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Anaerobic Fermentation of Glycerol to Ethanol

Chloe LeGendre
University of Pennsylvania

Eric Logan
University of Pennsylvania

Jordan Mendel
University of Pennsylvania

Tamara Seedial
University of Pennsylvania

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Anaerobic Fermentation of Glycerol to Ethanol

Abstract

The purpose of this design project is to examine the plant-scale economic viability of the anaerobic fermentation of crude glycerol to ethanol by a hypothetical wild strain of *Escherichia coli.* The manufactured ethanol, before being denatured with gasoline, has a purity requirement of 99.5% by weight. The capacity of the ethanol plant, as suggested by the problem statement, is 50 MM gallons per year. The process uses crude glycerol (a waste byproduct from the biodiesel industry) as a primary feedstock, so the manufactured ethanol can be considered a "green" or renewable fuel source. The process energy requirements must meet the current energy benchmark of 35,000 BTU/gallon of ethanol, typical for a modern corn-to-ethanol process of this scale according to the design problem statement. This goal is more than met, with an energy usage of 8,000 BTU/gallon of ethanol.

The process design consists of three main sections: upstream preparation of the glycerol feed for the E. coli, anaerobic fermentation of this glycerol feed to ethanol and succinic acid (a valuable specialty chemical and a side-product of fermentation), and downstream separation to recover the ethanol and succinic acid.

When performing the economic analysis, the plant was assumed to be a grass roots plant located in the Gulf Coast region of the United States. The total capital investment is $108 million, including a working capital of $23.6 million. In the base case scenario, with crude glycerol priced at $0.05/lb, ethanol priced at $2.50/gallon, gasoline priced at $3.15/gallon, and succinic acid priced at $2.00/lb, the net present value (NPV) of the project is $95 MM based on an interest rate of 15%, and the investor's rate of return (IRR) is 32.24%. The process profitability improves with increasing crude oil prices and decreasing crude glycerol prices, which we believe are highly likely scenarios based on our market research.

Disciplines

Chemical Engineering

Anaerobic Fermentation of Glycerol to Ethanol

Senior Design Project

Chloe LeGendre

Eric Logan

Jordan Mendel

Tamara Seedial

Submitted to:

Professor Leonard Fabiano

Professor Warren Seider

April 6, 2009

Chemical and Biomolecular Engineering CBE 459

Chemical and Biomolecular Engineering Department

University of Pennsylvania

Professor Leonard Fabiano
Professor Warren Seider
Chemical and Biomolecular Engineering Department
University of Pennsylvania
Philadelphia, PA 19104

April 6, 2009

Dear Professor Fabiano and Professor Seider,

Contained within this report is the design of a process to convert crude glycerol to ethanol for fuel consumption via the anaerobic fermentation of the feedstock by a wild strain of the microorganism *Escherichia coli.* As suggested by industrial consultant Mr. Bruce Vrana (DuPont), we have designed a plant to produce 50 MM gallons of denatured fuel ethanol annually using a combination of batch fermentation and continuous processing.

The plant design that we suggest is comprised of a continuous feed preparation section, a batch fermentation section, and a subsequent continuous separation section for the recovery of ethanol and succinic acid (a valuable fermentation side-product). In the feed preparation section, crude glycerol, a byproduct from the biodiesel industry, is treated to remove salts and other impurities and then mixed with a nutrient supplement, diluted, and sterilized. In the batch fermentation section, this sterile glycerol feed is anaerobically metabolized by the *E. coli*, resulting in the formation of ethanol and succinic acid. The broth and vapor from the fermentation section are then sent to the separation section of the plant for product recovery.

Although the design uses a hypothetical strain of *Escherichia coli as* per the problem statement, researchers Dharmadi, Murarka, and Gonzalez of Rice University present a case for the same fermentation process in existing *Escherichia coli*. As such, the design presented here is physically feasible. The design has a good economic outlook, assuming that crude oil prices continue to rise and that political support for renewable fuels continues. The process is projected to have an approximate investor's rate of return (IRR) of 32.24% on a total capital investment of about $108 MM. The net present value was estimated to be $95 MM based on an interest rate of 15%. Additionally, the energy consumption of the process was determined to be 8,000 BTU/gallon of ethanol, well below the 35,000 BTU/gallon energy benchmark provided in the problem statement.

If you have any questions, comments, or concerns regarding the report, please do not hesitate to contact us. We want to thank you very much for your support throughout the duration of the project and your present consideration.

Sincerely,

Chloe LeGendre Eric Logan Jordan Mendel Tamara Seedial

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Abstract

Section I

Abstract

The purpose of this design project is to examine the plant-scale economic viability of the anaerobic fermentation of crude glycerol to ethanol by a hypothetical wild strain of *Escherichia coli.* The manufactured ethanol, before being denatured with gasoline, has a purity requirement of 99.5% by weight. The capacity of the ethanol plant, as suggested by the problem statement, is 50 MM gallons per year. The process uses crude glycerol (a waste byproduct from the biodiesel industry) as a primary feedstock, so the manufactured ethanol can be considered a “green” or renewable fuel source. The process energy requirements must meet the current energy benchmark of 35,000 BTU/gallon of ethanol, typical for a modern corn-to-ethanol process of this scale according to the design problem statement. This goal is more than met, with an energy usage of 8,000 BTU/gallon of ethanol.

The process design consists of three main sections: upstream preparation of the glycerol feed for the *E. coli*, anaerobic fermentation of this glycerol feed to ethanol and succinic acid (a valuable specialty chemical and a side-product of fermentation), and downstream separation to recover the ethanol and succinic acid.

When performing the economic analysis, the plant was assumed to be a grass roots plant located in the Gulf Coast region of the United States. The total capital investment is $108 million, including a working capital of $23.6 million. In the base case scenario, with crude glycerol priced at $0.05/lb, ethanol priced at $2.50/gallon, gasoline priced at $3.15/gallon, and succinic acid priced at $2.00/lb, the net present value (NPV) of the project is $95 MM based on an interest rate of 15%, and the investor’s rate of return (IRR) is 32.24%. The process profitability improves with increasing crude oil prices and decreasing crude glycerol prices, which we believe are highly likely scenarios based on our market research.

Introduction

Section II

A. Process Overview

The process design for anaerobically fermenting crude glycerol to ethanol is presented in this report. The plant proposed is divided into three main sections: the upstream preparation of the crude glycerol fermentation feedstock, the fermentation of the glycerol to ethanol and succinic acid, and the downstream separation of products using distillation, molecular sieves, and other separation units.

The feed preparation stage purifies, dilutes, and sterilizes the incoming crude glycerol feedstock from biodiesel manufacturing to a glycerol feed appropriate for the microorganisms. The fermentation section is divided into three stages: the laboratory stage (for seed fermentation volumes of under 10 L, as specified in the problem statement), the plant-scale seed fermentation stage, and the main (large-scale, primary) fermentation stage. The seed fermentation in total consists of two seed trains of seven (7) seed fermenters each, which provide biomass volume for twelve (12) 2,000,000 L fermenter tanks in the main fermentation process where the majority of the ethanol is produced. The large fermenters are the bottleneck in the process, giving a total cycle time of 297 hours. Because biomass is recycled, this cycle time accounts for three fermentation batches of ethanol. Fresh biomass for the 2,000,000 L fermenters is supplied in one out of every three fermentation periods.

Once fermentation is complete, the dilute broth is sent to the separation section of the plant, along with the fermentation off-gases. The broth is heated to deactivate the microorganisms, which are then filtered out and removed. The filtrate proceeds to a distillation column, which brings the ethanol/water solution to the azeotropic point. Ethanol in the vapor stream from the fermentation section is absorbed in a column and sent to this distillation tower as well. The top product from the tower is sent to molecular sieves for further ethanol dehydration. The 99.5% ethanol by mass stream exiting the molecular sieves is then denatured with gasoline, and the ethanol is ready to be sold. The bottom product from the distillation tower, containing a dilute portion of succinic acid, is sent to an electro-dialysis unit that concentrates this solution so that succinic acid can then be crystallized out of solution. Succinic acid crystals are then dried and sold.

B. Importance for the Study

The demand for fuel has increased worldwide. As this demand increased, the number of oil refineries being built has decreased, reflecting a rise in oil prices, with an all time record high in July 2008 of $147/barrel (Simpkins). This rise in price has directed an increase in research into alternative fuel sources such as biofuels, which include ethanol, diesel, and butanol from renewable resources such as corn fiber, biomass, and other agricultural byproducts. Bioethanol is the most widely used alternative automotive fuel in the world. Brazil produces ethanol from sugar cane, and North America produces ethanol from corn for use as an octane enhancer of gasoline (in a small percentage). These countries account for more than 65% of global ethanol production (Organization for Economic Cooperation and Development). Biodiesel is another alternative to fossil fuels. The increased production of biodiesel as an alternative to petroleum has, however, led to a buildup of the by product, glycerol. Recently, crude glycerol has been proposed as an alternative to corn as the starting material for the production of ethanol for use as a fuel (Gonzalez et al. 2008). As such, this report is fueled by the need for a cheaper source of ethanol and by the overproduction of glycerol.

Ethanol Demand:

The Energy Policy Act of 2005 established the renewable fuels standard (RFS) which directs that gasoline sold in the United States contain a specified minimum volume of renewable fuel. Under the Act, the total volume of renewable fuel to be utilized starts at 4 billion gallons in 2006 and increases to 7.5 billion gallons in 2012. However, the Energy Independence and Security Act of 2007, signed into law on December 19th 2007, boosts the requirements for renewable fuel use to 36 billion gallons by 2022. The act requires "advanced biofuels"—defined as fuels that cut greenhouse gas emissions by at least 50%—to provide 21 billion gallons of fuel by 2022, or about 60% of the total requirement. In other words, cellulosic biofuels must contribute at least 0.1 billion gallons in 2010, accelerating to 10 billion gallons in 2020 and 16 billion gallons in 2022 (US Department of Energy). Such advanced biofuels could include ethanol derived from cellulosic biomass—such as wood waste, grasses, and agricultural wastes—as well as biodiesel, butanol, and other fuels. Title II of the Energy Act also prohibits petroleum companies from restricting the sale of alternative fuels under new franchise agreements, a provision that could allow gas station owners to install more pumps for E85, a blend of 85% ethanol and 15% gasoline (US DOE-EERE). The act also requires labeling diesel fuel pumps with their biodiesel content.

This new Energy Act was drafted at the time that oil prices were at a high. This quickened the demand for a less expensive source of energy. However, in 2009, the price of crude oil has dropped significantly from the summer 2008 high of $147 per barrel to $40.17 per barrel (Bloomberg). This drop in prices is a result of the unemployment in the United States climbing in January to the highest level since 1992. As such, oil futures in New York have traded between $38.60 and $42.68 in recent times as the recession in the U.S., Europe and Asia has led to layoffs and reduced spending.

Since the ethanol plant that is being proposed will start production in approximately two years, the market should stabilize as OPEC is at present shutting down some oil refineries in an effort to bring balance to the market. Even so, the production of inexpensive bioethanol is still in high demand due to the increasing demand for cleaner transportation fuels. There are great market opportunities for biofuels—agriculturally- derived renewable fuels such as ethanol and biodiesel. Since the new energy act of 2007, refiners are required by law to blend a certain amount of ethanol into gasoline or buy enough credits to balance out that amount. If ethanol supply in the United States becomes lower than demand, the United States could be forced to import fuel from Brazilian exporters. As such, there is now an even more pressing need for a less expensive source of ethanol than the traditional grain.

The Glycerol Glut:

Glycerol is produced in two ways: natural glycerol is produced as a by-product in the production of soap and in the conversion of fats and oils to fatty acids or fatty acid methyl esters, such as occurs in biodiesel manufacturing, and synthetic glycerol is produced in various manners. Natural glycerol is initially produced in a crude form that contains water and other impurities, which vary widely and depend on the manufacturing process.

Asia is the largest producer and consumer of refined glycerin, accounting for 44% and 35% of world production and consumption in 2007. Asia is expected to remain the largest market into 2012 with increasing demand in all applications as well as new markets for refined glycerin. Western Europe is the second-largest producer and consumer of refined glycerin, accounting for nearly 35% and 28% of world production and consumption, respectively, in 2007. North America was the third-largest market in 2007. These three regions accounted for nearly 91% of world production and 82% of world consumption in 2007 (SRI).

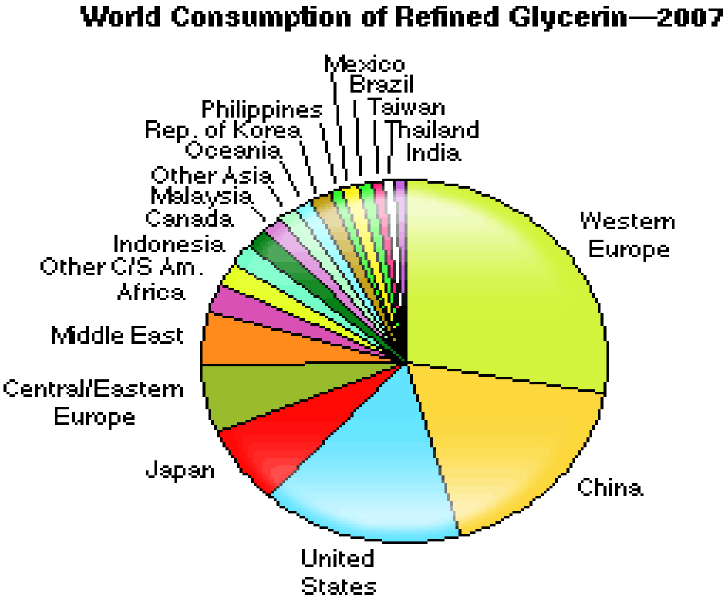

Fig IS-1: Consumption of Refined Glycerol by Country(SRI)

The increased use of biofuels as alternative to petroleum has lead to a buildup up of the biodiesel manufacturing byproduct, crude glycerol. In general, for every 1000 kilograms of biodiesel made from vegetable oil, 100 kilograms of glycerol is produced as a byproduct (McCoy). Since the previous glycerol supply and demand market was tight, recent increases in glycerol production from biodiesel refineries have created a glut in the glycerol market. As a result, the price of glycerol has fallen significantly, and biodiesel refineries are having difficulty in managing the glycerol by product which has become a waste stream. According to the National Biodiesel Board, U.S. companies produced about 450 million gallons of biodiesel in 2007, and about 60 new plants with a production capacity of 1.2 billion gallons are slated to open by 2010 (Voegele).

Purified glycerol has historically been a fairly high valued commercial chemical, usually valued at \$0.60-\$0.90 / lb and was primarily used in the pharmaceutical and food and beverage industry. At this time the price of glycerol as a feedstock was too high to pursue other uses for it. However, as of 2006 the price of glycerol had fallen to as low as \$ 0.05- \$0.15 /lb. This low price positions glycerol as a favorable feedstock for chemical processes (Voegele).

The Department of Energy estimated that if enough biodiesel was produced to replace 2% of petroleum diesel use, around 800 million pounds of glycerol would be produced. Since the US market for crude glycerol is around 600 million pounds, the increasing biodiesel production is producing a glycerol glut, and new markets for the excess glycerol need to be examined (US DOE-EERE).

Jerry Patak, director of commodities for Massachusetts-based World Energy Solutions Inc., says the U.S. crude glycerin market is being inundated with imports. Southeast Asia and Europe are exporting glycerin to the United States in large volumes at low prices. “The market is depressed as a result of that,” he says. Patak expects those depressed prices to continue through the end of 2008, and possibly into 2009 (Voegele).

The market is also experiencing reduced demand from Asia. Dave Elsenbast, Renewable Energy

Group Inc.'s vice president of procurement says his company has exported glycerin to Asia in the past. "The Asian demand that we were selling into seems to have dramatically slowed," he says. "They may have started buying more of their supplies out of the Argentinean biodiesel market as that market has developed." (Voegele)

With increased fuel production from the biodiesel industry and the lack of exports of glycerol, the price of crude glycerol can be expected to remain low for at least a few years.

Crude glycerol sells at a price comparable to that of sugars typically used in fermentation processes, and it has a higher reduced state than that of sugars such as glucose and xylose. This property of glycerol promises to increase the yield of chemicals from fermentation such as ethanol, succinic acid and propanediols. Previously, researchers did not believe that that *Escherichia coli* bacteria could anearobically metabolize glycerol. However, recent research done by researchers Gonzales and Dharmadi of Rice University on the lab scale has shown that this microorganism is capable of this process under certain pH and other external condition, producing a mixture of ethanol and a small quantity of succinic acid. Gonzales and Dharmadi found the process to be very efficient, with operational costs estimated to be about 40 percent less than those of producing ethanol from corn. Gonzalez has said that new fermentation technologies that produce high-value chemicals like succinate hold even more promise for biodiesel refiners because those chemicals are more profitable than ethanol (Boyd). Succinate is a high-demand chemical feedstock that is used to make everything from noncorrosive airport deicers and nontoxic solvents to plastics, drugs and food additives. Most succinate today comes from nonrenewable fossil fuels (Yazdani).

Our project seeks to scale up the fermentation of glycerol to ethanol by *Escherichia coli* bacteria and determine if it is economically feasible on the plant scale.

C. Initial Project Charter

Project Name	Anaerobic Fermentation of Glycerol to Ethanol
Project Champion	The biodiesel manufacturing industry, “Green” energy Proponents
Project Leader	Chloe LeGendre, Eric Logan, Jordan Mendel, and Tamara Seedial
Specific Goals	Design an economically viable chemical process with a low energy requirement to produce 50 MM gallons per year of ethanol by fermenting crude waste glycerol using *E. Coli*
Project Scope	In Scope: • Full process design of a plant that produces ethanol to be blended with gasoline for use in vehicles • Use crude glycerol as feedstock to reduce waste from the biodiesel industry • Small scale production of high valued specialty chemical Succinic Acid • Design a process more energy-efficient than the current corn-to-ethanol production method • Determine profitability of proposed process Out of Scope: • Specific biochemistry of *E.Coli*
Deliverables	• Full plant design • Economic analysis of process • Chemical cost sensitivity assessment
Timeline	Deliverables completed by April 14, 2009

Market and Competitive Analysis

Section III

Market and Competitive Analysis

Ethanol

The worldwide demand for fuel has prompted a rise in the biofuels production, especially after the fluctuation in oil prices in 2008. The most common biofuels are alcohols such as ethanol, butanol and propanol, along with vegetable mass oil or biodiesel. These are all produced from biomass and are beginning to infiltrate the world markets.

