Full Fuel Cycle Analysis of Biomass to Ethanol: Wastewater Treatment System Performance

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Introduction

Background

The Department of Energy, through the National Renewable Energy Laboratory (NREL) has embarked upon a program to develop technologies for the production of fuel grade ethanol from renewable biomass resources. One of the current projects in the overall program is the Biomass-to-Ethanol Total Energy Cycle Analysis. The objective of this project is to characterize the economic and environmental consequences of some of the transportation fuel alternatives.

The project is evaluating ethanol production from six sources. Five of the sources are assumed to be crops grown specifically for ethanol production. The five crop sources have been selected based on the crops most likely to be grown in different regions of the country. The sixth source of biomass is the cellulytic fraction of municipal solid waste (MSW). It has been assumed for these evaluations that the process to produce ethanol from MSW will be ready by the year 2000, while the production from the other sources will begin in 2010.

An important part of the biomass-to-ethanol conversion process is the wastewater treatment system. The system must treat all wastewater streams from the process so that the effluent is suitable for discharge or reuse in the process. This report summarizes a study that evaluated wastewater treatment systems capable of treating the wastewater from biomass-to-ethanol production facilities. The selected treatment system, along with the sizing and cost of the system, is discussed first. A discussion of the potential inputs/outputs and environmental effects of the treatment system follows.

Objectives

The objectives of the Wastewater Treatment System Performance Study were as follows:

- To define treatment systems potentially applicable for the wastewater from biomass-to-ethanol production facilities
- To provide preliminary sizing of the treatment systems
- To provide preliminary equipment lists and order-of-magnitude cost estimates for the proposed systems
- To estimate the inputs, outputs, and emissions resulting from system operation
- To provide qualitative and quantitative estimates of the environmental emissions and effects resulting from system operation

Wastewater Characteristics and Discharge Criteria

Wastewater Characteristics

Wastewater characteristics for the six waste streams were developed by NREL from mass balances on the ethanol production process. The mass balances were based on major components found in the biomass and ethanol production process. These components were converted to parameters more typically used for wastewater system design, including chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solids (TSS). Appendix A provides the conversions used and the raw data tables. Table 1 summarizes of the major characteristics of the combined waste streams from the production facilities, not including the utility waste streams (cooling tower blowdown and steam system blowdown).

Table 1
Wastewater Characteristic Summary

Case	Location	Flow (gpm)	COD (mg/l)	COD Load (lb/d)	Sulfate (mg/l)	TDS (mg/l)	TSS (mg/l)
1	Great Plains	153	140,000	257,000	602	7,200	470
2	Northeast	154	129,000	237,000	597	3,900	510
3	Southeast	160	119,000	228,000	617	3,300	560
4	Midwest/Lake St.	155	120,000	220,000	600	3,700	500
5	Pac. Northwest	158	72,000	138,000	589	2,300	680
6	MSW-Chicago	157	61,000	117,000	599	3,100	380

The COD concentration of these waste streams is very high; higher than has been reported in the literature for similar process. An attempt has been made in the design of the ethanol production process to minimize the use of water so that waste strengths at these levels may be expected. Much of the COD results from the presence of furfural (as much as 50 percent of the total). Although there may be ways to remove the furfural upstream in the production facility, this study did not consider that possibility. The high sulfate and total dissolved solids (TDS) concentrations in part result from the use of acid hydrolysis and lime for neutralization after hydrolysis. For this study, neutralization was assumed to occur in the production facility so the wastewater will have a pH of near neutral.

There will also be waste streams from "utilities" (for example, cooling tower blowdown and steam system blowdown). The volume of these streams was estimated from the utility sizing provided by NREL. These are rough estimates that assume the same makeup water quality for all six cases. The actual flows will depend on the inorganic quality of the water used as makeup. Table 2 summarizes the flows and the assumed TDS concentrations of the combined utility waste streams.

