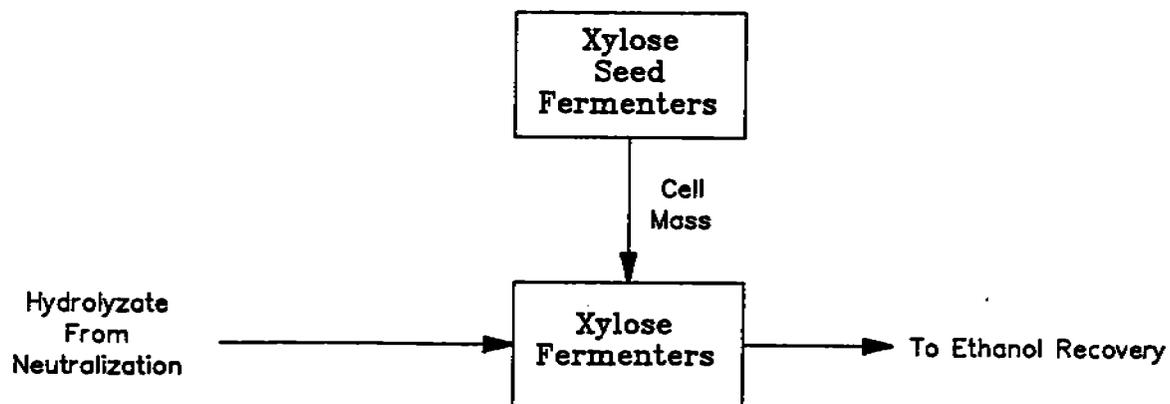


Figure C-5. Block Flow Diagram, Xylose Fermentation.

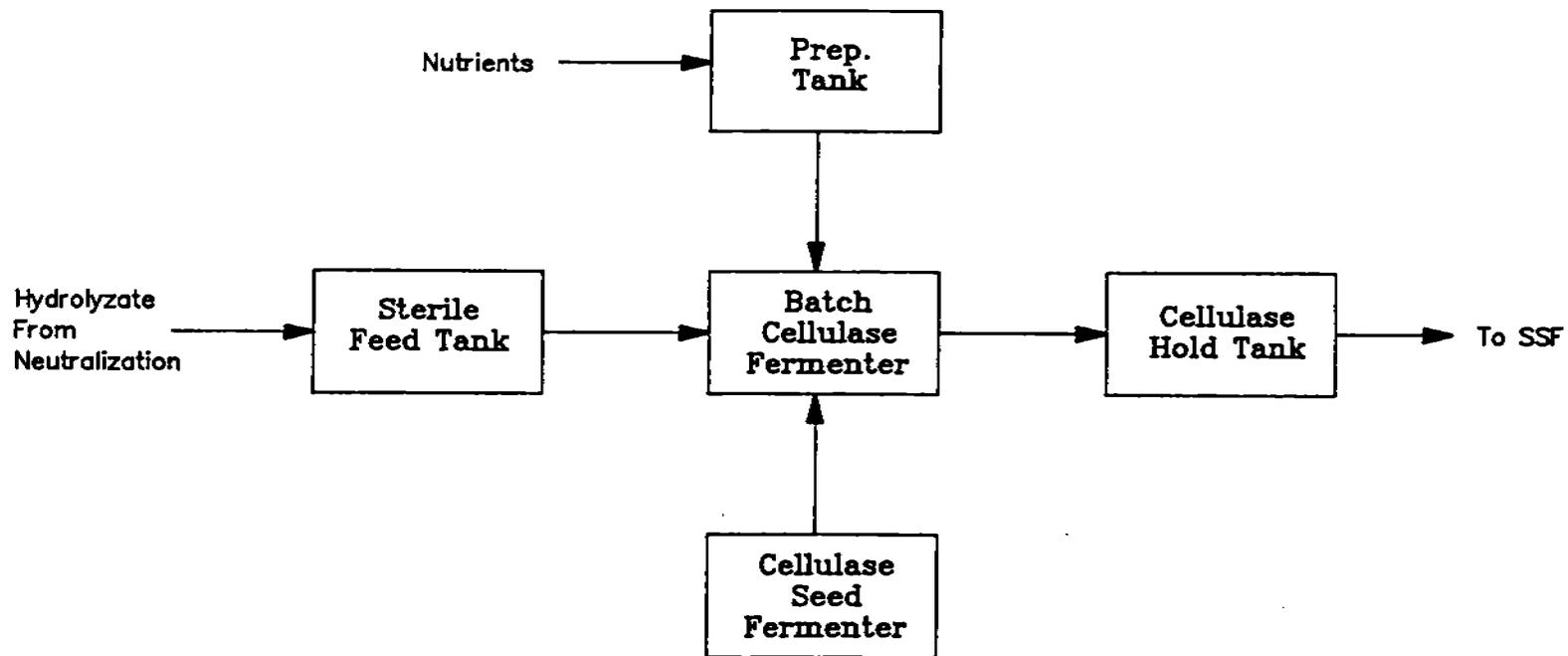


Figure C-6. Block Flow Diagram, Cellulase Production.