As a result of the Energy Independence and Security Act of 2007, signed into law on December 19th 2007, which boosts the requirements for renewable fuel use to 36 billion gallons by 2022, ethanol production in the United States is expected to increase. This act also states that there is to be more production of E85, a blend of 85% ethanol and 15% gasoline. (US Department of Energy-EERE). As such the price of ethanol is related to the price of gasoline and by extension crude oil.

According to OECD (Organization for Economic Cooperation and Development) figures, production of fuel ethanol on a global scale tripled to 52 billion liters (13.73 billion gallons) from 2000 to 2007, and by 2017 that number is expected to increase to 127 billion liters (33.54 billion gallons) per annum. As production of ethanol increases, the amount that is traded on the open market as opposed to being used domestically is expected to increase also, to 6 billion liters (1.58 billion gallons) in 2010 and further to more than 10 billion liters (2.64+ billion gallons) in 2017 (OECD).

Certain nations have a comparative advantage over others, in terms of necessary feed stocks and transportation costs, so it is first useful to examine the global ethanol market. According to the (international) OECD 2007 report, the global price of fuel ethanol is expected to hit a high of $55 per hectoliter ($2.082 per gallon) by 2009 and to level off to $52 per hectoliter by 2017 ($1.969 per gallon) (OECD).This global data is shown in Figure MA-1, along with comparative pricing data for biodiesel.

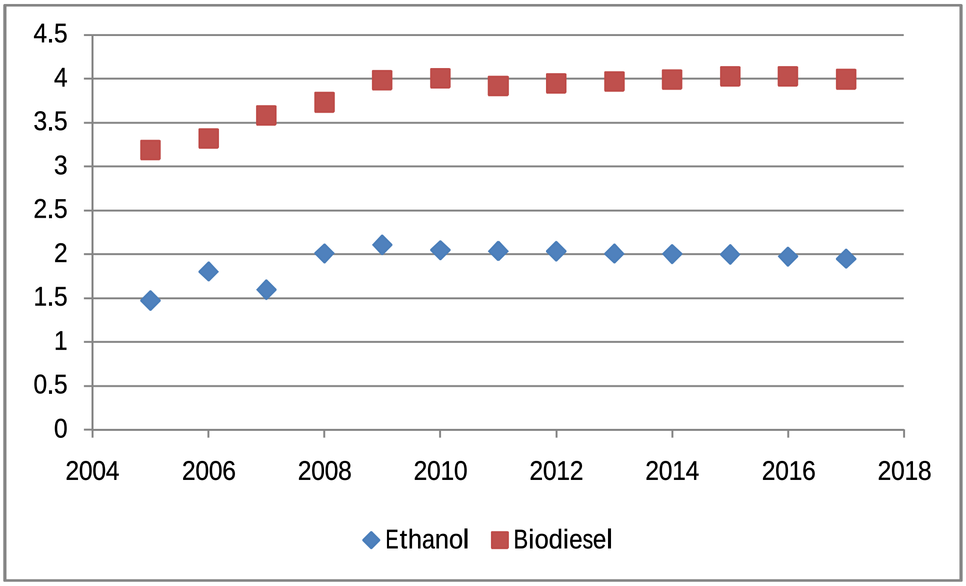

Figure MA-1. Global Prices of Ethanol and Biodiesel (USD)/gallon over the next 8 years (OECD data).

However, it is to be noted that this data that examines global markets ignores the influence of policy support and legislature within individual countries. For example, policies such as the US Energy Independence and Security Act (EISA) are not taken into account. Therefore one must look at nation-wide market analyses in addition to global figures. The global data shows an ethanol price leveling off at $1.97 per gallon at around 2017(OECD), which is significantly lower than the value predicted by data from the United States Department of Energy.

Data from the DOE and current market data show direct correlations between the price of gas and the price of ethanol within the United States (See Sensitivity Analysis Fig. SA-1). This correlation could be a result of the Energy Policy Act of 2005 which established the renewable fuels standard (RFS). This standard states that gasoline sold in the United States must contain a specified minimum volume of renewable fuel. In Fig. MA-2 below, the actual prices of oil and gas as recorded from the New York Stock Exchange by Interactive Data Corporation are used to create correlations between these prices and the price of ethanol. (See the Sensitivity Analysis for a summary of the correlation.)

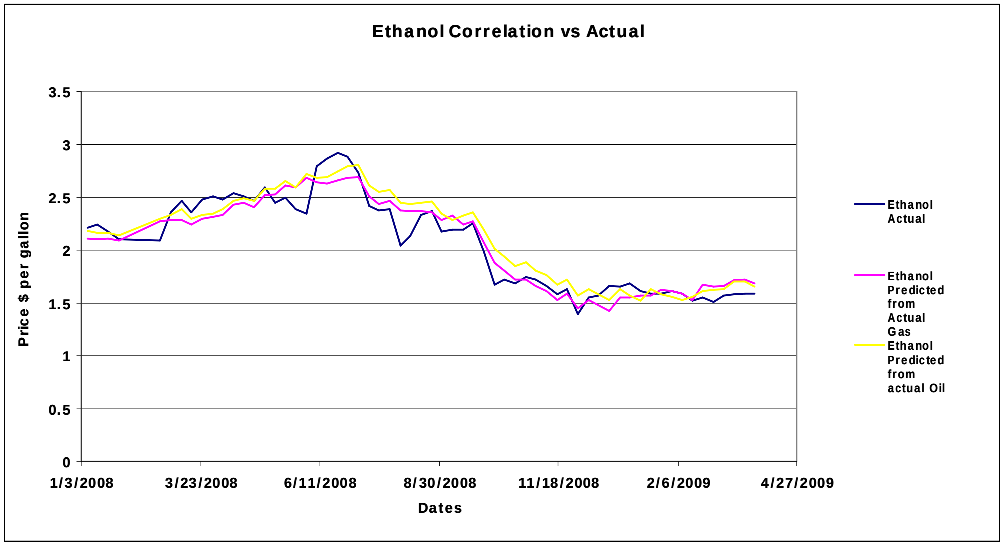

Figure MA-2. Actual price of ethanol compared with prices generated by linear correlations with actual oil and actual gas prices.

Since the ethanol prices predicted by actual oil and actual gas prices seem to correspond well to the actual prices of ethanol, the correlation between ethanol prices and oil prices can be validated. This correlation also allows the prediction of future ethanol prices based on future oil prices.

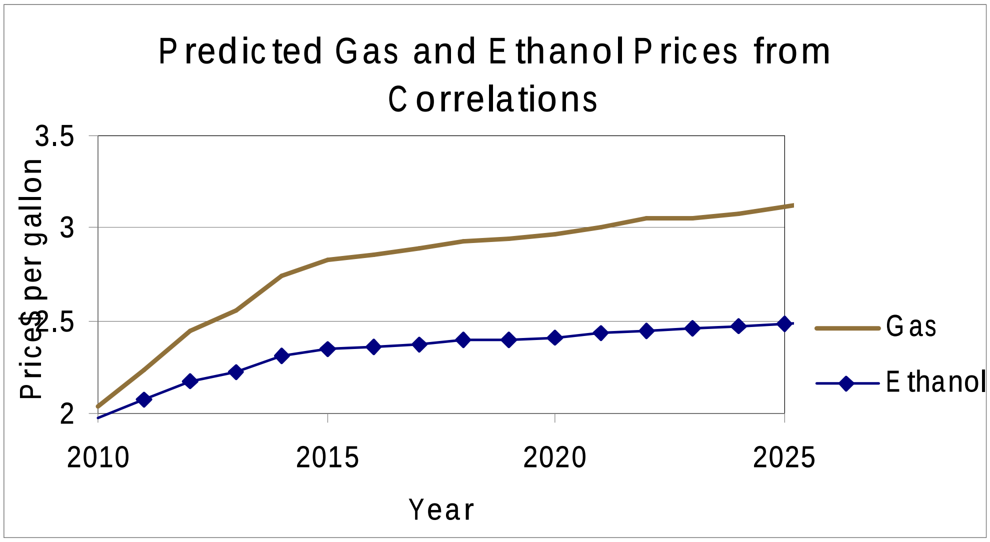

Figure MA-3. Predicted gasoline and ethanol prices from correlations with predicted crude oil values from the U.S. DOE. For details of correlation see the Sensitivity Analysis section.

The validated correlations were used to predict future gas and ethanol prices from future oil price data from the US Department of Energy. As seen in Fig. MA-3, the data predicts the price of ethanol to steadily increase until a cost of $ 2.58/gallon. This value is slightly higher than that predicted from the global data, and closer to the predicted value of ethanol in the design problem statement ($2.50/gallon) (See page 269).

Glycerol

Looking at the global OECD fuel production data from 2000 to 2007, biodiesel production saw an even more pronounced expansion, from less than 1 billion liters (0.26 billion gallons) annually to about 11 billion liters (2.91 billion gallons). For every 1000 kg of biodiesel produced, roughly 100 kg of glycerol is produced as a byproduct. When global production of biodiesel reaches its stable peak at 2.91 billion gallons, or 9.69 billion metric tons (21.4 billion lbs) per year, roughly 2.91 billion gallons of glycerol per year will be produced as a waste product (The Glycerol Challenge). The price of biodiesel in the same period that production is increasing is expected to reach a steady value of $105.49 per hectoliter ($3.99 per gallon). This global data predicts that the crude glycerol bulk prices will be at or around the $0.05 per pound ($0.00475 per gallon) floor that prices have been hovering around in the last few years (Lefebvre).

There is again a slight discrepancy between the global and domestic data since crude glycerol prices seem to be dropping even lower than $0.05/lb in the United States. In January 2006, Dow Chemical closed a glycerol-producing plant in Freeport, Texas due to the global glut of glycerol as a byproduct created by the rise in production of biodiesel. This event signaled that the world had entered into a new period in the market of crude glycerol. Whereas refined glycerol, mostly from Asia, is still a market commodity with an adequate demand for its supply, and therefore subject to market influences, crude glycerol is a chemical that few processes can or want to touch. This glycerol glut creates significant opportunities for a plant, such as this one, that can use glycerol in its crude form (McCoy 7).

While demand for biodiesel is certainly rising, as signaled by the large predicted rate of growth until the year 2017, demand for crude glycerol is not nearly rising as quickly. This will lead to a long period, until innovation can catch up with favorable market conditions, of crude glycerol prices being determined almost exclusively by the production rate of biodiesel. Since this rate is rising, there is a direct relationship between the production of biodiesel and glycerol. The higher the supply of crude glycerol, the lower its price falls. There should be an inverse relationship between production of biodiesel and cost of glycerol (Voegele).

This inverse relationship is further corroborated by some of the limited data available on glycerol prices since the expansion of the biodiesel industry. This data is illustrated in the Fig. MA-4, which is quoted from “Anaerobic fermentation of glycerol: a path to economic viability for the biofuels industry." (Gonzales 2009)

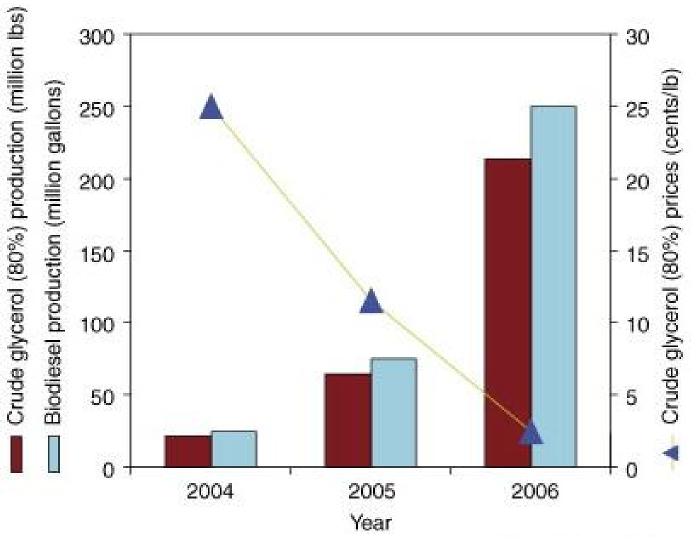

Figure MA-4. Prices of Crude Glycerol in relation to biodiesel production since 2004 (Gonzales 2009)

This data illustrates that glycerol prices may drop even lower than the 5 cents per pound that was quoted as global data. If the price of ethanol increases until 2030, as predicted by the correlation in Fig. MA-3, and the price of glycerol decreases, as seen in Fig. MA-4, the process of fermenting glycerol into ethanol should be a profitable investment.

Succinic Acid

The anaerobic fermentation of glycerol to ethanol also produces succinic acid. Succinic acid is used as a starting material for many important chemicals in the food, chemical and pharmaceutical industries. Industrial succinic acid is usually produced from butane through maleic anhydride, and food grade succinic acid is produced through older fermentation and separation technology (Paster et al). These methods are costly, and succinic acid use remains limited. The current worldwide usage of succinic acid is around 20,000 to 30,000 tons per year, but this will increase by around 10% per year in light of new technologies (such as this fermentation process) that may decrease the price of succinic acid production (Kidwell).

At present, succinic acid is mostly produced by the chemical process from *n*-butane through maleic anhydride. In 2005, succinic acid was sold for $5.90-$9.00/kg ($2.68-$4.00 per pound) depending on its purity (Song et al).This high cost was a result of expensive feed materials and a costly separation process. The use of glycerol as a starting point should drop the price of production. In 2006, maleic anhydride made from *n*-butane was sold for $0.977/kg ($0.45 per pound) (Song et al.), while the price of glycerol was a little more than a tenth of that price ($0.05 per pound) (Yazdani). As such, it is reasonable to assume that the price of succinic acid will be $2.00- $3.00/pound, as fermentation technologies cause the price of production to decrease. At the price of $2.00/pound, the succinic acid revenue will increase the profitability of the plant.

Process Flowsheets and Material Balances

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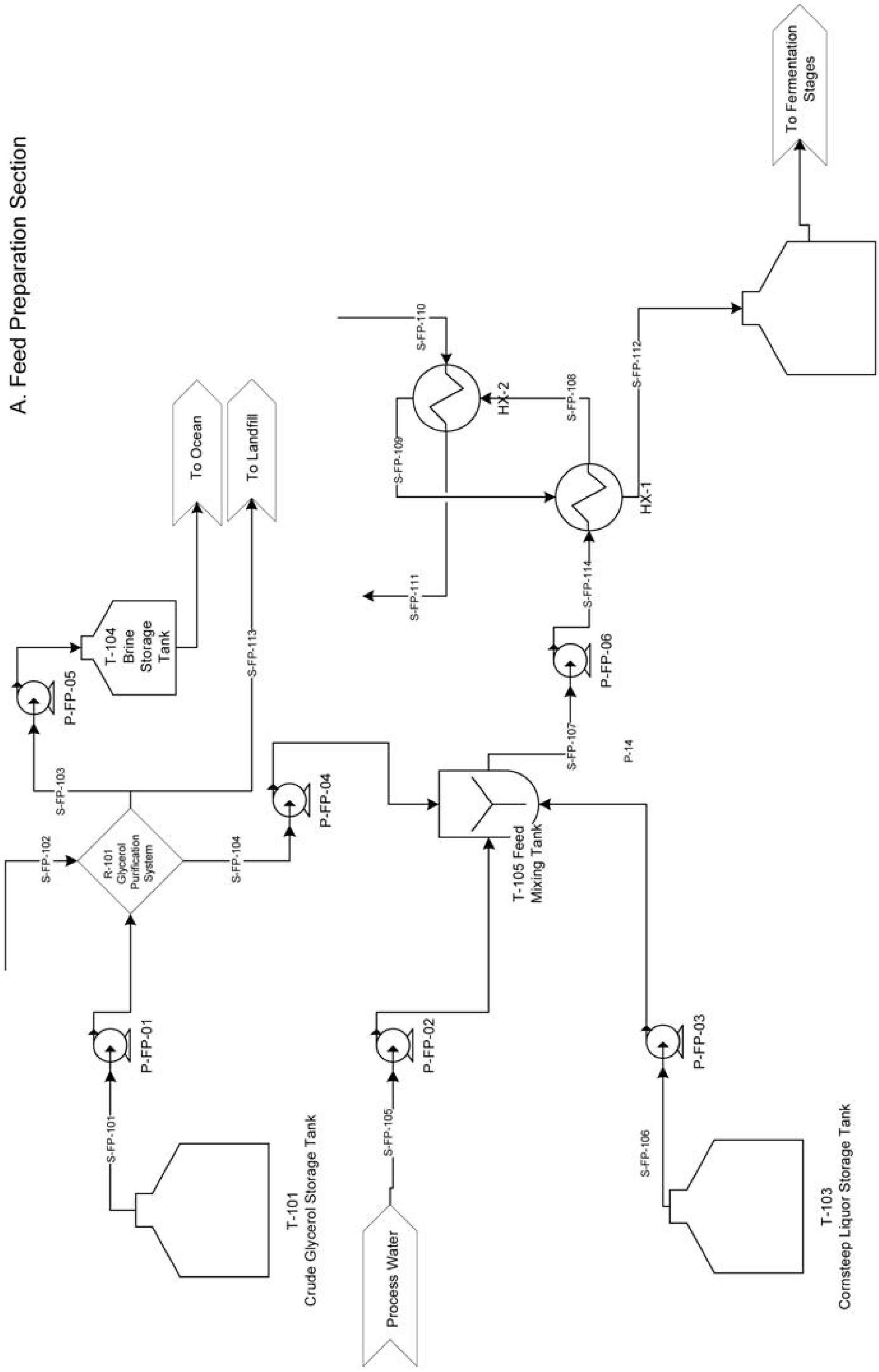
A. Feed Preparation Section