Table 2 Summary of Utility Waste Streams		
Case	Flow (gpm)	TDS (mg/l)
1	242	4,000
2	269	4,000
3	269	4,000
4	276	4,000
5	364	4,000
6	253	4,000

Discharge Criteria

Discharge locations had to be assumed because sites for the ethanol production facilities have not yet been defined. For Case 6 (MSW-year 2000), the effluent was assumed to be discharged to a publicly owned treatment works (POTW) since the facility is likely to be near an urban area. POTWs often require that industrial wastewaters be treated to levels similar to municipal wastewater. Consequently, the following discharge criteria were selected:

- BOD: 300 mg/l
- TSS: 300 mg/l

A COD of 600 mg/l was used to size the treatment systems. This level of total organics may not be achievable, depending on the concentration of non-biodegradable organics in the wastewater and produced during treatment.

The ethanol production facilities for Cases 1 through 5 are likely to be near the land used to grow the biomass crops, and thus away from urban areas. Consequently, no POTW is likely to be close enough to accept the effluent. Land application of the effluent, along with the sludge, to the land used to grow the crops was selected as the disposal method. There are no set criteria for such disposal. In general, the effluent and the sludge should be biologically stable enough not to cause odors when they are applied. Achieving the same criteria as above for discharge to a POTW should produce a stable effluent.

Wastewater System Description

System Selection

Processes used for wastewater treatment are generally a function of the strength of the wastes. The strength of these wastewaters is in a range higher than that typically used for anaerobic biological treatment but lower than that for direct incineration in a boiler. Some type of concentration (for example, evaporation or ultrafiltration) would have to be used before incineration to reduce the amount of water sent to the boiler. The evaporation or ultrafiltration processes are both relatively costly and have other associated concerns. For example, extensive off-gas treatment would probably be required for the evaporation process. Ultrafiltration, a concentrating process using membranes, has been plagued by technical problems. It also produces a sidestream water that requires further treatment. However, during a more detailed analysis of wastewater treatment options, these alternatives should be considered further.

Although these waste strengths are higher than typical, they should be treatable using staged anaerobic/aerobic biological processes. As will be discussed below, although a large number of tanks will be required to achieve the treatment, the total cost should be similar or less than the concentration/incineration processes discussed above. Studies into the treatment of similar wastes have not found major problems with inhibition from the wastes. Recycling effluent may be required for most of the cases to dilute the waste to ensure that it is not inhibitory to the microbial activity. Mixing the utility waste streams with the process waste streams could also be used for dilution. Dilution with the utility streams will not significantly impact the sizing of the system or system emissions, so it was not considered this analysis.

Process Description for Case 6

Figure 1 shows the processes selected for treatment of the wastewaters from Case 6 (MSW in the year 2000). The wastewater will be screened using a bar screen (1/2 inch spacing) as it leaves the ethanol production facility to remove any large solids that could cause mechanical problems. The wastewater will then flow to a flow-and-concentration equalization tank. Although the production process is likely to be relatively consistent, some variations will occur that will require organic concentration equalization. A 24-hour retention time was selected as a conservative estimate. Filtrate from sludge dewatering will be returned to the process at the equalization tank. The tank will be mixed using a mixer (side entry or submersible) to maintain a uniform wastewater concentration and temperature.

The equalized wastewater will be pumped through a heat exchanger to cool the wastewater to 55°C (the temperature required for thermophilic microbial activity) and into the anaerobic reactors. The heat exchanger will be a shell and tube type with the process water in the tube side. The heat exchanger cooling water blowdown could be used in the process plant, sent to the POTW for Case 6, or sent to land application for Cases 1 through 5.

Thermophilic anaerobic treatment is not commonly used because of the cost of heating the wastewater up to the thermophilic range. Because heating is not required here (the wastewater is already hot) and because thermophilic anaerobic treatment should result in higher reaction rates and thus, potentially smaller anaerobic reactors, thermophilic anaerobic treatment was selected. Completely mixed