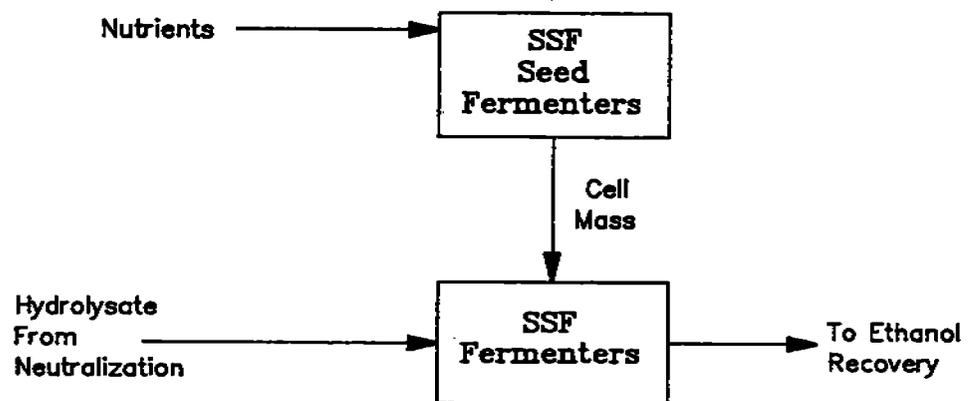


Figure C-7. Block Flow Diagram, Simultaneous Saccharification and Fermentation (SSF).

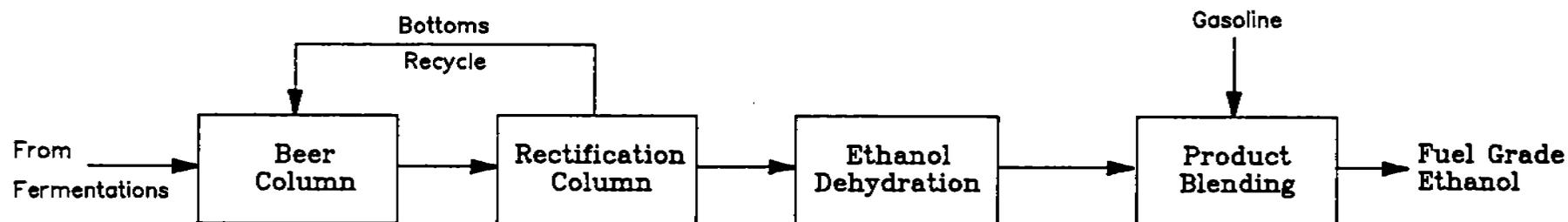


Figure C-8. Block Flow Diagram, Ethanol Recovery and Solids Separation.