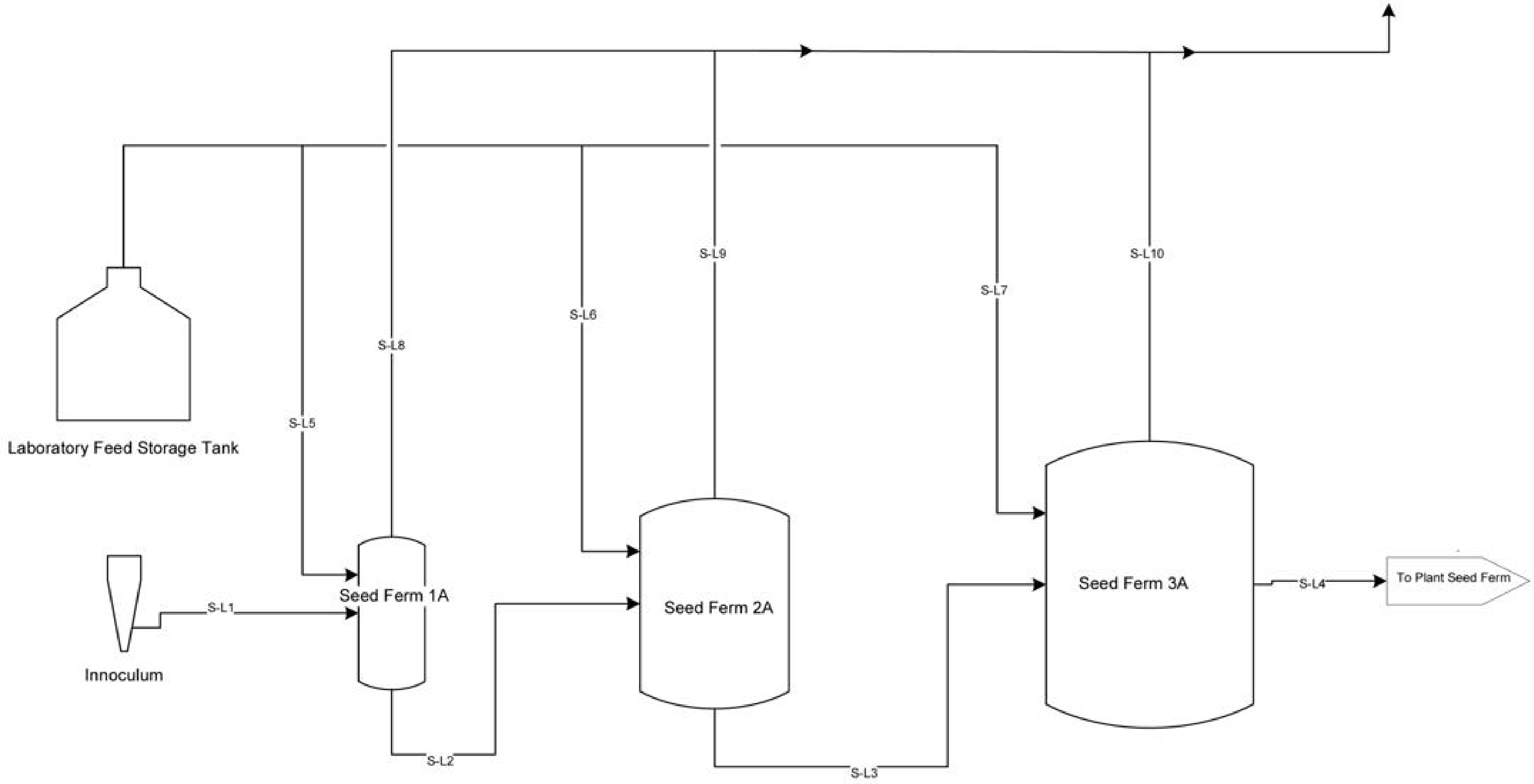


Feed Preparation Stage Material Balance Block (1 of 2)

Stream number	S-FP-101	S-FP-102	S-FP-103	S-FP-104	S-FP-105	S-FP-106	S-FP-107
Temperature °C	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Pressure (psi)	14.60	14.60	14.60	14.60	14.60	14.60	14.60
Vapor Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/hr)	43370.09	4832.32	6567.13	39900.49	151104.77	927.42	191932.67
Mole (kmol/hr)	--	268.24	--	569.20	8387.72	9.27	8966.20
Volume (L/hr)	35169.79	4832.32	4832.32	32356.21	151104.77	927.42	185192.86
State	Solution	Liquid	Solution	Solution	Liquid	Solution	Solution
Molar components (kmol/hr)							
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	0.00	0.00	0.00	0.00	0.00	9.27	9.27
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	400.20	0.00	0.00	400.20	0.00	0.00	400.20
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	169.00	268.24	268.24	169.00	8387.72	0.00	8556.72
Wastes (Salts, MONG)	----	0.00	----	0.00	0.00	0.00	0.00
Mass components (kg/hr)							
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	0.00	0.00	0.00	0.00	0.00	927.42	927.42
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	36855.87	0.00	0.00	36855.87	0.00	0.00	36855.87
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	3044.62	4832.32	4832.32	3044.62	151104.77	0.00	154149.38
Wastes (Salts, MONG)	3469.61	0.00	1734.80	0.00	0.00	0.00	0.00

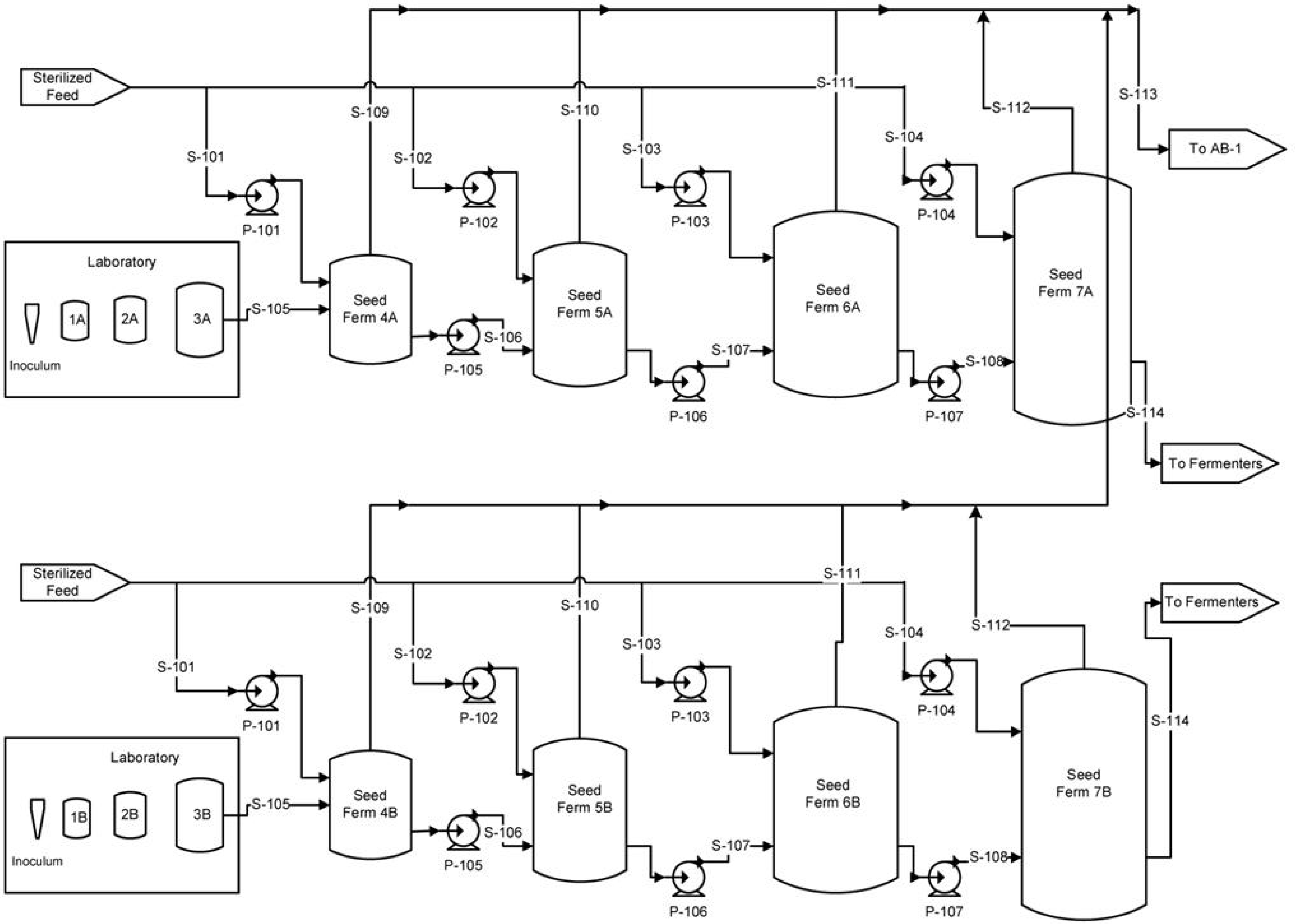
Feed Preparation Stage Material Balance Block (2 of 2)							
Stream number	S-FP-108	S-FP-109	S-FP-110	S-FP-111	S-FP-112	S-FP-113	S-FP-114
Temperature ℃	111.04	121.00	186.11	179.97	37.00	25.00	25.00
Pressure (psi)	40.00	35.00	150.00	145.00	30.00	14.60	45.00
Vapor Fraction	0.00	0.00	1.00	0.01	0.00	0.00	0.00
Mass (kg/hr)	191932.67	191932.67	4044.94	4044.94	191932.67	1734.80	191932.67
Mole (kmol/hr)	8966.20	8966.20	224.53	224.53	8966.20	n/a	8966.20
Volume (L/hr)	185192.86	185192.86	755015.75	9646.96	185192.86	n/a	185192.86
State	Solution	Solution	Vapor	Liquid	Solution	Cake	Solution
Molar components (kmol/hr)							
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	9.27	9.27	0.00	0.00	9.27	0.00	9.27
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	400.20	400.20	0.00	0.00	400.20	0.00	400.20
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	8556.72	8556.72	224.53	224.53	8556.72	0.00	8556.72
Wastes (Salts, MONG)	0.00	0.00	0.00	0.00	0.00	n/a	0.00
Mass components (kg/hr)							
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	927.42	927.42	0.00	0.00	927.42	0.00	927.42
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	36855.87	36855.87	0.00	0.00	36855.87	0.00	36855.87
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	154149.38	154149.38	4044.94	4044.94	154149.38	0.00	154149.38
Wastes (Salts, MONG)	0.00	0.00	0.00	0.00	0.00	1734.80	0.00

B. Laboratory Seed Train Fermenters



Lab Scale Material Balance Block										
Stream number	SL-1	SL-2	SL-3	SL-4	SL-5	SL-6	SL-7	SL-8	SL-9	SL-10
Temperature °C	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00
Pressure (psi)	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80
Vapor Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Mass (g/batch)	1.05	18.81	381.33	7630.03	19.89	403.54	8073.46	2.12	41.29	824.06
Mole (mol/batch)	0.04	0.96	19.71	394.76	0.92	18.85	377.16	0.09	1.78	35.59
Volume (mL/batch)	1.00	19.44	395.30	7911.00	19.15	389.42	7790.00	--	--	--
Ethanol Conc. (g/L)	0.00	95.70	96.28	96.19	0.00	0.00	0.00	--	--	--
State	Slurry	Solution	Solution	Solution	Solution	Solution	Solution	Vapor	Vapor	Vapor
Molar components (mol/batch)										
Biomass	0.04	0.04	0.07	0.58	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.82	16.33
Corn Steep Liquor	0.00	0.00	0.02	0.41	0.00	0.02	0.39	0.00	0.00	0.00
Ethanol	0.00	0.04	0.83	16.51	0.00	0.00	0.00	0.00	0.04	0.80
Glycerol	0.00	0.00	0.00	0.00	0.04	0.84	16.83	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.82	16.50
Succinic Acid	0.00	0.00	0.01	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.87	18.79	377.08	0.88	17.99	359.93	0.00	0.09	1.96
Mass components (g/batch)										
Biomass	1.05	1.08	1.70	14.16	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.84	36.13	718.64
Corn Steep Liquor	0.00	0.10	2.05	41.06	0.10	1.95	39.01	0.00	0.00	0.00
Ethanol	0.00	1.86	38.06	760.73	0.00	0.00	0.00	0.10	1.80	36.86
Glycerol	0.00	0.00	0.00	0.00	4.00	77.50	1550.32	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	1.66	33.26
Succinic Acid	0.00	0.05	1.05	20.92	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	15.72	338.47	6793.16	15.79	324.09	6484.14	0.09	1.70	35.30

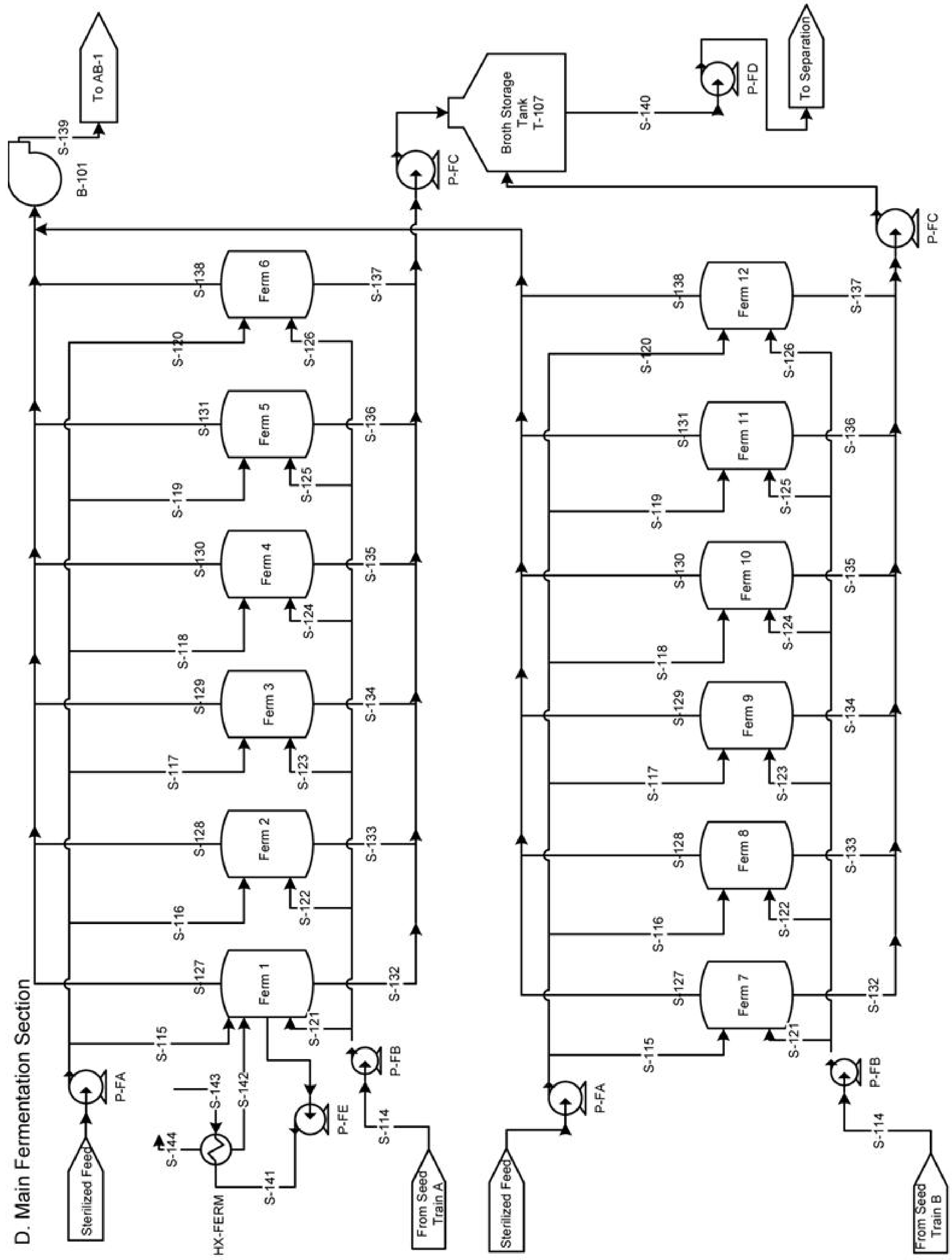
C. Plant Seed Fermentation Train



Plant Scale Seed Fermentation Train Material Balance Block (Batch) (1 of 2)							
Stream number	S-101	S-102	S-103	S-104	S-105	S-106	S-107
Temperature °C	37.00	37.00	37.00	37.00	37.00	37.00	37.00
Pressure (psi)	14.80	14.80	14.80	14.80	14.80	14.80	14.80
Vapor Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/batch)	160.92	3230.44	64593.22	423410.27	7.63	152.12	3052.67
Mole (mol/batch)	7517.65	150910.97	3017493.24	19779746.86	394.76	7870.57	157943.69
Volume (L/batch)	156.00	3117.00	62325.00	408542.00	7.91	157.71	3164.95
Ethanol Conc. (g/L)	--	--	--	--	96.19	96.16	96.17
State	Solution	Solution	Solution	Solution	Solution	Solution	Solution
Molar components (mol/batch)							
Biomass	0.00	0.00	0.00	0.00	0.58	10.67	213.25
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	7.78	156.09	3121.14	20459.18	0.41	8.19	164.28
Ethanol	0.00	0.00	0.00	0.00	16.51	329.22	6606.64
Glycerol	335.54	6735.78	134683.19	882851.83	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.18	3.53	70.89
Water	7174.33	144019.10	2879688.90	18876435.84	377.08	7518.97	150888.64
Mass components (kg/batch)							
Biomass	0.00	0.00	0.00	0.00	0.01	0.26	5.25
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	0.78	15.61	312.11	2045.92	0.04	0.82	16.43
Ethanol	0.00	0.00	0.00	0.00	0.76	15.17	304.36
Glycerol	30.90	620.32	12403.51	81305.36	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.02	0.42	8.37
Water	129.25	2594.50	51877.60	340058.99	6.79	135.45	2718.26