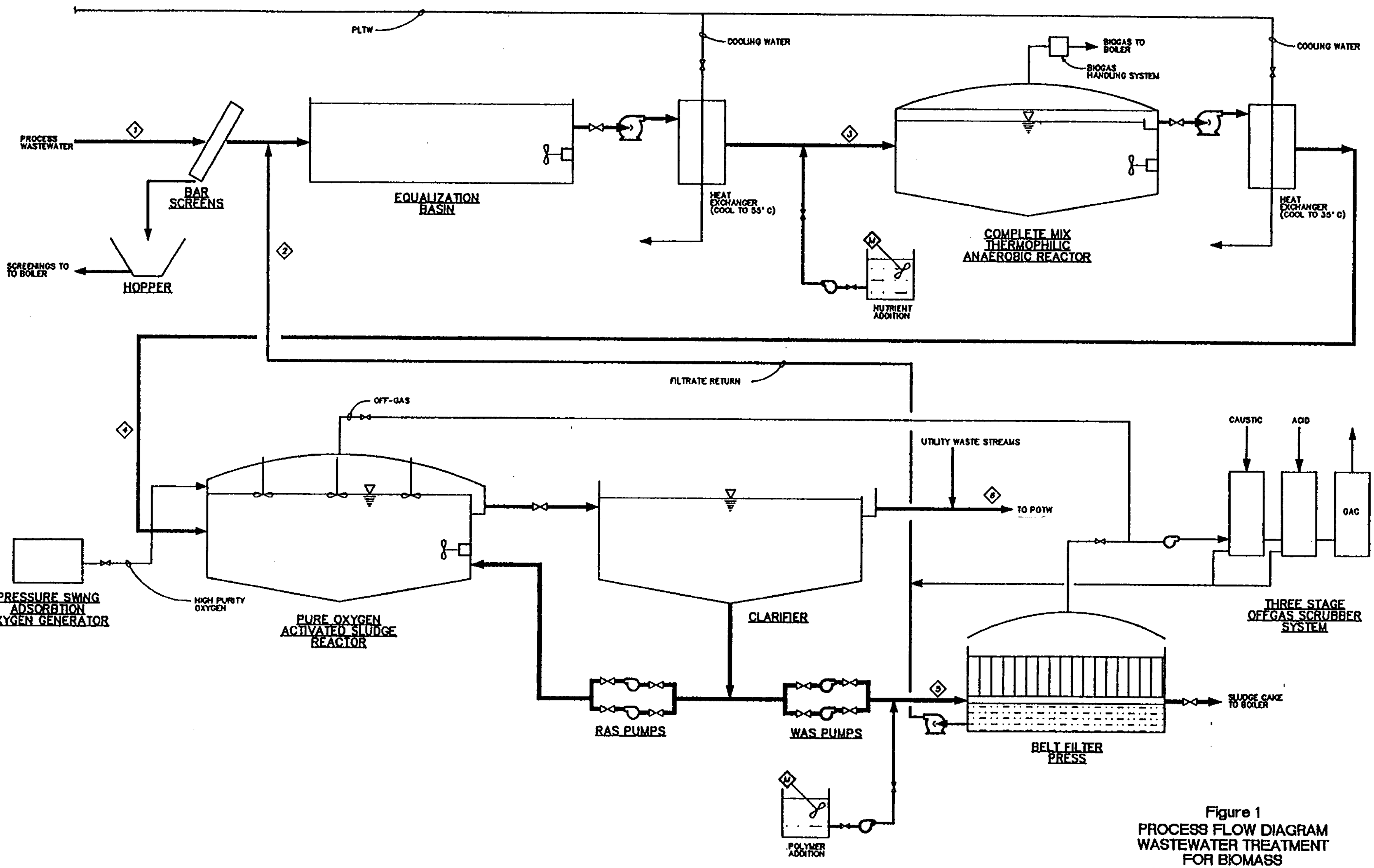

Figure 1
PROCESS FLOW DIAGRAM
WASTEWATER TREATMENT
FOR BIOMASS
TO ETHANOL FACILITY
CASE 6

anaerobic reactors will be used. The concentration of sludge in such reactors is the same as that in the effluent (that is, it is not concentrated in any way). Because of the high wastewater strength, enough anaerobic organisms should grow each day to maintain a relatively high sludge concentration. Consequently, it is not necessary to have mechanisms or devices to concentrate the sludge in the reactor such as is done in fixed film reactor, upflow sludge blanket reactors, or solids contact reactors. The cost per gallon of capacity of completely mixed reactors is significantly less than that of other reactors with concentrating mechanisms. The anaerobic reactors will be mixed with mechanical mixers (side entry or submersible).