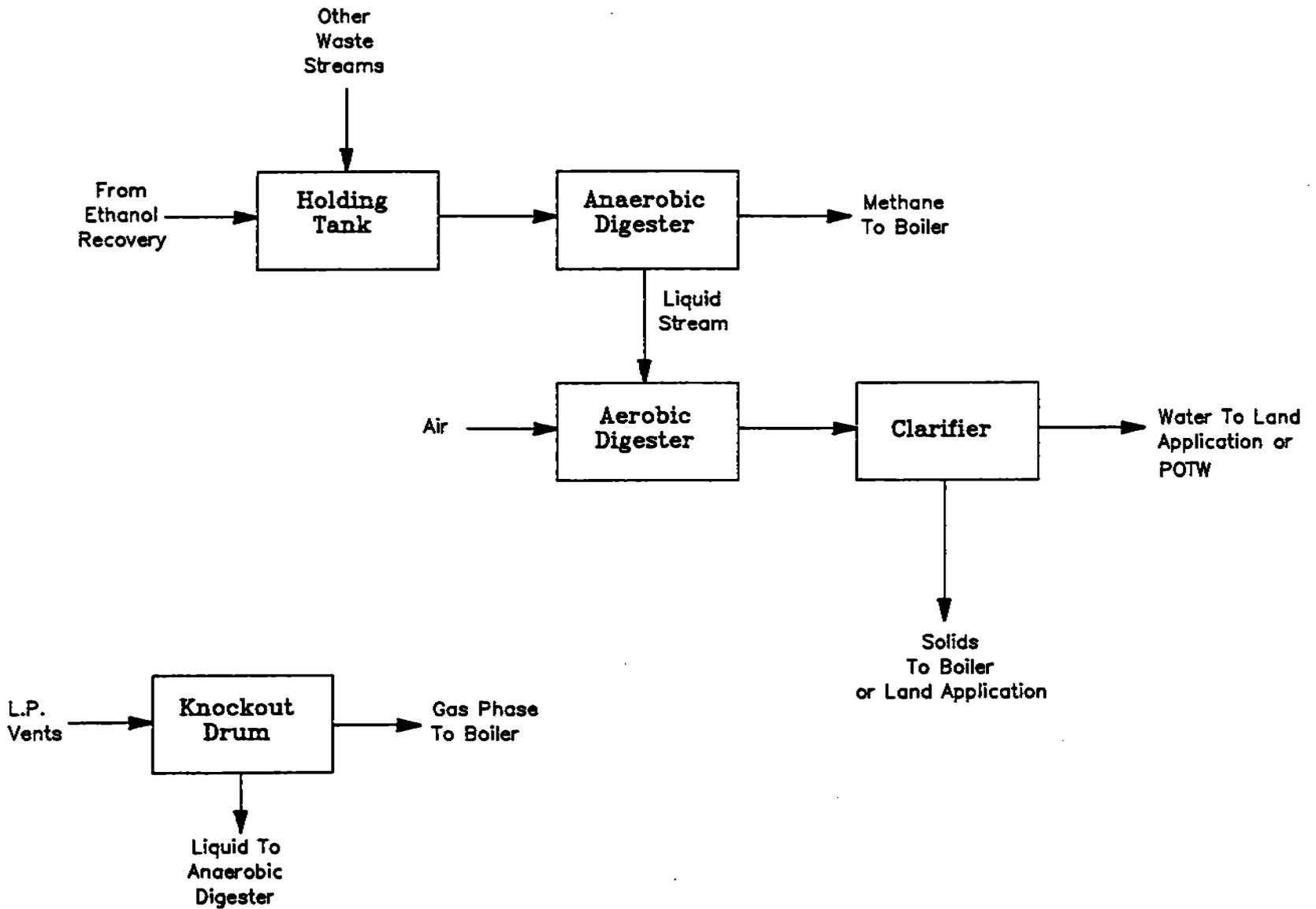
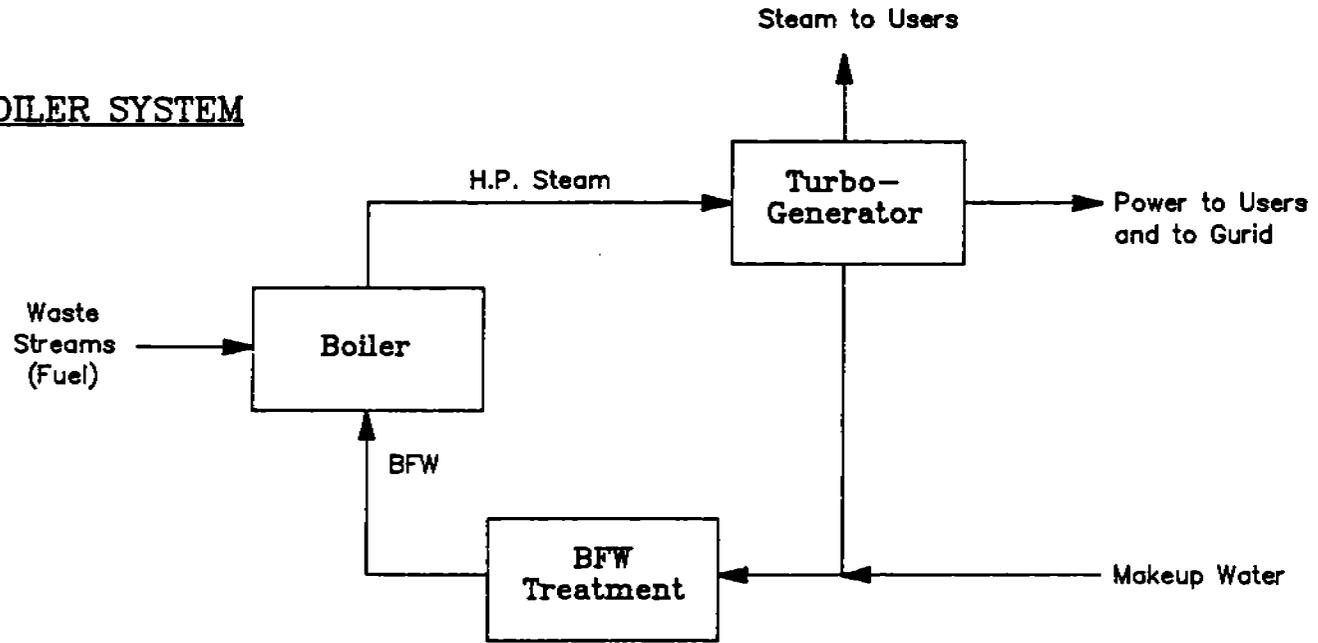


Figure C-9. Block Flow Diagram, Waste Treatment.

BOILER SYSTEM



Other Utility Systems

- Cooling Water
- Chilled Water
- Fermenter Air
- Process Water
- Instrument/Plant Air

Figure C-10. Block Flow Diagram, Utilities.