Plant Scale Seed Fermentation Train Material Balance Block (Batch) (2 of 2)							
Stream number	S-108	S-109	S-110	S-111	S-112	S-113	S-114
Temperature °C	37.00	37.00	37.00	37.00	37.00	37.00	37.00
Pressure (psi)	14.80	14.80	14.80	14.80	14.80	14.80	14.80
Vapor Fraction	0.00	1.00	1.00	1.00	1.00	1.00	0.00
Mass (kg/batch)	61047.80	16.44	329.89	6598.10	43596.29	50540.72	440861.80
Mole (mol/batch)	3158605.38	709.59	14242.56	284861.20	1879984.19	2179797.55	22815309.40
Volume (L/batch)	63293.21	--	--	--	--	--	457030.26
Ethanol Conc. (g/L)	96.16	--	--	--	--	--	95.82
State	Solution	Vapor	Vapor	Vapor	Vapor	Vapor	Solution
Molar components (mol/batch)							
Biomass	4263.84	0.00	0.00	0.00	0.00	0.00	30815.61
Carbon Dioxide	0.00	325.48	6533.71	130642.69	856366.25	993868.13	0.00
Corn Steep Liquor	3285.43	0.00	0.00	0.00	0.00	0.00	23744.61
Ethanol	132109.86	16.13	323.64	6486.30	46673.86	53499.93	950630.80
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	328.83	6601.06	131989.53	865194.82	1004114.24	0.00
Succinic Acid	1417.72	0.00	0.00	0.00	0.00	0.00	10246.24
Water	3017528.53	39.15	784.15	15742.68	111749.27	128315.25	21799872.14
Mass components (kg/batch)							
Biomass	104.89	0.00	0.00	0.00	0.00	0.00	758.06
Carbon Dioxide	0.00	14.32	287.55	5749.58	37688.68	43740.14	0.00
Corn Steep Liquor	328.54	0.00	0.00	0.00	0.00	0.00	2374.46
Ethanol	6086.17	0.74	14.91	298.82	2150.22	2464.69	43794.61
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.66	13.31	266.09	1744.23	2024.29	0.00
Succinic Acid	167.42	0.00	0.00	0.00	0.00	0.00	1209.97
Water	54360.78	0.71	14.13	283.60	2013.16	2311.60	392724.70

D. Main Fermentation Section



Main Fermentation Section (Batch) (1 of 4)

Stream number	S-114	S-115	S-116	S-117	S-118	S-119	S-120	S-121	S-122
Temperature °C	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00
Pressure (psi)	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80
Vapor Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/batch)	440861.80	1556144.82	1556144.82	1556144.82	1556144.82	1556144.82	1556144.82	73447.58	73447.58
Mole (kmol/batch	22815.31	72695.81	72695.81	72695.81	72695.81	72695.81	72695.81	3801.03	3801.03
Volume (L/batch)	457030.26	1501500.00	1501501.00	1501502.00	1501503.00	1501504.00	1501505.00	76141.62	76141.62
Ethanol Conc. (g/L	95.82	--	--	--	--	--	--	95.82	95.82
State	Solution	Solution	Solution	Solution	Solution	Solution	Solution	Solution	Solution
Molar components (kmol/batch)									
Biomass	30.82	0.00	0.00	0.00	0.00	0.00	0.00	5.13	5.13
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	23.74	75.19	75.19	75.19	75.19	75.19	75.19	3.96	3.96
Ethanol	950.63	0.00	0.00	0.00	0.00	0.00	0.00	158.38	158.38
Glycerol	0.00	3244.71	3244.71	3244.71	3244.71	3244.71	3244.71	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	10.25	0.00	0.00	0.00	0.00	0.00	0.00	1.71	1.71
Water	21799.87	69375.90	69375.90	69375.90	69375.90	69375.90	69375.90	3631.86	3631.86
Mass components (kg/batch)									
Biomass	758.06	0.00	0.00	0.00	0.00	0.00	0.00	126.29	126.29
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	2374.46	7519.29	7519.29	7519.29	7519.29	7519.29	7519.29	395.59	395.59
Ethanol	43794.61	0.00	0.00	0.00	0.00	0.00	0.00	7296.18	7296.18
Glycerol	0.00	298818.71	298818.71	298818.71	298818.71	298818.71	298818.71	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	1209.97	0.00	0.00	0.00	0.00	0.00	0.00	201.58	201.58
Water	392724.70	1249806.82	1249806.82	1249806.82	1249806.82	1249806.82	1249806.82	65427.93	65427.93

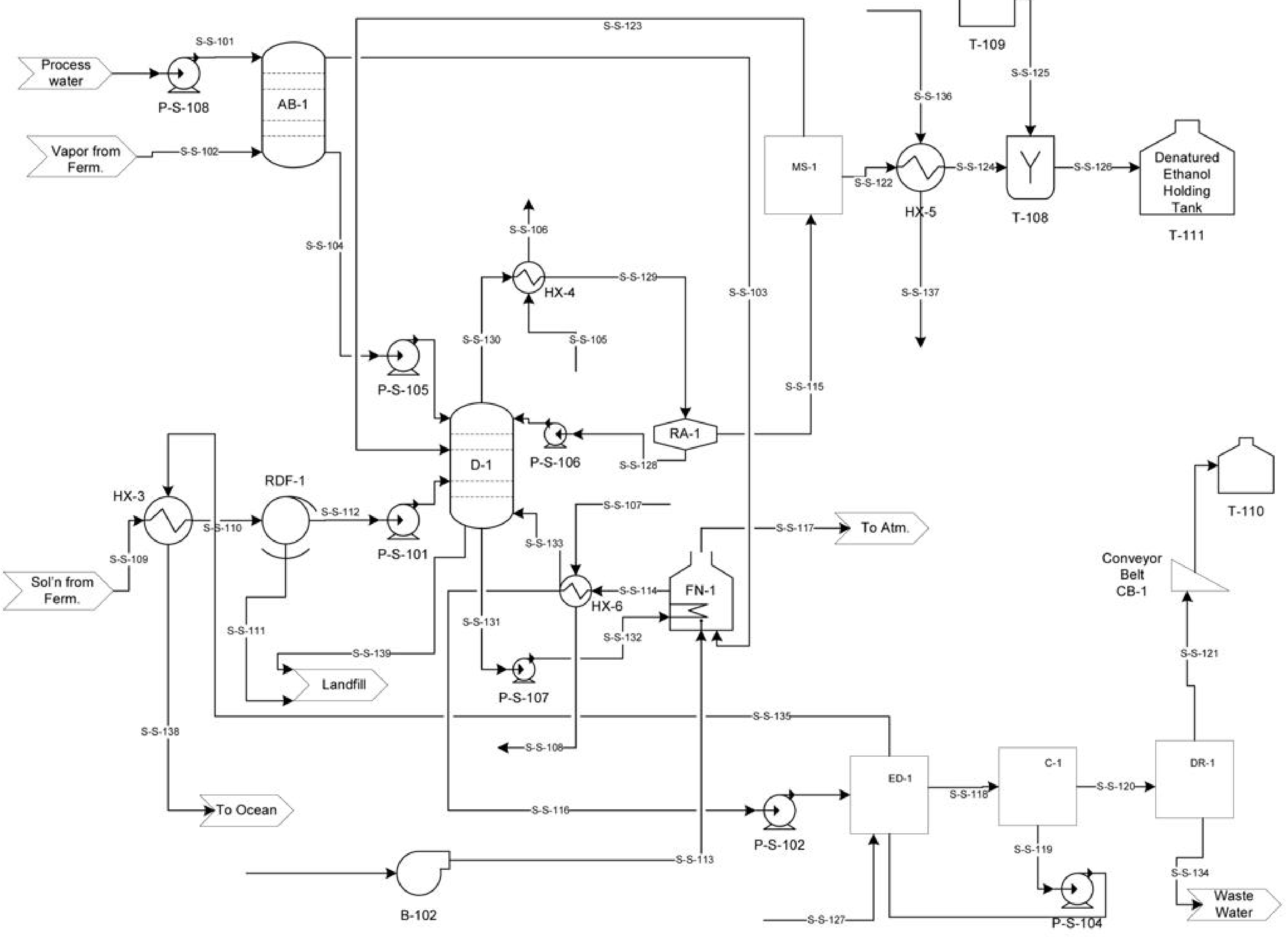
Main Fermentation Section (Batch) (2 of 4)

Stream number	S-123	S-124	S-125	S-126	S-127	S-128	S-129	S-130	S-131
Temperature °C	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00	37.00
Pressure (psi)	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80	14.80
Vapor Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/batch)	73447.58	73447.58	73447.58	73447.58	158271.24	158271.24	158271.24	158271.24	158271.24
Mole (kmol/batch)	3801.03	3801.03	3801.03	3801.03	6824.67	6824.67	6824.67	6824.67	6824.67
Volume (L/batch)	76141.62	76141.62	76141.62	76141.62	--	--	--	--	--
Ethanol Conc. (g/L)	95.82	95.82	95.82	95.82	--	--	--	--	--
State	Solution	Solution	Solution	Solution	Vapor	Vapor	Vapor	Vapor	Vapor
Molar components (kmol/batch)									
Biomass	5.13	5.13	5.13	5.13	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	3147.37	3147.37	3147.37	3147.37	3147.37
Corn Steep Liquor	3.96	3.96	3.96	3.96	0.00	0.00	0.00	0.00	0.00
Ethanol	158.38	158.38	158.38	158.38	156.23	156.23	156.23	156.23	156.23
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	3179.82	3179.82	3179.82	3179.82	3179.82
Succinic Acid	1.71	1.71	1.71	1.71	0.00	0.00	0.00	0.00	0.00
Water	3631.86	3631.86	3631.86	3631.86	341.25	341.25	341.25	341.25	341.25
Mass components (kg/batch)									
Biomass	126.29	126.29	126.29	126.29	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	138515.88	138515.88	138515.88	138515.88	138515.88
Corn Steep Liquor	395.59	395.59	395.59	395.59	0.00	0.00	0.00	0.00	0.00
Ethanol	7296.18	7296.18	7296.18	7296.18	7197.25	7197.25	7197.25	7197.25	7197.25
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	6410.52	6410.52	6410.52	6410.52	6410.52
Succinic Acid	201.58	201.58	201.58	201.58	0.00	0.00	0.00	0.00	0.00
Water	65427.93	65427.93	65427.93	65427.93	6147.61	6147.61	6147.61	6147.61	6147.61

Main Fermentation Section (Batch) (3 of 4)							
Stream number	S-132	S-133	S-134	S-135	S-136	S-137	S-138
Temperature °C	37.00	37.00	37.00	37.00	37.00	37.00	37.00
Pressure (psi)	14.80	14.80	14.80	14.80	14.80	14.80	14.80
Vapor Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/batch)	1471321.26	1471321.26	1471321.26	1471321.26	1471321.26	1471321.26	158271.24
Mole (kmol/batch	76129.39	76129.39	76129.39	76129.39	76129.39	76129.39	6824.67
Volume (L/batch)	1525403.90	1525403.90	1525403.90	1525403.90	1525403.90	1525403.90	--
Ethanol Conc. (g/L	96.01	96.01	96.01	96.01	96.01	96.01	--
State	Solution	Solution	Solution	Solution	Solution	Solution	Vapor
Molar components (kmol/batch)							
Biomass	102.72	102.72	102.72	102.72	102.72	102.72	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	3147.37
Corn Steep Liquor	79.15	79.15	79.15	79.15	79.15	79.15	0.00
Ethanol	3181.97	3181.97	3181.97	3181.97	3181.97	3181.97	156.23
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	3179.82
Succinic Acid	34.15	34.15	34.15	34.15	34.15	34.15	0.00
Water	72731.40	72731.40	72731.40	72731.40	72731.40	72731.40	341.25
Mass components (kg/batch)							
Biomass	2526.88	2526.88	2526.88	2526.88	2526.88	2526.88	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	138515.88
Corn Steep Liquor	7914.88	7914.88	7914.88	7914.88	7914.88	7914.88	0.00
Ethanol	146590.06	146590.06	146590.06	146590.06	146590.06	146590.06	7197.25
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	6410.52
Succinic Acid	4033.23	4033.23	4033.23	4033.23	4033.23	4033.23	0.00
Water	1310256.21	1310256.21	1310256.21	1310256.21	1310256.21	1310256.21	6147.61

Main Fermentation Section (Continuous*) (4 of 4)						
Stream number	S-139*	S-140*	S-141*	S-142*	S-143*	S-144*
Temperature °C	37.00	37.00	42.72	37.00	31.44	36.60
Pressure (psi)	19.00	14.80	14.80	14.80	14.60	14.60
Vapor Fraction	1.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/hr)	19524.73	172397.24	24522.02	24522.02	22063.00	22063.00
Mole (kmol/hr)	841.91	8920.21	1268.82	1268.82	1224.70	1224.70
Volume (L/hr)	21275721.11	178734.19	25423.40	25423.40	22063.00	22063.00
Ethanol Conc. (g/L)		96.01	--	--	--	--
State	Vapor	Solution	Solution	Solution	Liquid	Liquid
Molar components (kmol/hr)						
Biomass	0.00	12.04	1.71	1.71	0.00	0.00
Carbon Dioxide	388.19	0.00	0.00	1.00	0.00	0.00
Corn Steep Liquor	0.00	9.27	1.32	1.32	0.00	0.00
Ethanol	19.30	372.84	53.03	53.03	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	392.19	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	4.00	0.57	0.57	0.00	0.00
Water	42.23	8522.06	1212.19	1212.19	1224.70	1224.70
Mass components (kg/hr)						
Biomass	0.00	296.08	42.11	42.11	0.00	0.00
Carbon Dioxide	17084.35	0.00	0.00	1.00	0.00	0.00
Corn Steep Liquor	0.00	927.40	131.91	131.91	0.00	0.00
Ethanol	888.99	17176.21	2443.17	2443.17	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	790.66	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	472.58	67.22	67.22	0.00	0.00
Water	760.73	153524.97	21837.60	21837.60	22063.00	22063.00

E. Separation Section



Separation Section Material Balance Block (1 of 4)										
Stream number	S-S-101	S-S-102	S-S-103	S-S-104	S-S-105	S-S-106	S-S-107	S-S-108	S-S-109	S-S-110
Temperature °C	25.00	37.00	28.98	41.22	32.22	48.89	147.70	147.70	37.00	92.22
Pressure (psi)	14.60	16.00	16.00	20.00	14.60	14.60	64.70	64.70	14.80	14.80
Vapor Fraction	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/hr)	27,022.50	19,524.80	18,362.04	28,185.64	1,087,869.82	1,087,869.82	16,775.34	16,775.34	172,397.24	172,397.24
Mole (kmol/hr)	1,500.00	841.91	807.41	1,534.51	60,386.89	60,386.89	931.19	931.19	8,920.21	8,920.21
Volume (L/hr)	27,022.50	21275721.11	17,090,746.03	28,423.42	1,087,869.82	1,087,869.82	--	16,775.34	175,294.56	175,294.56
State	Liquid	Vapor	Vapor	Liquid	Liquid	Liquid	Vapor	Liquid	Solution	Solution
Molar components (kmol/hr)										
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.04	12.04
Carbon Dioxide	0.00	388.19	388.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.27	9.27
Ethanol	0.00	19.30	0.00	19.30	0.00	0.00	0.00	0.00	372.84	372.84
Gasoline	--	--	--	--	--	--	--	--	--	--
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	392.19	392.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00
Water	1,500.00	42.23	27.03	1,515.21	60,386.89	60,386.89	931.19	931.19	8,522.06	8,522.06
Mass components (kg/hr)										
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	296.08	296.08
Carbon Dioxide	0.00	17,084.24	17,084.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	927.40	927.40
Ethanol	0.00	889.13	0.22	889.13	0.00	0.00	0.00	0.00	17,176.21	17,176.21
Gasoline	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	790.66	790.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	472.58	472.58
Water	27,022.50	760.77	486.92	27,296.51	1,087,869.82	1,087,869.82	16,775.34	16,775.34	153,524.97	153,524.97