A nutrient solution will be pumped into the piping that feeds the anaerobic reactor. The composition of the nutrient solution will depend on what is locally available at the lowest cost. For example, urea and triple super phosphates are typically inexpensive forms of nitrogen and phosphorus.

Biogas from the anaerobic reactor will be fed to the boiler after it passes through a biogas system. The mass of sulfur in the gas should be relatively low compared to that in the other fuels feeding the boiler. Consequently, treatment of the gas to remove sulfur was assumed to not be necessary. The biogas system will include gas compressors, a sediment trap, a control system, and an emergency flare.

Effluent from the anaerobic reactor will be further cooled to between 30° and 35°C in a second shell and tube-type heat exchanger before it goes to the aerobic reactor. Although aerobic thermophilic processes can be used, they typically produce sludge with poor settling properties, which makes the operation of an activated sludge process difficult, or impossible. Consequently, a mesophilic activated sludge system was selected as the process of choice. Aerated lagoons can also be used if large amounts of land are available. The high strength of the wastewater, even after anaerobic treatment, makes the use of fixed-film systems impractical because the media could easily plug with biological growth.

With a desire to minimize emissions to the atmosphere, a pure oxygen activated sludge system was selected. A pure oxygen system will decrease both the quantity of gas requiring treatment and the mass of volatile compounds that are stripped. With the high strength waste, the cost of a pure oxygen system should be nearly identical to that of an air system, also making it economically feasible. For the mass of oxygen required, a pressure swing adsorption (PSA) system is the most economical. Surface mechanical aerators will provide mixing and oxygen transfer in the reactor. The activated sludge reactors will be compartmentalized—with the gas flowing through the reactor concurrently with the wastewater flow to maximize oxygen transfer to the water.

Effluent from the activated sludge reactors will flow by gravity to clarifiers, in which the sludge will be concentrated and separated from the clear liquid. Much of the sludge will be recycled back to the reactor (return activated sludge [RAS]) to increase the sludge concentration in the reactor. The excess sludge that is produced in both the anaerobic and the aerobic reactors will be wasted (waste activated sludge [WAS]) from the underflow of the clarifier. The utility waste streams will be mixed with the treated effluent, and both will be pumped to a POTW for final treatment before discharge to a receiving stream. The utility waste streams should not require treatment, because they are only likely to contain dissolved solids that should not impact the POTW.

The WAS will be dewatered using a belt filter press. Polymer will be added to the sludge to aid the dewatering process. Sludge cake will be sent to the boilers to be burned. The belt press will be operated for 12 hours per day.

Off gas from the activated sludge reactor and from a hood over the belt filter press will be sent to a scrubber system to remove odors and volatile compounds. The scrubber system will include an acid mist scrubber to remove ammonia and other caustic compounds, a caustic mist scrubber to remove hydrogen sulfide and other acidic compounds, and a activated carbon column to remove any organics that should get through the mist scrubbers. This is a conservative system that may not be necessary in its entirety. A less costly system may be suitable if air emissions are low and if they are not a regulatory or health concern.

Process Description for Cases 1 to 5

Although the waste strengths of the five cases vary somewhat, one common process was developed for use in all cases. The size of the systems will differ for most of the cases.

The process train selected for Cases 1 through 5 is similar to that for Case 6. Figure 2 presents a process flow diagram for the Case 1-5 system. The following are the differences between the two systems:

- Effluent from the activated sludge clarifier will be recycled to the equalization tank to dilute the waste water. Recycle rates were selected to produce COD concentrations of about 60,000 mg/l (similar to that of Case 6).

- Both the sludge and the effluent will be land applied. POTWs will not likely be near the ethanol production facilities to accept the effluent so 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 that the biomass crops are grown on is also suggested. The organic matter and nutrients in the sludge will serve as soil enhancers.

  The nitrogen uptake of the biomass crops controls the amount of land required for land application. No more nitrogen can be added to the land than is taken up by the crops. A high of 9,200 acres to a low of 5,000 acres is estimated to be needed to balance the nitrogen uptake of the crops to that applied in sludge.