Separation Section Material Balance Block (2 of 4)										
Stream number	S-S-111	S-S-112	S-S-113	S-S-114	S-S-115	S-S-116	S-S-117	S-S-118	S-S-119	S-S-120
Temperature °C	92.22	92.22	37.00	108.89	81.96	108.81	121.00	40.00	40.00	40.00
Pressure (psi)	14.60	14.60	14.70	21.50	14.70	21.50	17.00	14.70	14.70	14.70
Vapor Fraction	0.00	0.00	1.00	0.16	1.00	0.00	1.00	0.00	0.00	0.00
Mass (kg/hr)	977.20	171,420.74	135,234.48	233,698.14	24,372.05	181,540.75	153,597.31	50,826.80	45,331.18	5,495.61
Mole (kmol/hr)	30.23	8,890.00	4,687.45	12,927.02	590.80	10,031.80	5,298.77	2,561.64	2,301.98	259.66
Volume (L/hr)	--	174,995.04	119,294,100.00	232,716.50	12,041,435.90	180,559.12	171,375,000.00	45,139.78	40,625.80	4,513.98
State	Cake	Solution	Vapor	Liquid	Vapor	Solution		Solution	Liquid	Liquid
Molar components (kmol/hr)										
Biomass	10.83	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	388.20	0.00	0.00	0.00
Corn Steep Liquor	4.18	5.09	0.00	5.09	0.00	5.09	0.00	50.93	45.84	5.09
Ethanol	0.64	372.20	0.00	0.00	489.37	0.00	0.00	0.00	0.00	0.00
Gasoline	--	--	--	--	--	--	--	--	--	--
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	984.36	0.00	0.00	0.00	788.25	0.00	0.00	0.00
Nitrogen	0.00	0.00	3,703.09	0.00	0.00	0.00	3,703.09	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.01	4.00	0.00	4.00	0.00	4.00	0.00	5.03	1.03	4.00
Water	14.57	8,507.50	0.00	12,917.93	101.43	10,022.71	419.23	2,505.68	2,255.11	250.57
Mass components (kg/hr)										
Biomass	266.47	29.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	17,084.68	0.00	0.00	0.00
Corn Steep Liquor	418.12	509.28	0.00	509.28	0.00	509.28	0.00	5,092.78	4,583.50	509.28
Ethanol	29.36	17,146.88	0.00	0.01	22,544.79	0.00	0.00	0.00	0.00	0.00
Gasoline	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	31,498.34	0.00	0.00	0.00	25,223.05	0.00	0.00	0.00
Nitrogen	0.00	0.00	103,736.14	0.00	0.00	0.00	103,736.14	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	0.81	472.36	0.00	472.36	0.00	472.36	0.00	594.23	121.88	472.36
Water	262.44	153,262.61	0.00	232,716.49	1,827.26	180,559.12	7,552.43	45,139.78	40,625.80	4,513.98

Separation Section Material Balance Block (3 of 4)										
Stream number	S-S-121	S-S-122	S-S-123	S-S-124	S-S-125	S-S-126	S-S-127	S-S-128	S-S-129	S-S-130
Temperature °C	40.00	78.40	81.95	50.00	25.00	50.00	33.00	81.95	81.95	81.95
Pressure (psi)	14.70	14.70	14.70	14.70	14.70	14.70	14.70	17.00	17.00	17.00
Vapor Fraction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	1.00
Mass (kg/hr)	458.81	18,035.83	6,336.03	18,035.83	360.72	18,396.55	4,513.98	165,301.18	189,673.23	189,673.23
Mole (kmol/hr)	3.89	391.50	199.30	391.50	--	--	250.57	4,046.71	4,637.51	4,637.51
Volume (L/hr)		22,859.10	7,541.80	22,859.10	457.18	22,859.10	4,513.98	205,879.09	236,280.23	236,280.23
State	Solid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Mixed	Vapor
Molar components (kmol/batch)										
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	391.50	97.87	391.50	0.00	391.50	0.00	3,293.63	3,783.00	3,783.00
Gasoline	--	--	--	--	--	--	--	--	--	--
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	3.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	101.43	0.00	0.00	0.00	250.57	753.08	854.51	854.51
Mass components (kg/batch)										
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	18,035.83	4,508.77	18,035.83	0.00	18,035.83	0.00	151,734.45	174,279.23	174,279.23
Gasoline	0.00	0.00	0.00	0.00	360.72	360.72	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	458.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	0.00	0.00	1,827.26	0.00	0.00	0.00	4,513.98	13,566.74	15,394.00	15,394.00

Separation Section Material Balance Block (4 of 4)									
Stream number	S-S-131	S-S-132	S-S-133	S-S-134	S-S-135	S-S-136	S-S-137	S-S-138	S-S-139
Temperature °C	108.89	108.89	108.89	40.00	108.89	32.22	48.89	42.56	108.89
Pressure (psi)	21.50	21.50	21.50	14.70	21.50	14.70	14.70	14.70	14.70
Vapor Fraction	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Mass (kg/hr)	233,698.14	233,698.14	52,157.39	5,036.80	180,559.12	23,766.11	23,766.11	180,559.12	29.61
Mole (kmol/hr)	12,927.02	12,927.02	2,895.22	255.78	10,022.71	1,319.24	1,319.24	10,022.71	1.20
Volume (L/hr)	232,716.50	232,716.50			197,424.53	23,766.11	23,766.11	197,424.53	
State	Liquid	Liquid	Vapor	Liquid	Liquid	Liquid	Liquid	Liquid	Cake
Molar components (kmol/batch)									
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	5.09	5.09	0.00	5.09	0.00	0.00	0.00	0.00	0.00
Ethanol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gasoline	--	--	--	--	--	--	--	--	--
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	4.00	4.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
Water	12,917.93	12,917.93	2,895.22	250.57	10,022.71	1,319.24	1,319.24	10,022.71	0.00
Mass components (kg/batch)									
Biomass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.61
Carbon Dioxide	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Corn Steep Liquor	509.28	509.28	0.00	509.28	0.00	0.00	0.00	0.00	0.00
Ethanol	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Gasoline	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Methane	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nitrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Glycerol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Succinic Acid	472.36	472.36	0.01	13.54	0.00	0.00	0.00	0.00	0.00
Water	232,716.49	232,716.49	52,157.37	4,513.98	180,559.12	23,766.11	23,766.11	180,559.12	0.00

Process Description

Section V

Process Description

Fermentation Feed Preparation Section

In the continuous feed preparation section, crude glycerol is processed and diluted in preparation for subsequent fermentation of glycerol to ethanol by *Escherichia coli* in the fermentation plant sections.

A three day supply of crude glycerol is kept in stock in a storage tank. This glycerol feedstock is a byproduct of biodiesel manufacturing, and its exact composition will differ based on the type of oil (soybean, rape-seed, others) used in the upstream biodiesel process, the type of caustic solution used in the biodiesel process, and the degree of methanol removal processing in the biodiesel plant. Methanol is typically separated from the crude glycerol for recycle back into the biodiesel process, so the assumption that there is no methanol in the incoming feed for the material balance calculations is sound. However, the crude feedstock purification system is designed to remove methanol in the worst case scenario that a small amount of methanol is contained in the feedstock and not previously removed by the biodiesel manufacturing process. Crude glycerol feedstock is highly variable in composition, but a typical composition according to EET Corporation (supplier of the crude glycerol purification system) is summarized in Table PD-1, where MONG refers to Matter: Organic, Non-Glycerol, which includes free fatty acids, monoglycerides, and diglycerides. This typical composition is in agreement with a technical data sheet on a crude glycerol product from industrial glycerol supplier Emergent Industrial Solutions.

Material	Weight Percent
Glycerol	85
Water	7
NaCl	4
MONG	4

Table PD-1. Typical composition of crude glycerol feedstock.

The crude glycerol feedstock is purified so that it contains only water and glycerol. This purification takes place in a patent-pending, fully-contained, and licensed glycerol purification system sold by company EET Corporation. The purification takes place by a parallel combination of reverse osmosis, electro-pressure membrane technology, and electro-dialysis. The process requires an input of process water and yields a cake of MONG and a concentrated brine stream. The MONG, at the suggestion of industrial consultant Mr. Bruce Vrana, may be distributed to farmers as a nutrient.

The concentration of salts in the crude glycerol, although specified in the problem statement as helpful for the *E. coli*, is high enough in actuality that any 304 stainless steel processing equipment would be easily corroded according to Mr. Bruce Vrana. Additionally, it is likely that any potentially higher quantity of salts would kill microorganisms such as *E. coli*. As such, the crude glycerol salts and impurities are removed, and then a nutrient supplement, Corn Steep Liquor (CSL), an inexpensive nutrient-rich byproduct of the wet-milling of corn, is added. A three day supply of the CSL nutrient is stored in T-103, and it is mixed with a 10 minutes residence time with the purified glycerol and water in mixing tank T-105 to prepare a feed with a concentration of 5 g/L CSL as suggested by Agarwal et al. CSL is typically 50% solids and 50% water by weight. It contains variable concentrations of salts, minerals, and amino acids to promote microorganism metabolism. The glycerol is diluted with additional process water at this step so that the ethanol concentration in the downstream batch fermenters does not exceed 100 g/L, as specified in the problem statement (see page 269).

The mixed glycerol feedstock solution at this point consists of 80.3% water, 19.2 % glycerol, and 0.5 % CSL (percentages by weight) at room temperature. This feedstock must be sterilized to a temperature of 121°C (sterilization temperature for all microorganisms, including heat-resistant spores) before it can be sent to the fermentation section of the plant. In order to minimize both hot and cold utility requirements, the feed is sterilized in a network of two heat exchangers, HX-1 and HX-2. In the first heat exchanger, the cold feed is pre-heated to 111 °C, using already sterilized feed at 121 °C on the hot side of the exchanger. This sterilized feed is cooled to 37 °C, the optimal temperature for fermentation. The second exchanger requires a 150 psig steam utility, at 4045 kg/hr, to heat the pre-heated feed from 111 °C to 121 °C. The sterilized and cooled feed is then stored in the sterilized feed holding tank, T-106, from which batch portions of sterilized feed will be fed to the seed fermentation and main fermentation sections of the plant.

Laboratory Section

A batch seed fermentation process is designed to account for the fact that a 1 mL aliquot of cells cannot be added to fermenter tanks of the large required volume for the 50 MM gallon/year ethanol production rate. This seed fermentation occurs first in a laboratory, and then in the plant, before significant enough volumes of seed fermentation broth have been produced for charging the main fermentation section of the plant. There are two seed fermentation trains, each of which will provide the appropriate cell volumes for six of the twelve full-scale fermenters in the main fermentation section. These two trains are labeled as A and B on the process flow diagrams. The laboratory process flow diagram shows only one of these two fermentation seed trains. They occur in the process in a staggered manner to be later described.

The laboratory section begins with a 1 mL aliquot or inoculum of *E. coli*, which is a hypothetical naturally occurring strain of the microorganism that has been shown to anaerobically ferment glycerol to ethanol (as per the problem statement). It is stored frozen in the laboratory. The reactions and conversions of glycerol by the organism (given in the problem statement) are summarized below:

Glycerol **à** CO_2 + H_2 + Ethanol (98%)

CO_2 + Glycerol **à** Succinic Acid + H_2O (1%)

Glycerol **à** 3.0075(Biomass) + H_2O (1%)

The problem statement specifies that a sample volume of *E. coli* may be grown to a volume equal to 20 times that of the original sample in each successive scale-up step. The problem statement additionally specifies a desired end ethanol titer of 100 g/L, and an ethanol production rate of 1.6 grams ethanol formed per liter of reaction volume per hour. Dimensional analysis reveals that 62.5 hours are required for the first scale-up, in which the 1 mL aliquot is added to ~19 mL of sterilized glycerol feed in a vapor-locked 25 mL test tube (Seed Ferm 1A/1B) to provide a working volume of 20 mL. The volume of the reaction changes over time, so the volume requirements are approximations. The optimal pH of 7, temperature of 37 °C, and anaerobic conditions are maintained.

The 20 mL portion is then transferred to a second vapor-locked seed fermenter (Seed Ferm 2A/2B) with a volume of 500 mL. Sterilized glycerol feed is added to create a working volume of about 400 mL. The time for reaction is reduced to 60 hours, as the sample added to Seed Ferm 2A/2B already contains a small portion of ethanol. This 400 mL sample is then charged to the last laboratory stage fermenter (Seed Ferm 3A/3B), with a working volume of 8 L and an actual volume of 10 L and 304 stainless steel construction. The volume difference is made up with the sterilized glycerol feed. Another 60 hour reaction period follows. Then, the 8 L volumes of prepared cells are taken to the plant seed fermentation section, where they are added to the first plant seed fermenters (Seed Ferm 4A/4B).

Plant Seed Fermentation Section

The 8 L samples from the largest lab scale fermenters (Seed Ferm 3A/3B) provide the *E. coli* source for the first plant scale fermenters (Seed Ferm 4A/4B), with working volumes of 160 L. Pumped into these 200 L, 304 stainless steel vessels, is a ~152 L portion of the sterilized glycerol feed from the feed preparation section. The reaction proceeds for 60 hours. In this and all subsequent fermenter units, the optimal pH of 7, temperature of 37 °C, and anaerobic conditions are maintained. A slight positive pressure (14.8 psia) as suggested in the problem statement maintains the anaerobic condition required for the reaction.

The total volume from Seed Ferm 4A/4B is then pumped to Seed Ferm 5A/5B, which are 4,500 L vessels of 304 stainless steel construction. Sterilized glycerol feed from the feed preparation section is pumped to the fermenters to provide a working volume of ~3,200 L. The reaction proceeds for 60 hours. Then, the total volume from Seed Ferm 5A/5B is pumped to Seed Ferm 6A/6B, which are 85,000 L vessels of 304 stainless steel construction. Sterilized glycerol feed from the feed preparation section is pumped to the fermenters to provide a working volume of ~64,000 L. The reaction proceeds for 60 hours. The volume from Seed Ferm 6A/6B is then pumped to Seed Ferm 7A/7B, which are 650,000 L vessels of 304 stainless steel construction. Sterilized glycerol feed from the feed preparation section is pumped to the fermenters to provide a working volume of ~460,000 L. This volume is not a multiple of twenty from the previous scale fermenter, but rather it is determined by the portion of *E. coli* solution required for charging the twelve fermenters in the main fermentation section. After the 60 hour fermentation period, one sixth of the solution contained in Seed Ferm 7A/7B (~77,090 L) is pumped to one of the large fermenter (FERM1-12) units in the main fermentation section. This volume corresponds to 1/20 of the working volume required in the large scale fermenters, which have an initial working volume of 1,577,624 and an end working volume of 1,525,404 L.

The hydrogen and carbon dioxide gas evolved from these fermenters, along with the small portions of ethanol and water vaporized (4.9% and 0.49% by mass respectively) are sent through a blower (B-101) to the Absorber column (AB-1) in the separation section.

Main Fermentation Section

Twelve 2,000,000 L fermenter tanks of 304 stainless steel construction are the most important part of the process, where the majority of the ethanol and succinic acid are produced in a fully staggered batch processing mode. These fermenters also represent the bottleneck in the process schedule. The schedule of charging, fermenting, and draining in these fermenters is presented in Table PD-2.

Cycle based on largest fermenters (bottleneck):	time (hr)
Charge with biomass from Seed 7A/B	27 (stagger time)
Charge with glycerol feed from T-106	5
Ferment/React	60
Drain to T-107 (95%)	5
Charge with glycerol feed	5
Ferment/React	60
Drain to T-107 (95%)	5
Charge with glycerol feed	5
Ferment/React	60
Drain to T-107 (100%)	5
Clean-in-Place	60
Total	297 hours

Table PD-2. Schedule for Batch Operation in Main Fermentation Section

One cycle consists of three fermentation/ reaction periods or batches, as seen above. All flow rate values in the batch material balance blocks refer to the flow requirements for one batch within each three-batch cycle.

Before the first fermentation period, each FERM-1 through FERM-12 tank is charged with a volume from the smaller reactor Seed Ferm 7A/B (this volume corresponding to 1/20 of total FERM1 working volume), and then charged with sterilized glycerol feed from T-106 to reach the full working volume of ~1,525,404 L. The fermentation proceeds for 60 hours.

After the first fermentation period, however, in FERM1 – FERM12, 5% (1/20) of the volume is saved in the fermenter tank rather than drained to T-107. This portion remains as the seed from which the next reaction period begins. Therefore only 95% of the material proceeds to the continuous process at this point. After the second 60-hour fermentation period in FERM1-FERM12, 5% of the volume is again retained. After the third fermentation, 100% is drained so that the tank can be cleaned.

Shuler & Kargi outline the process of cell/biomass recycle and warn against it only in the case of genetically modified cells. Oftentimes in industrial processes, new *E. coli* cells are provided for every fermentation step (all grown from separate seed trains). However, the *E. coli* cells are not genetically modified, and are a wild strain, so there is little risk for genetic mutations. By recycling biomass, the cost for the landfill of solids is greatly reduced, and the number of seed fermenters is minimized. Due to the 95% draining for the first and second fermentation periods, to convert from batch to continuous in the mass balances, a multiplying factor of 2.9 (rather than 3) must be used, for determining the total liquid flow rate leaving the batch section over the 297 hour cycle time.

Cleanliness dictates that eventually new biomass is used, however, as the sterilization of the equipment and incoming feed may not have been 100% effective. The number of fermentation periods before cleaning, three, was suggested by industrial consultant Mr. Bruce Vrana, along with the 60 hour duration of the cleaning period. The cleaning system is designed as a clean-in-place system with a series of spray nozzles which will apply a dilute caustic solution to the inside of the fermentation units.

The slightly exothermic fermentation reaction corresponds to an adiabatic temperature rise of about 10.4 °F in each FERM1-12 unit, so a pump and heat exchanger (HX-FERM) are designed to maintain the optimal temperature of 37 °C (98.6 °F) by recirculating the material in the fermentation units for the duration of the fermentation periods.

At the end of each fermentation period, the fermentation broth in each reactor contains about 10% ethanol by mass. The “beer” or broth is pumped from each fermenter unit to the fermentation broth holding tank, T-107. From this tank, broth is fed to the separation section, starting at HX-3.

The hydrogen and carbon dioxide gases evolved from these fermenters, along with the small portions of ethanol and water vaporized (4.9% and 0.49% by mass respectively) are sent through a blower (B-101) to the Absorber column (AB-1) in the separation section for further ethanol recovery.

A visualization of the staggered schedule time is provided in Figure PD-1. Three separate 3-batch, 297 hour cycles are displayed in the Gantt chart. The top bands of the Gantt chart represent the two seed fermentation trains, with seed fermenter 7A/7B represented by the bands with the gray portions, and the bottom bands represent the twelve 2,000,000 L fermentation tanks, with three 60 hour reaction times and one 60 hour cleaning time.

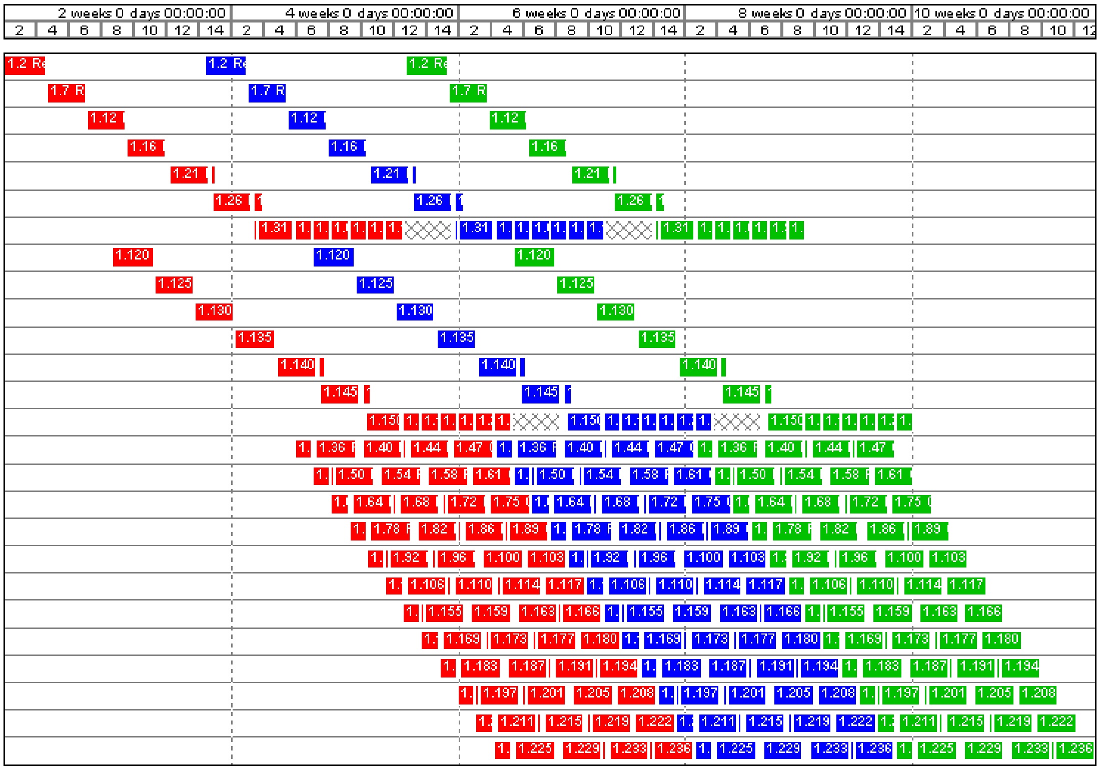


Figure PD-1. Gantt Chart: Schedule for Batch Operation in Main Fermentation Section

Separation Section

The separation section serves several purposes: recovering ethanol from the vapor phase leaving the fermenters, separating biomass from the fermentation broth, separating ethanol from water and succinic acid, and finally separating succinic acid from water.

The biomass is separated in two steps, first through a rotary drum filter (RDF-1) which removes 266.5 kg/hr of biomass. The remaining 29.6 kg/hr is removed through a hopper in the bottom of the distillation tower.

There are two ethanol feeds to the separations section of the plant. First and mainly, ethanol is fed from the fermenters through stream S-S-109. First, HX-3 heats up the fermentation broth to 92°C, past the deactivation temperature of *E. coli*, by utilizing the heat from the bottoms stream of the distillation tower to reduce the re-boiler heat duty. After filtering out the biomass, this stream is fed into the distillation column (D-1). The second feed comes from the vapor released from the fermenters during the reaction period. This feed is supplied to the absorber tower AB-1 which absorbs the ethanol from the vapor. This stream is then fed into the distillation tower. The remaining vapor from AB-1, which contains a significant quantity of hydrogen, is fed into the furnace which supplies part of the reboiler heat duty.

The distillation tower (D-1) is the main ethanol separation section. According to the molecular sieve specification information from Mr. Bruce Vrana, the column top product must be at least 92% by weight ethanol. The third feed to the tower is a recycle stream from the molecular sieves, which is used to purge the water extracted from the azeotropic feed. There are 32 theoretical stages which correlate to 79 internal actual stages plus the reboiler and condenser. The reboiler has a heat duty of 110.7MMBtu/hr, of which, 76.9MMBtu/hr is provided by the furnace (FN-1) which is fed by the hydrogen from the fermenters, while the remaining 33.8MMBtu/hr is provided by steam through a kettle vaporizer heat exchanger (HX-6). The condenser is a partial condenser because the feed to the molecular sieve must be vapor. The condenser heat duty is -68.1MMBtu/hr, which is provided by cooling water through a heat exchanger (HX-4).

The molecular sieves (MS-1) produce a stream of pure ethanol (>99.5% by weight) (S-S-112). However, in order to desorb the water from the molecular sieves, 20% of the ethanol produced must be used to flush the water out of the system, resulting in a steam with 37% by weight water (the remainder ethanol) that must be recycled to the distillation column in stream S-S-123. Stream S-S-123 can vary in composition according to the problem statement, so the distillation column was designed to produce 92.5% by weight Ethanol as the distillate so that small fluctuations do not result in lower than 92% by weight ethanol concentrations fed to the molecular sieves.

The pure ethanol is then cooled to reduce its volatility in heat exchanger HX-5, which uses a cooling water utility. The ethanol is then denatured with Gasoline to 5% by volume before being stored to be sold.

The bottoms product from the distillation column feeds into the section where succinic acid is separated. Here the feed contains water, succinic acid, and some remnants of corn steep liquor (mostly water and any salts not consumed by growing *E. coli*). Succinic acid is minimally soluble in water, while the salts in corn steep liquor are highly soluble. All solids that were part of the corn steep liquor have already been filtered out by RDF-1 and the hopper in the distillation column. In stream S-S-116 the concentration of succinic acid is 2.62 g/L, just below the solubility point of about 3 g/L. Electrodialysis can increase the concentration of succinic acid by at least four times according to Meynial-Salles et al. At 10.4 g/L or more, the succinic acid and corn steep liquor is fed into the crystallizer where the succinic acid precipitates to 3 g/L. The liquid is then re-circulated to the concentrated steam of the electro-dialysis unit to reduce the loss of succinic acid. 10% by volume of the electro-dialysis solution is replenished by stream S-S-127, while 10% by volume is purged in S-S-134 to provide an outlet for the corn steep liquor. As the exact manner in which the corn steep liquor and succinic acid will precipitate is more difficult to model, excessive quantities of purging and low increases in concentration through the electro-dialysis have been assumed to ensure the cost is lower than calculated. The specifics of this portion will need to be found through direct experimentation with the system. The succinic acid crystals are then dried in DR-1 before being stored and sold.

Energy Balance and Benchmark

Section V

Energy Balance and Benchmark

According to the problem statement, a current energy benchmark for a corn-based ethanol plant is 35,000 BTU/gallon of product. This includes all heat and electricity required by the process, excluding fuel required for the main distillation tower reboiler (as suggested in the problem statement, page 266). The bulk of this energy is likely used for processing corn solids. The glycerol to ethanol process has heating feeds of low pressure steam and high pressure steam, as well as electricity consumption. The total energy usage is 8,002 BTU/gallon ethanol, well below the benchmark number, broken down as follows:

	$/year	$/kg	kg/year	BTU/year	BTU/gallon ethanol
50 psig Steam	914,652	0.0066	138,583,668	279,523,258,356	5,552
	$/year	$/kg	kg/year	BTU/year	BTU/gallon ethanol
150 psig Steam	336,377	0.0105	32,035,925	60,611,969,722	1,204
	$/year	$/kW-hr	kW-hr/year	BTU/year	BTU/gallon ethanol
Electricity	1,103,316	0.0600	18,388,608	62,760,317,398	1,247
					BTU/gallon ethanol
				Total:	8,002

Table E-2. Energy consumption in BTU/gallon of Ethanol for Energy Benchmark Comparison.

Energy use has been reduced significantly by two means. First, the hydrogen produced in the fermenters is fed to a furnace which provides most of the heat duty required for the reboiler. This reduces the amount of steam required for the plant. Second, the water from the bottoms product of the distillation column is fed back into a heat exchanger (HX-3) to heat sterilize the feed to the column and to reduce the energy requirement on the reboiler. The distillation column was also designed with minimal reflux, which reduces the heat requirement of the reboiler even further.

In the glycerol feed preparation stage, continuous sterilization of the fermentation medium is performed using heat exchangers HX-1 and HX-2. HX-1 is used to reduce energy requirements of the plant. Glycerol is fed at 25°C and heated to 111°C by the sterilized glycerol, which enters at 121°C and exits at 37°C and transfers 59.6 MMBTU/hr. See calculations on page 226.

As the broth from the fermenter is fed to the distillation column, HX-3 heats the feed to reduce the heat requirement of the re-boiler and deactivate the *E. coli* in the fermentation broth. This is done by using the water from the bottoms product of the tower. Feed enters at 37°C and is heated to 92.2°C while cooling the water from 109°C to 43.3°C. Both HX-1 and HX-3 save the energy required to heat the stream and the cooling water that would have been necessary to cool the other stream.

Furnace FN-1 is used to take advantage of the hydrogen energy source produced in the fermenters. Hydrogen would be expensive to isolate and package, however the process takes advantage of the hydrogen energy content by using it to supply heat to the reboiler. By combusting the hydrogen, 76.9 MMBTU/hr is able to be transferred to the reboiler at no cost.

In addition to the balances discussed above, additional energy requirements are necessary to provide cooling, heating and power during the process. Cooling is needed in the condenser of the distillation column, in HX-5 to cool the ethanol to reduce volatility, and in HX-FERM (1-12) to cool the fermenters during reaction times. A portion of chilled water is mixed with the cooling water to cool the fermenters.

Low pressure steam is used in the distillation tower reboiler (HX-6) and for the molecular sieves (MS-1). High pressure steam is used to heat the glycerol sterilizer (HX-2) due to the high temperature required. Electricity is used to run all the agitators, pumps, blowers, rotary drum filter, electro-dialysis system, and molecular sieves.

Shown below are the energy requirements of our process broken down by utility type. Utilities which remove heat have been included here, such as cooling water and chilled water.

150 psig Steam

Equipment	kg/hr		cost($/1000 kg)	Cost/hour	Cost/year
HX-2	4045		$10.50	$42.47	$336,377.21
Total:					$336,377.21

50 psig Steam

Equipment	kg/hr		cost($/1000 kg)	cost/hr	cost/yr
HX-6	16775		$6.60	$110.72	$876,862.80
MS-1	723		$6.60	$4.77	$37,789.41
Total:					$914,652.21

Cooling Water

Equipment	l/hr	m^3/hr	$/m^3	cost/hr	
HX-4	1087870	1087.87	$0.02	$21.76	$172,318.61
HX-5	23766	23.77	$0.02	$0.48	$3,764.55
MS-1	447318	447.32	$0.02	$8.95	$70,855.17
HX-FERM	21003	21.00	$0.02	$0.42	$2,015.78
Total:					$248,954.11

Chilled Water

Equipment	BTU/HR	BTU/day	$/btu	$/day	$/yr
HX-FERM	298540	7164949.62	$0.0000041667	$29.85	$9,851.81
Total:					$9,851.81

Electricity

Equipment	HP	Kw	cost($ / kW-hr)	cost/hr	cost/yr
P-S-101	68	50.67	$0.06	$3.04	$24,078.53
P-S-102	37	27.82	$0.06	$1.67	$13,221.04
P-S-104	10	7.81	$0.06	$0.47	$3,710.11
P-S-105	15	11.12	$0.06	$0.67	$5,283.46
P-S-106	68	50.92	$0.06	$3.05	$24,195.47
P-S-107	47	34.91	$0.06	$2.09	$16,587.43
P-S-108	7	5.30	$0.06	$0.32	$2,516.47
CB-1	1	0.75	$0.06	$0.04	$354.36
RDF-1	12	8.78	$0.06	$0.53	$4,173.26
Agitator for T-108	4	2.98	$0.06	$0.18	$1,417.43
ED-1					$190,200.00
B-102	1603	1195.09	$0.06	$71.71	$567,908.07
MS-1				$4.77	$37,789.41
P-FA A	67	50.13	$0.06	$3.01	$1,202.75
P-FA B	67	50.13	$0.06	$3.01	$1,202.75
P-FB A	2	1.72	$0.06	$0.10	$445.47
P-FB B	2	1.72	$0.06	$0.10	$445.47

P-FC A	43	31.89	$0.06	$1.91	$4,591.53
P-FC B	43	31.89	$0.06	$1.91	$4,591.53
P-FD	37	27.55	$0.06	$1.65	$13,089.93
B-101	416	310.51	$0.06	$18.63	$89,404.36
Agitators Ferm 1-12	240	178.97	$0.06	$10.74	$51,529.89
Agitator for T-107	20	14.91	$0.06	$0.89	$7,087.13
P-FE(1-12)	44	32.66	$0.06	$1.96	$9,404.20
P-101A	1	0.83	$0.06	$0.05	$0.13
P-101B	1	0.83	$0.06	$0.05	$0.13
P-102A	7	5.59	$0.06	$0.34	$8.93
P-102B	7	5.59	$0.06	$0.34	$8.93
P-103A	11	8.03	$0.06	$0.48	$12.84
P-103B	11	8.03	$0.06	$0.48	$12.84
P-104A	20	15.10	$0.06	$0.91	$96.62
P-104B	20	15.10	$0.06	$0.91	$96.62
P-105A	1	0.91	$0.06	$0.05	$0.15
P-105B	1	0.91	$0.06	$0.05	$0.15
P-106A	9	6.91	$0.06	$0.41	$1.10
P-106B	9	6.91	$0.06	$0.41	$1.10
P-107A	14	10.20	$0.06	$0.61	$16.32
P-107B	14	10.20	$0.06	$0.61	$16.32
Agitator for Ferm6A	2	1.67	$0.06	$0.10	$482.12
Agitator for Ferm6B	2	1.67	$0.06	$0.10	$482.12
Agitator for Ferm7A	17	12.80	$0.06	$0.77	$3,686.79
Agitator for Ferm7B	17	12.80	$0.06	$0.77	$3,686.79
P-FP-01	9	6.96	$0.06	$0.42	$3,308.48
P-FP-02	34	25.11	$0.06	$1.51	$11,934.38
P-FP-03	0	0.11	$0.06	$0.01	$51.66
P-FP-04	5	3.75	$0.06	$0.22	$1,780.29
P-FP-05	2	1.14	$0.06	$0.07	$542.02
P-FP-06	45	33.88	$0.06	$2.03	$16,099.56
Agitator for T-105	33	24.31	$0.06	$1.46	$11,552.02
Total:					$1,103,316.45

Table E-2. Energy Utility Requirements for the Process.

Unit Descriptions

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Feed Preparation Section

Storage Tanks:

Crude Glycerol Storage Tank T-101

Base Purchase Cost: $ 564,600

T-101 is a floating roof storage vessel constructed of 304 stainless steel with a volume of 3,165,300 L. This tank holds the crude glycerol feedstock that comes as the byproduct of the biodiesel industry. The feed is assumed to be at standard temperature and pressure conditions of 25°C and 1 atm and will be stored at these conditions. This storage tank holds three days worth of feed and has a working volume of 80%. Stream S-FP-101 leaves this holding tank at a flow rate of 35,170 L/hr and flows through pump P-FP-01 then to the Glycerol Purification System, R-101. The composition of the crude glycerol feedstock is assumed to be 85% glycerol, 7% water, 4% salts, and 4% MONG (Matter Organic, Non-Glycerol) by weight, as per the suggested average crude glycerol feed (EET Corporation). These percentages were used for completing the material balance, however, it should be noted that crude glycerol is characterized by an unpredictable composition. The process has been designed to be flexible regarding the glycerol feedstock composition. The vessel has a floating roof due the possible presence of methanol or other volatiles in the crude glycerol feedstock.

Calculations on page 242.

Cornsteep Liquor Storage Tank T-103

Base Purchase Cost: $49,600

T-103 is a cone roof storage vessel constructed of 304 stainless steel with a volume of 83,500 L. This vessel stores three days worth of corn steep liquor, a material that provides minerals and amino acids for the *E. Coli*. Stream S-FP-106 leaves this tank at a flow rate of 927 L/hr and flows through pump

P-FP-03 then into mixing tank, T-105.The corn steep liquor will be stored at a temperature of 25 °C and a pressure of 1 atm. The storage tank is assumed to have a working volume of 80%.

Calculations on page 225.

Brine Storage Tank T-104

Base Purchase Cost: $65,700

T-104 is a cone roof storage vessel constructed of 304 stainless steel with a volume of 145,000 L. This is one day's worth of salt solution (brine 36% by weight) extracted from the glycerol feed. It will be stored at a temperature of 25°C and a pressure of 1 atm. Stream S-FP-103 flows into this tank via pump P-FP-05, from the Glycerol Purification System at a flow rate of 4,832 L/hr. The storage tank is assumed to have a working volume of 80%. Salt water will leave the process from this tank to be sent to the ocean.

Calculations on page 242.

Mixing Tank T-105

Base Purchase Cost: $ 42,500

T-105 is a cone roof storage vessel constructed of 304 stainless steel with a volume of 61,730 L. Streams S-FP-115 (fresh water), S-P-104 (purified glycerol/water mixture), S-FP-105 (recycle water) and S-FP-106 (corn steep liquor) all flow into this tank for mixing. The tank is assumed to have a working volume of 50% and a residence time of 10 minutes. It is assumed to operate at 25 °C and 1 atm. The tank has an agitator (turbine, closed tank) for mixing that is priced at $29,900 (see page 210) including the motor and shaft costs.

Calculations on page 242.