  The high TDS content of the wastewater and the utility stream will require that the effluent be diluted (or blended) with low TDS water as it is applied or soon after it is applied. The high TDS of the effluents could injure the crops if it is not diluted. The ratio of blend water to wastewater is quite high; as high as 6:1. This translates to 5 to 8 inches per year of total water be applied to the crop land used for land application. During rainy periods, rain water could provide the required dilution. Cooling water from the heat exchangers could also be used for dilution. If this much water is not available, would not be otherwise applied for irrigation, or does not fall as rain, land application may not be viable.

  The salts in the water will also have to be leached from the soil to avoid salt buildup. This will require the addition of low TDS irrigation water (or rain) and that the soils be well drained. If they do not drain, a drainage system may be required.

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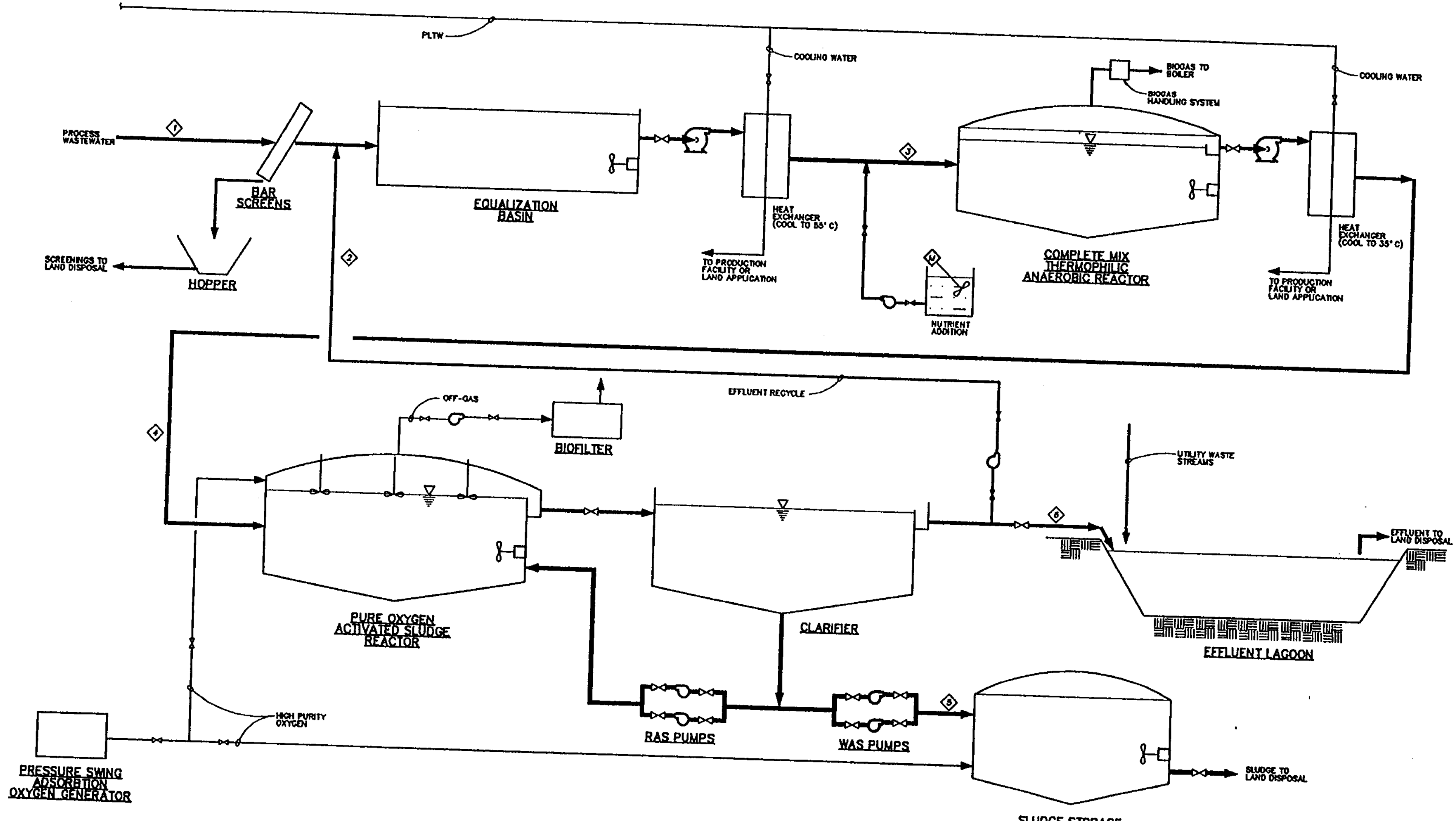