Sterilized Feed Holding Tank T-106

Base Purchase Cost: $ 338,000

T-106 is a floating roof storage vessel constructed of 304 stainless steel with a volume of 1,157,500 L. This tank is the transition point between the continuous feed preparation section and the batch fermentation sections. Sterilized feed in stream S-FP-112 flows into this tank at a flow rate of 185,192 L/hr then out to the fermentation stage section. The sterilized feed is stored at a temperature of 25 °C and a pressure of 1 atm. This storage tank is assumed to have a working volume of 80%.

Calculations on page 242.

Heat Exchangers:

HX-1

Base Purchase Cost: $132,300

HX-1 is a floating head shell and tube heat exchanger that preheats the feed from mixing tank T-105 before it enters HX-2. This preheating reduces the amount of steam needed in HX-2 to bring the feed to the sterilization temperature 121°C (250 °F) and cools the sterilized feed to the required fermentation temperature. Stream S-FP-114 is heated from 25°C to 111°C (or 77 °F to 231.86 °F) by the hot sterile feed from HX-2, S-FP-109 that is cooled from 121 °C to 37 °C (or 250 °F to 98.6 °F). The heat duty is 59,665,811 BTU /hr. The heat exchanger is 304 stainless steel shell side/ 304 stainless steel tube side since both sides are in contact with feed.

Calculations on page 226.

HX-2

Base Purchase Cost: $22,100

Pre heated stream Feed (S-FP-108) is heated further by steam from 111°C to 121°C (or from 231.86°F to 250° F). This is the sterilization temperature (for all organisms, spores). This is a floating head shell and tube heat exchanger.. The heat duty is 7,738,512 BTU/hr. This exchanger is a carbon steel shell side / 304 stainless steel tube side because the shell side material is steam.

Calculations on page 226.

Pumps:

P-FP-01

Base Purchase Cost: $ 4,500

This is a centrifugal pump constructed of 304 stainless steel that pumps crude glycerol from tank T-101 to the Glycerol Purification System. The flow rate through the pump is 35,170 L/hr. The energy requirement for the pump is 9.34 Hp and the pump operates at an efficiency of 0.59 while the motor operates at an efficiency of 0.82. A pressure change of 50 psia (344 kPa) was assumed as a result of frictional forces of the fluid flow.

Calculations on page 233.

P-FP-02

Base Purchase Cost: $ 8,400

This is a centrifugal pump constructed of 304 stainless steel that pumps process water to the mixing tank T-105 for dilution of the glycerol feed. The flow rate through the pump is 151,105 L/ hr. The energy requirement for the pump is 33.68 Hp and the pump operates at an efficiency of 0.74 while the motor operates at an efficiency of 0.83. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of the fluid flow.

Calculations on page 233.

P-FP-03

Base Purchase Cost: $ 4,100

This is a centrifugal pump constructed of 304 stainless steel that pumps corn steep liquor from tank T-103 to the mixing tank T-105. The flow rate through the pump is 927 L/ hr. The energy requirement for the pump is 0.15 Hp and the pump operates at an efficiency of 0.60 while the motor operates at an efficiency of 0.76. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

P-FP-04

Base Purchase Cost: $ 3,900

This is a centrifugal pump constructed of 304 stainless steel that pumps a glycerol/water solution from the Glycerol Purification System R-101 to the mixing tank T-105. The flow rate through the pump is 32,356 L/ hr. The energy requirement for the pump is 5.02 Hp and the pump operates at an efficiency of 0.58 while the motor operates at an efficiency of 0.82. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

P-FP-05

Base Purchase Cost: $ 3,500

This is a centrifugal pump constructed of 304 stainless steel that pumps a salt solution from the Glycerol Purification System R-101 to the Brine Storage Tank T-104. The flow rate through the pump is 4,832 L/ hr. The energy requirement for the pump is 1.53 Hp and the pump operates at an efficiency of 0.31 while the motor operates at an efficiency of 0.80. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

P-FP-06

Base Purchase Cost: $ 10,100

This is a centrifugal pump constructed of 304 stainless steel that pumps mixed feed solution from the mixing tank T-105 through the sterilization heat exchangers and then to the Sterilized Feed Storage Tank T-106. The flow rate through the pump is 185,192 L/ hr. The energy requirement for the pump is 45.53 Hp and the pump operates at an efficiency of 0.76 while the motor operates at an efficiency of 0.83. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow .

Calculations on page 233.

Miscellaneous:

Glycerol Purification System R-101

Estimated Purchase Cost: $ 430,800

The Glycerol Purification System is a licensed unit purchased from EET Corporation that has the ability to purify a variety of incoming crude glycerol feeds from the biodiesel industry. It removes MONG (Matter Organic Non-Glycerol, typically monoglycerides, diglycerides, and free fatty acids), any methanol present, chloride or phosphate salts, and any solids. The glycerol purification system uses the patent pending (See Appendix C for patent application) HEED® (High-Efficiency Electro-Dialysis) and HEEPM® (High-Efficiency Electro-Pressure Membrane) technologies, in parallel with reverse osmosis, to purify the crude glycerol stream S-FP-101. The output from the process is a cake of MONG that, at the suggestion of industrial consultant Mr. Bruce Vrana can be given to farmers for use as a nutrient (S-FP-113), a concentrated salt water solution (S-S-103) that can be sent to the ocean, and a glycerol/water solution (S-FP-104) that is sent to the mixing tank T-105 to be combined with water and corn steep liquor for feed preparation. The quantity of crude glycerol purified by the system will depend on the feed, but at the average value of 85 % by weight glycerol in the crude glycerol feed, the system will handle 43,370 kg solution per hour, removing 1,735 kg/hr of MONG and 1,735 kg/hr of salts. Although precise technical information was not available from EET Corporation, extensive information from the EET Corporation website is provided in Appendix D. Operating costs for the glycerol purification system were not estimated because technical specifications were not available.

Calculations on page 225.

Seed Fermentation Train (Plant and Lab)

Fermenters:

Laboratory Scale Fermenters (Seed Ferm 1A/1B, Seed Ferm 2A/2B, Seed Ferm 3A/3B) (2 each)

Every 297 hour cycle starts with two 1mL aliquots of *E. Coli* cells, one for seed fermentation train A, and one for seed fermentation train B. The cells are grown to larger volumes in a train of fermenters, where each successive fermenter working volume is 20 times the size of the initial, because 2,000,000 L tanks cannot be charged with 1 mL portions of cells (too much dilution). Each cell aliquot is charged first to either Seed Ferm 1A or 1B (test tubes with volumes of 25 mL), then grown up in each successive laboratory-sized fermenter (Seed 2A/2B: 400 mL of solution in 500 mL flask, Seed 3A/3B: 8 L of solution in 10 L tank) until the contents of Seed Ferm 3A/3B can be transferred to 200 L tanks Seed Ferm 4A/4B in the plant-scale section. The cells are grown in these fermenters for 60 hours, until the ethanol concentration is 100 g/L, at a temperature of 37°C, 14.8 psia and pH 7, consuming the same glycerol feed solution that is used in the plant-scale section. The positive pressure maintains the anaerobic condition required for fermentation. These fermenters are made of glass (test tube, flask) or 304 stainless steel (tank).

Calculations on page 220.

Seed Ferm 4A/4B (2)

This is the first vessel outside of the laboratory setting in the seed fermentation train. This vessel is constructed of 304 stainless steel and has a capacity of 200 L, while its working volume is 78-81% of this value. The product from Seed Ferm 3A is gravity-transferred to Seed Ferm 4A, and the product from Seed Ferm 3B is gravity-transferred to Seed Ferm 4B. This product contains enough *E. coli* to grow in a fermenter unit of this size. Sterilized feed is pumped from the Sterilized Feed Holding Tank T-106 to the units through pumps P-101 (1 and 2). The fermenter has a height of 3.30 ft and diameter of 1.65 ft.

Optimal growth conditions of 37°C, 14.8 psia and pH 7 are maintained in the vessel. The positive pressure maintains the anaerobic condition required for fermentation. The fermentation time is 60 hours since the end ethanol concentration is 100 g/L. The product from this is fed to either Seed Ferm 5A or Seed Ferm 5B.

Calculations on page 220.

Seed Ferm 5A/5B (2)

Base Purchase Cost: $30,700

This is the second vessel outside of the laboratory setting, in the plant-scale section. The vessel is constructed of 304 stainless steel and has a capacity of 4,500 L, while its working volume is 70-72% of this value. The product from Seed Ferm 4A is pumped to Seed Ferm 5A through pump P-105 (1) or the product from Seed Ferm 4B is pumped to Seed Ferm 5B through pump P-105 (2). Sterilized feed is pumped from the Sterilized Feed Holding Tank T-106 to the units through pumps P-102 (1 and 2).The fermenter has a height of 9.31 ft and diameter of 4.66 ft. Optimal growth conditions of 37°C, 14.8 psia and pH 7 are maintained in the vessel. The positive pressure maintains the anaerobic condition required for fermentation. The fermentation time for this is 60 hours since the end ethanol concentration is 100 g/L. The product from this is fed to either Seed Ferm 6A or Seed Ferm 6B.

Calculations on page 220.

Seed Ferm 6A/6B (2)

Base Purchase Cost: $ 100,900

This is the third vessel outside of the laboratory setting, in the plant-scale section. The product from Seed Ferm 5A is pumped to Seed Ferm 6A through pump P-106 (1) or the product from Seed Ferm 5B is pumped to Seed Ferm 6B through pump P-106 (2). The vessel is constructed of 304 stainless steel and has a capacity of 85,000 liters, while its working volume is 74-77% of this value. Sterilized feed is pumped from the Sterilized Feed Holding Tank T-106 to the units through pumps P-103 (1 and 2).The fermenter has a height of 24.81 ft and diameter of 12.41 ft. Optimal growth conditions of 37°C, 14.8 psia and pH 7 are maintained in the vessel. The positive pressure maintains the anaerobic condition required for fermentation. The fermentation time for this is 60 hours since the end ethanol concentration is 100 g/L. The product from this is then fed to Seed Ferm 7A/7B.). Seed fermenters 6A and 6B have 304 stainless steel agitators to maintain cell suspension and prevent adverse temperature or pH gradients. These agitators have a base purchase cost of $6,500.

Calculations on page 220.

Seed Ferm 7A/7B (2)

Base Purchase Cost: $ 150,400.00

This is the last fermentation vessel in the seed train. The vessel is constructed of 304 stainless steel and has a capacity of 650,000 liters. The working volume ranges from 70-72%. One sixth of the working volume of each of these two fermenters is fed to each one of the large-scale fermenters FERM1-12 during the cycle. One sixth of the working volume of Seed Ferm 7A is equivalent to the 1/20 by volume portion required to charge fermenters FERM1-12. The volume transferred to each large fermenter is ~77,090 L. Therefore the working volume of these tanks is approximated to ~460,000 L. The product from Seed Ferm 6A is pumped to Seed Ferm 7A through pump P-107 (1) or the product from Seed Ferm 6B is pumped to Seed Ferm 7B through pump P-107 (2). Sterilized feed is pumped from the Sterilized Feed Holding Tank T-106 to the units through pumps P-104 (1 and 2).The fermenter has a height of 48.88 ft and diameter of 24.44 ft. Optimal growth conditions of 37°C, 14.8 psia and pH 7 are maintained in the vessel. The positive pressure maintains the anaerobic condition required for fermentation. The fermentation time for this is 60 hours since the end ethanol concentration is 100 g/L. One sixth of the working volume of each 7A/7B reactor is fed to each of the fermenters FERM 1 through FERM 6 (from Seed Ferm 7A) through pump P-FB (1) or fermenters FERM through FERM 12 (from Seed Ferm 7B) through pump P-FB (2). Seed fermenters 7A and 7B have 304 stainless steel agitators to maintain cell suspension and prevent adverse temperature or pH gradients. These agitators have a base purchase cost of $20,700.

Calculations on page 220.

Pumps:

P-101 (2)

Base Purchase Cost: $3,700

This is a centrifugal pump constructed of 304 stainless steel that pumps sterilized feed from T-106 to the first plant scale fermentation tank, which is either Ferm 4A or Ferm 4B. Sterilized feed flows through the pump at a flow rate of 2600 L/ hr. The energy requirement for the pump is 1.12 Hp and the pump operates at an efficiency of 0.20 while the motor operates at an efficiency of 0.80. The pump head is 59.21 ft. The pressure change across the pump, neglecting friction, is 10.2 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow. The pump runs for 0.06 hours of the 297 hour cycle.

Calculations on page 233.

P-102 (2)

Base Purchase Cost: $4,400

This is a centrifugal pump constructed of 304 stainless steel that pumps sterilized feed from T-106 to the second plant scale fermentation tank, which is either Ferm 5A or 5B. Sterilized feed flows through the pump at a flow rate of 51,950 L/ hr. The energy requirement for the pump is 7.49 Hp and the pump operates at an efficiency of 0.63 while the motor operates at an efficiency of 0.82. The pump head is 64.97 ft. The pressure change across the pump, neglecting friction is 28.9 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow. The pump runs for 0.06 hours of the 297 hour cycle. Calculations on page 233.

P-103 (2)

Base Purchase Cost: $4,900

This is a centrifugal pump constructed of 304 stainless steel that pumps sterilized feed from T-106 to the third plant scale fermentation tank, which is either Ferm 6A or 6B. Sterilized feed flows through the pump at a flow rate of 62,325 L/ hr. The energy requirement for the pump is 10.76 Hp and the pump operates at an efficiency of 0.65 while the motor operates at an efficiency of 0.82. The pump head is 80.46 ft. The pressure change across the pump, neglecting friction is 76.9 kPa . An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow. The pump runs 1 hour of the 297 hour cycle.

Calculations on page 233.

P-104 (2)

Base Purchase Cost: $6,400

This is a centrifugal pump constructed of 304 stainless steel that pumps sterilized feed from T-106 to the fourth plant scale fermentation tank, which is either Ferm 7A or 7B. Sterilized feed flows through the pump at a flow rate of 96,683 L/ hr. The energy requirement for the pump is 20.25 Hp and the pump operates at an efficiency of 0.70 while the motor operates at an efficiency of 0.82. The pump head is 104.5 ft. The pressure change across the pump, neglecting friction is 151.5 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow. The pump runs 4 hours of the 297 hour cycle.

Calculations on page 233.

P-105 (2)

Base Purchase Cost: $3,600

This is a centrifugal pump constructed of 304 stainless steel that pumps the volume of product in S-106 either from seed Ferm 4A into seed Ferm 5A or seed Ferm 4B to seed Ferm 5B. It pumps liquid at a rate of 2,628 L/ hr. The energy requirement for the pump is 1.22 Hp and the pump operates at an efficiency of 0.20 while the motor operates at an efficiency of 0.80. The pump head is 69.1 ft. The pressure change across the pump, neglecting friction is 26.9 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow. The pump runs 0.06 hours of the 297 hour cycle.

Calculations on page 233.

P-106 (2)

Base Purchase Cost: $4,700

This is a centrifugal pump constructed of 304 stainless steel that pumps the volume of product in S-107 either from Ferm 5A into Ferm 6A or seed Ferm 5B to Ferm 6B. It pumps liquid at a rate of 53,349.40 L/ hr. The energy requirement for the pump is 9.26 Hp and the pump operates at an efficiency of 0.64 while the motor operates at an efficiency of 0.82. The pump head is 84.7 ft. The pressure change across the pump, neglecting friction is 71.5 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow. The pump runs 0.06 hours of the 297 hour cycle.

Calculations on page 233.

P-107 (2)

Base Purchase Cost: $5,300

This is a centrifugal pump constructed of stainless steel 304 that pumps the volume of product in S-108 from either Ferm 6A into Ferm 7A or seed Ferm 6B to Ferm 7B. It operates at a rate of

63,293.21 litres/ hr. The energy requirement for the pump is 13.68 Hp and the pump operates at an efficiency of 0.66 while the motor operates at an efficiency of 0.82. The pump head is 108.7 ft. The pressure change across the pump, neglecting friction is 141.0 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow. The pump runs 1 hour of the 297 hour cycle.

Calculations on page 233.

Main Fermentation Section

Fermenters:

FERM 1-12 (12)

Base Purchase Cost: $341,500

The most important units in the fermentation process are the large production fermentation vessels, each having a volume of 2,000,000 L, with a working volume ranging from 76-79%. In these twelve tanks, *E. coli* cells produce the majority of the ethanol via the anaerobic fermentation of the glycerol feedstock. Optimal growth conditions of 37°C, 14.8 psia and pH 7 are maintained in the vessel. The positive pressure maintains the anaerobic condition required for fermentation. The fermentation time for this is 60 hours since the end ethanol concentration is 100 g/L.

After the fermentation in Seed Ferm 7A/7B is complete, a 1/6 by volume portion of each of the seed fermenters' contents are charged to each of Ferm 1-12, this portion corresponding to a volume of 5% (1/20) of the total FERM 1-12 working volume. The charging time is 27 hrs to allow for a staggered batch running of the fermenters. The contents of Seed Ferm 7A/7B are only supplied to the large fermenters at the start of the first fermentation period of each three-fermentation-period cycle. Sterilized feed from Sterilized Feed Holding Tank T-106 is fed to the large fermenters through pump P-FA over the course of 5 hours at a rate of 311,228 kg/hr, at the start of all three fermentation periods per cycle.

After the first 60-hour fermentation period, 95% of the volume is drained into the fermentation broth storage tank T-107.The remaining 5% remains in the vessel as the seed from which the next reaction period begins. This is done twice, and at the end of the third reaction cycle, 100% of the contents are drained into T-107. At this point the fermenters are cleaned using the clean-in-place technique, during which a dilute caustic solution is applied to the tank surface through spray nozzles. As the initial stagger/ charging time is 27 hours, the feed charging time is 5 hours (x3 charging periods), the reaction time is 60 hours (x3 fermentation periods), the fermenter draining time is 5 hours (x3 draining periods), and the cleaning time is 60 hours, the resulting total cycle time, after 3 fermentation periods, is 297 hours. The large fermenters are the equipment bottleneck in the process.