Figure 2
PROCESS FLOW DIAGRAM
WASTEWATER TREATMENT
FOR BIOMASS
TO ETHANOL FACILITY
CASES 1-5

In many parts of the country, there will be at least 3 months out of each year that effluent and sludge cannot be land applied because of frozen ground or excess rainfall. Consequently, a storage lagoon from 18 to 22 acres in area will be provided to store the effluent and sludge.

The suitability of land application depends on the rainfall patterns of the site location, the soil type, and the background water quality. Consequently, the applicability will have to be more closely studied once sites are selected.

- The off gas from the activated sludge reactor will be passed through a biofilter rather than scrubbers. Biofilters are piles of composted manure and/or other organic material that can adsorb the volatile compounds, which allows microorganisms the time to degrade the volatile compounds. After the useful life of the biofilter material, it can be applied to crop land as a soil enhancer. Although only currently used in a few installations for odor control, biofilters also show promise for removing many volatile organic compounds.

Wastewater System Sizing

Appendix B contains a design summary for the systems selected for each alternative. Sizing criteria are also provided. In general, conservative design assumptions and simplified design procedures were used for this sizing. More detailed design procedures should be used once the nature of the wastewater and the site constraints are better defined. The procedures used should not impact the definition of the system emissions, although they may result in cost estimates that are somewhat higher than actual costs will be.

Wastewater System Cost Estimate

Capital cost estimates were prepared for each case by obtaining budget prices for major pieces of equipment from equipment vendors or from estimates of similar projects. A factor was added to the cost of each piece of equipment to account for installation. Other factors were added to account for general requirements, instrumentation, and mechanical and electrical items. Estimates for buildings were based on the square footage of the facility and on the type of facility. The cost of sitework was based on the overall area of the site for each case. A contingency of 30 percent was added to the bottom line of each estimate, which is typical for an "order of magnitude" estimate.

These cost estimates can be considered "order-of-magnitude" estimates based on definitions of the American Association of Cost Engineers. The accuracy of the estimates is plus 50 percent, minus 30 percent. These cost estimates have been prepared for guidance in project evaluation from the information available at the time the estimates were prepared. The final cost of the project will depend on the final project scope, actual labor and material costs, competitive market conditions, the implementation schedule, and other variable factors as they occur. As a result, the final project cost will vary from the estimates presented herein.

The cost estimates presented here are based on 1991 dollars and construction of the facilities in the Denver area. Estimates of costs in other locations can be prepared by adjusting these costs by using the *Engineering News-Record* Construction Cost Index (ENR CCI) for each city.

Operations and maintenance (O&M) costs were prepared covering major items including labor, utilities, chemicals, and maintenance. The NREL provided the unit costs for many of the items.

Table 3 provides a summary of the capital and O&M cost estimates; details of the cost estimates can be found in Appendix D. Also included in Appendix D is a list of assumptions used to prepare the cost estimates.

Table 3
Summary of Cost Estimates

Case	Total Capital Costs ($)	Total O&M Costs ($/year)
1	22,800,000	3,120,000
2	22,000,000	2,980,000
3	19,910,000	2,780,000
4	19,910,000	2,760,000
5	14,700,000	2,010,000
6	11,400,000	1,970,000

Mass Balance of Inputs and Outputs

Major inputs and outputs/emissions of the wastewater treatments systems for all cases, along with approximate estimates of the mass of each, are provided in Table 4. A detailed mass balance of the wastewater system for COD and TSS is provided in Appendix C . Minor outputs/emissions are discussed in the following section.

The resin in the PSA oxygen generation unit will require replacement after a number of years. The mass of the resin was considered too small to take into account here. Likewise, the activated carbon in the off-gas scrubber of Case 1 will have to be replaced at some time. The life of the carbon will likely be long since the two-stage mist scrubber located upstream of the carbon will remove much of the hydrogen sulfide and organics in the off gas.

Table 4
Summary of Inputs and Outputs

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Inputs						
Process Wastewater (Mill lb/d)	2.00	2.00	2.06	2.00	1.99	1.96
Utility Waste Water (Mill lb/d)	2.91	3.23	3.23	3.31	4.37	3.04
Blend Water for Land Application (Mill lb/d)	30.5	23.8	22.0	23.3	5.13	–
Urea (lb/d)	8,400	7,800	7,450	7,300	4,400	3,700
Triple Super Phosphate (lb/d)	3,300	3,000	2,900	2,800	1,700	1,500
Cooling Water (Mill lb/d)	7.6	7.6	7.6	7.6	5.7	5.7
Manure (lb/d)	83.8	77.8	74.5	72.8	44.3	–
Acid for Off–gas Scrubber (lb/d)	–	–	–	–	–	12
Caustic for Off–gas Scrubber (lb/d)	–	–	–	–	–	12
Polymer (lb/d)	–	–	–	–	–	31.8
Outputs/Emissions						
Combined Effluent to POTW (Mill lbs/d)	–	–	–	–	–	5.0
Combined Effluent to Land Application (Mill lb/d)	4.91	5.23	5.29	5.31	6.36	–
Blend or Cooling Water to Land Application (Mill lb/d)	30.5	23.8	22.0	23.3	5.13	–
Sludge to Boiler (dry lb/d)	—	–	–	–	–	6,360
Sludge to Land Application (dry lb/d)	14,200	13,200	12,700	12,400	7,580	–
Screenings to Boiler (lb/d)	small quantities	small quantities	small quantities	small quantities	small quantities	small quantities
Heat Exchanger Blowdown (Mill lb/d)	7.6	7.6	7.6	7.6	5.7	5.7
Methane to Boiler (lb/d)	62,000	57,500	55,100	53,800	32,900	27,700
Carbon Dioxide to Boiler (lb/d)	41,300	38,300	36,700	35,900	21,900	18,500
Hydrogen Sulfide to Boiler (lb/d)	277	276	296	279	279	282
Carbon Dioxide from Activated Sludge (lb/d)	47,500	44,100	42,200	41,200	25,200	21,300
"Spent" Biofilter Material (lb/d)	83.8	77.8	74.5	72.8	44.3	–

Environmental Emissions and Effects

Table 5 summarizes the environmental emissions and concerns directly from the biomass to ethanol wastewater treatment system. This table follows the format of Figure 1 of the Statement of Work. Emissions indirectly from the wastewater system, such as from the burning of the biogas in the boiler, are not discussed here. More detailed discussion of the emissions and concerns follows.

Air Releases

Emissions to the air of criteria pollutants and toxics should be minimal or non-exist from this wastewater system. The biogas from the anaerobic system will contain some pollutants that will be destroyed in the boiler when the biogas is burned. Although the boiler may emit criteria pollutants (for example, sulfur dioxide) from biogas combustion, emissions from the boiler are outside the scope of this study.

Volatilization of organics formed in the anaerobic reactor (for example, acetic acid) could potentially occur in the aerobic reactor. However, most of these compounds are biodegradable under aerobic conditions, so that they will be degraded before they can be volatilized. Reducing the gas flow in the reactor by using pure oxygen will favor degradation overstripping. Any compounds that are stripped will be removed from the gas stream in either the off-gas scrubbers or in the biofilter.

Carbon dioxide will be emitted from the wastewater system. Table 4 provides estimates of the emissions rates.

Air toxics are not expected to be emitted from the wastewater system because they are not present in the wastewater, and they will not be formed in the treatment process. The one possible exception to this is Case 6, with MSW as the biomass feed stock. MSW may contain volatile organics from household hazardous wastes. If these volatiles are not removed in the ethanol production facilities, they may make it into the wastewater stream and be stripped in the anaerobic or aerobic reactors. However, much of what is stripped from the reactors will be removed from the gas stream or destroyed in the gaseous treatment process (the boiler, off-gas scrubbers, or the biofilter). Consequently, even if volatile organic compounds reach the wastewater treatment system, few will be emitted to the atmosphere.

The gas from the aerobic activated sludge system is likely to be at water temperature (35°C) so it can be elevated relative to ambient temperatures. Some heat will also be emitted from the tanks.

Water Releases

For Case 6, effluent will be indirectly released to a surface water. The release will be indirect, because the effluent will be sent to a POTW for further treatment. The effluent from the POTW will discharge water with a probable suspended solids content of 30 mg/l or less. Consequently, the suspended solids contributed by the ethanol production wastewater would be at most 57 lb/d. 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

Table 5
Summary of Environmental Emissions and Concerns from the Wastewater Treatment System

Parameter	Quantitative	Qualitative
Air Releases		
Sulfur Dioxide	None directly	
Nitrogen Oxide	None directly	
Carbon Monoxide	None directly	
PM-10	None directly	
Lead	None directly	
VOC-total	Minimal or none	
VOC-breakdown	Minimal or none	
Carbon Dioxide	see Table 4	
CH_4	None (sent to boiler)	
Acetaldehyde	None expected	
Formaldehyde	None expected	
Other Toxics		None expected
Radionuclides		None
Thermal		See text
Water Releases		
Suspended Solids	Case 6 only: 57 lb/d at POTW discharge	
Oil and Grease		Little or none
Priority Pollutants		Little or none
Thermal	430 Mill Btu/day	
Land Concerns		
Land Area	Cases 1-4—28 acres Case 5—38 acres Case 6—8 acres	
Erosion	Minimal additional	
Other Concerns		
Health/Safety		No additional concern
Noise		No additional concern
Odors		No additional concern
Catastrophic Events		No additional concern
Aesthetics		See text

amount of color that should not be a 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 increased temperature may or may not raise the temperature of the POTW effluent. The heat value listed in Table 4 assumes that the wastewater will be discharged at a temperature of 30°C and that no cooling occurs in the POTW.

For Cases 1-5, there will be no direct discharge to a surface water because the effluent will be land applied. With proper design and operation, there should be minimal runoff of the effluent to surface waters.

Land Concerns

The wastewater treatment system will require approximately 8 to 12 acres of land to contain all of the tanks needed. An approximate footprint for the wastewater systems was developed by assuming 2-million-gallon tanks, 20 feet deep (see Table 5). The values listed for cases 1 through 5 include land for an effluent storage lagoon.

Some erosion is likely to occur during the construction of the wastewater treatment systems. With good construction practices, erosion should be minimal or typical of an construction project. Once this facility is completed, there will be little or no erosion if land is properly landscaped.

Some erosion may occur from the land application of the effluent and sludge for Cases 1-5. With a proper design and good management practices, minimal erosion should take place.

As discussed above, the land application of the effluent and sludge will add TDS and nitrogen to the soil. The TDS content of the applied water will have to be diluted as it is applied (or soon thereafter) to avoid salt toxicity to the plants. Low TDS water will also have to be applied or come from rain fall to avoid TDS build up. The TDS may be leached into the groundwater where 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 into the groundwater if the application rates are not controlled to match the uptake by the crops.

Other Concerns

The wastewater treatment system should impose minimal additional health and safety concerns over that of the ethanol production facility. Standard health and safety design consideration and operational practices will have to be followed for the wastewater system. Prime areas of concern include the biogas handling system, the pure oxygen system, and any confined spaces.

Some noise could be released from the wastewater treatment system. Most of the noise will come from blowers and pumps. Methods are available to effectively control the noise if it is a concern at the location of the production facilities. Thus, it can be assumed that methods will be employed so that no additional noise will be released from the wastewater treatment facilities.

With proper design and operations, odors should not be released from the wastewater system. The design discussed above includes the use of off-gas treatment methods that will effectively control odors from the wastewater system.

The wastewater system should not increase the risk of a catastrophic event. No facility or activity in the system can cause a catastrophic event. Although health and safety concerns exist, they do not have the capability of causing a catastrophic event.

The wastewater system will impact the aesthetics of the area of the facilities, because the system will change the native land use. The aesthetic impacts will vary, depending on the amount of money that is spent to minimize the impacts. For the capital cost included here, conventional efforts were assumed for improving the aesthetics of the site. Thus, even though the site will visually look like a wastewater treatment facility, through landscaping and appropriate architectural design of buildings, it will look acceptable to the average person.