During the reaction time carbon dioxide and hydrogen gas are evolved, and 4.9% of the produced ethanol and 0.49% of the water are vaporized. This gaseous stream leaving the fermentation units is moved by a blower near the top of all the fermenters that sends the fermentation gases to the Absorber unit AB-1 in the separation section. The gases leave the fermenters at a flow rate of 879.28 kg/hr.

Heat is evolved in one fermentation reactor due to the slightly exothermic reaction from glycerol to ethanol. The adiabatic temperature rise corresponds to 5.7°C (10.4°F) A heat exchanger, HX-Ferm, is required for each of the twelve fermenters to ensure the temperature of the reactors remain at 37°C. The fermenters are constructed from 304 stainless steel. With a 2:1 height to width ratio, the cylindrical vessels are 71 ft tall and have a diameter of 35.5 ft. They are field fabricated.

These fermentation tanks also have 304 stainless steel agitators to prevent cell settling and adverse concentration or pH gradients. These agitators have a base purchase cost of $44,200 (see page 210 for Agitator pricing calculations).

Calculations on page 220.

Storage Tanks:

Broth Storage Tank: T-107

Base Purchase Cost: $ 582,900

T-107 is a floating roof storage vessel constructed of 304 stainless steel with a volume of 3,370,600 L. Fermentation broth containing ethanol is pumped into the tank from all twelve 2,000,000 L fermenters through pump P-FC (1 and 2) at the end of all fermentation periods. Broth leaves the storage tank continuously at a flow rate of 178,735 L/hr and is pumped through pump P-FD to the separation section, where it first enters HX-3. The broth is stored at a temperature of 37 °C and a pressure of 1 atm. This storage tank is assumed to have a maximum working volume of 80%, but the working volume changes depending on the time in the cycle. This tank has an agitator to prevent the settling of *E. coli* cells at the bottom of the tank before continuous filtration. This agitator has a base price of $44,100.

Calculations on page 220.

Heat Exchangers:

HX-FERM (12)

Base Purchase Cost: $4,200

This is the heat exchanger that is used to cool the contents of each 2,000,000 L fermentation tank FERM1-12. One heat exchanger and accompanying pump is provided for each fermenter, so as to prevent total contamination in the case that one fermenter unit is somehow contaminated. The solution from stream S-141 flows through the heat exchanger at a flow rate of 25,423 L/hr. The fluid is circulated over a period of 60 hours (fermentation time) and the heat duty corresponds to the amount of heat required to cool the contents of one reactor from 109 °F to 98.6 °F (42.7 °C to 37 °C), determined from the adiabatic temperature rise associated with the slightly exothermic fermentation reaction. The fermentation solution is cooled using a mixture of cooling water and chilled water (where cooling water makes up 95% of the heat duty) at a mass flow rate of 22,063 kg/hr, which is heated from 87.6 °F to 99 °F (30.9 °C to 37.2 °C). This is a Double Pipe Heat Exchanger due to the smaller exchanger area requirements. The heat duty is 518,297 BTU/hr. This exchanger is carbon steel shell side / stainless steel tube side because the shell side material is water.

Calculations on page 226.

Pumps:

P-FA (2)

Base Purchase Cost: $19,400

This is a centrifugal pump constructed of 304 stainless steel that pumps sterilized feed from T-106 to the 6 fermenter tanks that are operating in each fermentation train. It pumps sterilized feed at a rate of 300,300 L/ hr. The energy requirement for the pump is 67.22 Hp and the pump operates at an efficiency of 0.79 while the motor operates at an efficiency of 0.83. The pump head is 126.8 ft. The pressure change across the pump, neglecting friction is 220 kPa. An additional pressure change of 25 psia was assumed as a result of the frictional forces of fluid flow. The pump is operational for 15 hours of the 297 hour cycle time.

Calculations on page 233.

P-FB (2)

Base Purchase Cost: $3,600

This is a centrifugal pump constructed of 304 stainless steel that pumps seed feed from the Seed Fermentation Train A/B to each of the fermenters Ferm 1-12. It pumps the volume of Seed 7A/7B to the main fermentation section at a rate of 2,820 L/ hr. The energy requirement for the pump is 2.31 Hp and the pump operates at an efficiency of 0.21 while the motor operates at an efficiency of 0.81. The pump head is 130.9 ft. The pressure change across the pump, neglecting friction is 205 kPa. An additional pressure change of 25 psia (17.2 kPa) was assumed as a result of the frictional forces of fluid flow. The pump is operational for 162 hours of the 297 hour cycle time.

Calculations on page 233.

P-FC (2)

Base Purchase Cost: $ 15,700

This is a centrifugal pump constructed of 304 stainless steel that pumps the broth product from the fermenters Ferm 1-12 into Broth Storage Tank T-107. It operates at a rate of 1,525,403 L/ hr. The energy requirement for the pump is 42.77 Hp and the pump operates at an efficiency of 0.79 while the motor operates at an efficiency of 0.83. The pump head is 85.4ft. The pressure change across the pump, neglecting friction is 73.9 kPa. An additional pressure change of 25 psia (17.2 kPa) was assumed as a result of the frictional forces of fluid flow. The pump is operational for 90 hours of the 297 hour cycle time.

Calculations on page 233.

P-FD

Base Purchase Cost: $9,000

This is a centrifugal pump constructed of 304 stainless steel that pumps the fermentation product from the broth storage tank, T-107 to the separation process section. It pumps fermentation broth continuously at a rate of 178,734 L/ hr. The energy requirement for the pump is 36.94 Hp and the pump operates at an efficiency of 0.75 while the motor operates at an efficiency of 0.83. The pump head is 120 ft. The pressure change across the pump, neglecting friction is 205 kPa. An additional pressure change of 25 psia (17.2 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

P-FE (12)

Base Purchase Cost: $6,600

This is a centrifugal pump constructed of 304 stainless steel that continuously pumps the solution in each fermenter tank through a heat exchanger, HX FERM, to maintain the fermentation temperature of 37°C. It pumps fermentation solution at a flow rate of 25,423 L/hr in a closed circuit through HX FERM and back to the FERM1-12. The energy requirement for the pump is 3.65 Hp and the pump operates at an efficiency of 0.55 while the motor operates at an efficiency of 0.81. The pump head is 59.8 ft. The pressure change across the pump, neglecting friction is 205 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

Blowers:

B-101

Base Purchase Cost: $70,500

This centrifugal blower facilitates the transport of the fermentation gases and vapors from the fermentation seed fermenters and the large 2,000,000 L fermentation tanks to the absorber in the separation section so that the vaporized ethanol can be saved and the effluent hydrogen gas can be burned to fuel the distillation tower reboiler. The flow rate of gases through the blower is 10,614 ft^3/min. The blower efficiency is 0.75, and the motor that powers the blower has an efficiency of 0.92. The power consumption is 300 HP. The blower is made of aluminum.

Calculations on page 213.

Separation Section

Storage Tanks:

Mixing Tank T-108

Base Purchase Cost: $26,800

T-108 is a floating roof storage vessel constructed of 304 stainless steel with a volume of 8,021 L. Streams S-S-124 (ethanol) and S-S-125(gasoline) flow into this tank for mixing. The tank is assumed to have a working volume of 50% and a residence time of 10 minutes. It is assumed to operate at 50 °C and 1 atm. The tank has an agitator (turbine, closed tank) for mixing that is priced at $9,100 including the motor and shaft costs.

Calculations on page 242.

Gasoline Storage Tank T-109

Base Purchase Cost $ 101,000

T-109 is a floating roof storage vessel constructed of 304 stainless steel with a volume of 108,278 L. This vessel stores three days worth of gasoline, a material that is added to denature the ethanol that is produced. Stream S-S-125 leaves this tank at a flow rate of 475 L/hr and flows into mixing tank, T-108.The gasoline will be stored at a temperature of 25 °C and a pressure of 1 atm. The storage tank is assumed to have a working volume of 80%.

Calculations on page 242.

Succinic Acid Storage TankT-110

Base Purchase Cost $ 27,600

T-110 is a cone roof storage vessel constructed of 304 stainless steel with a volume 26,478 L. This vessel stores three days worth of succinic acid . Stream S-S-121 flows into this tank via a conveyor belt at a rate of 459 kg/hr. The solid succinic acid will be stored at a temperature of 25 °C and a pressure of 1 atm. The storage tank is assumed to have a working volume of 80%.

Calculations on page 242.

Denatured Ethanol Holding Tank T-111

Base Purchase Cost $ 453,300

T-111 is a floating roof storage vessel constructed of 304 stainless steel with a volume of 2,057,287 L. This vessel stores three days worth of denatured ethanol. This stream (S-S-126) enters the tank after being denatured in the mixing tank T-108. Stream S-S-126 enters this tank at a flow rate of 22,859 L/hr. The ethanol will be stored at a temperature of 50 °C and a pressure of 1 atm. The storage tank is assumed to have a working volume of 80%.

Calculations on page 242.

Heat Exchangers:

HX-3

Base Purchase Cost: $113,900

The waste water from the electro-dialysis unit, Stream S-S-135, is used to sterilize the fermentation product (S-S-109). The sterilized stream then flows into the Rotary Drum Filter (RDF-1). The heat duty is 48,041,600 BTU/hr. Stream S-S-109 is heated from 37 °C to 92.2 °C, past the deactivation temperature for *E. coli* of 62.2°C, (or from 98.6 °F to 198 °F) while the 21 psi water (S-S-135) leaving ED-1 (Electrodialysis) is cooled from 100 °C to 43.3 °C (or from 228 °F to 110.4 °F). HX-3 is a Floating Head Shell/Tube heat exchanger and is modeled as a carbon steel shell side/ stainless steel tube side since the shell side material is hot water. The heat exchanger area is 9997 ft^2.

Calculations on page 226.

Partial Condenser: HX-4

Base Purchase Cost: $ 65,900

This is a partial condenser for the distillation tower D-1.The top product from the tower(S-S-130) flows through this heat exchanger before entering the reflux accumulator, RA-1. The heat duty is 68,130,000 BTU/hr. Stream S-S-130 has a flow rate of 189,673 kg/hr and is partially condensed at 82 °C (179.5 °F) using cooling water (S-S-106) that is heated from 32.2 °C to 48.9 °C (90 °F to 120 °F). The cooling water has a flow rate of 1,087,869 kg/hr. HX-4 is a Floating Head Shell/Tube heat exchanger and is a carbon steel on the shell side and stainless steel on the tube side since the shell side material is water. The exchanger area is 4,636 ft^2.

Calculations on page 226.

HX-5

Base Purchase Cost: $21,200

The ethanol product stream (S-S-122) from the molecular sieve (MS-1) is cooled before entering the mixing tank to be denatured. The ethanol is cooled from its atmospheric boiling point of 78.4 °C to 50 °C (173 °F to 122 °F) using cooling water. The flow rate of the cooling water(S-S-136) IS 23,766 kg/hr and it is warmed from 32.2 °C to 48.9 °C (90 °F to 120 °F). The heat duty is 1,488,726 BTU/hr. HX-5 is a Floating Head Shell/Tube heat exchanger and is modeled as a carbon steel shell side/ stainless steel tube side since the shell side material is cooling water. The heat exchanger area is 239 ft^2.

Calculations on page 226.

Reboiler: HX-6

Base Purchase Cost: $60,300

The remaining 33.78MMBtu/hr of the heat duty for the reboiler is provided by a kettle reboiler heat exchanger which is heated with 16,775 kg/hr of condensing 50 psig steam. A heat transfer coefficient of 200 Btu/hr-ft^2-°F was used to calculate a heat transfer area of 2,412 ft^3. The heat exchanger is 304 stainless steel on the tube side, and carbon steel on the shell side. The vapor stream leaving the reboiler (S-S-133) is sent back to the distillation column, while the liquid stream leaving the reboiler is sent to the electro-dialysis (ED-1) system.

Calculations on page 226.

Pumps:

P-S-101

Base Purchase Cost: $13,100

This is a centrifugal pump constructed of 304 stainless steel that pumps the liquid fermentation product from the rotary drum filter, RDF-1 to the distillation tower, D-1. The flow rate through the pump is 174,995 L/ hr. The energy requirement for the pump is 67.9 Hp and the pump operates at an efficiency of 0.75 while the motor operates at an efficiency of 0.83. The pump head is 221 ft. The pressure change across the pump, neglecting friction is 475 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

P-S-102

Base Purchase Cost: $9,000

This is a centrifugal pump constructed of 304 stainless steel that pumps the stream containing the succinic acid product, S-S-116 from the furnace (FN-1) to the electro-dialysis system (ED-1). The flow rate through the pump is 180,559 L/ hr. The energy requirement for the pump is 37.3 Hp and the pump operates at an efficiency of 0.75 while the motor operates at an efficiency of 0.83. A pressure change of 50 psia (344 kPa) was assumed as a result of frictional forces of the fluid flow.

Calculations on page 233.

P-S-104

Base Purchase Cost: $4,700

This is a centrifugal pump constructed of 304 stainless steel that pumps the product stream S-S-119 from the crystallizer C-1 back to the electro dialysis unit. The flow rate through the pump is 40,625 L/ hr. The energy requirement for the pump is 10.5 Hp and the pump operates at an efficiency of 0.61 while the motor operates at an efficiency of 0.82. A pressure change of 50 psia (344 kPa) was assumed as a result of frictional forces of the fluid flow.

Calculations on page 233.

P-S-105

Base Purchase Cost: $ 5,200

This is a centrifugal pump constructed of 304 stainless steel that pumps the liquid stream S-S-104 scrubbed out in the absorber AB-1 to the distillation tower D-1. The flow rate through the pump is 29,396 L/ hr. The energy requirement for the pump is 14.9 Hp and the pump operates at an efficiency of 0.57 while the motor operates at an efficiency of 0.83. The pump head is 222 ft. The pressure change across the pump, neglecting friction is 464 kPa. An additional pressure change of 25 psia (172.5kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

P-S-106

Base Purchase Cost: $ 13,500

This is a centrifugal pump constructed of 304 stainless steel that pumps the stream S-S-128 from the reflux accumulator RA-1 to the distillation tower D-1. It operates continuously at a rate of 205,879 L/ hr. The energy requirement for the pump is 68.28 Hp and the pump operates at an efficiency of 0.76 while the motor operates at an efficiency of 0.83. The pump head is 234 ft. The pressure change across the pump, neglecting friction is 389 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 233.

P-S-107

Base Purchase Cost: $15,700

This is a centrifugal pump constructed of 304 stainless steel that pumps the bottoms product of the distillation column D-1 to the furnace FN-1 via stream S-131. The flow rate through the pump is 232,717 L/ hr. The energy requirement for the pump is 46.81 Hp and the pump operates at an efficiency of 0.77 while the motor operates at an efficiency of 0.83. A pressure change of 50 psia (344 kPa) was assumed as a result of frictional forces of the fluid flow.

Calculations on page 233.

P-S-108

Base Purchase Cost: $7,200

This is a centrifugal pump constructed of stainless steel 304 that pumps process water to the absorber. It operates continuously at a rate of 27,023 L/ hr. The energy requirement for the pump is 7.1 Hp and the pump operates at an efficiency of 0.56 while the motor operates at an efficiency of 0.82. The pump head is 108 ft. The pressure change across the pump, neglecting friction is 150 kPa. An additional pressure change of 25 psia (172.5 kPa) was assumed as a result of the frictional forces of fluid flow.

Calculations on page 223320.

Blowers:

B-102

Base Purchase Cost: $ 264,200

This centrifugal blower facilitates the transport of air to the furnace (FN-1) in the separation section so that the effluent gases can be burned to fuel the distillation tower reboiler. The flow rate of air through the blower is 70,214 ft^3/min. The blower efficiency is 0.75, and the motor that powers the blower has an efficiency of 0.94. The power consumption is 1602 HP. The blower is made of aluminum. Calculations on page 213.

Columns:

Distillation Column : D-1

Base Purchase Cost: $ 798,000

The distillation column serves to remove a majority of the water and all the succinic acid from the feed streams (S-S-104 & S-S-112) and recycle stream (S-S-123) which together have a flow rate of 205,972 kg/hr and are composed of water, succinic acid, corn steep liquor, biomass, and ethanol. Streams S-S-104, S-S-112 and S-S-123 enter the column at stages 16, 12, and 11 respectively. By this point, the corn steep liquor has had all solids filtered out, and is a selection of water and salts which do not vaporize and therefore leave as bottoms product. It is necessary that the top product be 92% ethanol by weight for the subsequent processing by molecular sieves, so 179,000 kg/hr of water, along with all the corn steep liquor and succinic acid must leave as bottoms product. The small quantity of remaining biomass is filtered out by a hopper, and leaves as a separate stream (S-S-139, 29.6 kg/hr) from the bottom of the tower as suggested by industrial consultant Mr. Bruce Vrana. The tower was modeled in Aspen, with components of succinic acid, water, and ethanol. Biomass and Corn Steep Liquor were added separately due to their unknown composition, but known properties; both absolutely will not vaporize at the tower temperatures. The top of the tower has a pressure of 18 psia and operates at 81.95 °C while the bottom operates at 25 psia and 108.89 °C. In order to achieve the desired separation, 32 theoretical stages are required. At a stage efficiency of 0.40 as suggested by Bruce Vrana, there are a total of 79 stages plus the re-boiler and partial condenser. Aspen calculated a diameter of 12 ft for the column and with 2 ft spacing between the stages, the column is 172 ft tall. The trays in use are baffle trays, as suggested by Bruce Vrana, for distillation columns with small solids content. The column is constructed of 304 stainless steel, as some salts and succinic acid remain in solution.

Calculations on page 215.

Absorber Column: AB-1

Base Purchase Cost: $117,100

The absorber column receives the effluent vapors from the seed and main fermentation plant sections, which enter at the bottom stage of the tower at a mass flow rate of 19,525 kg/hr. Process water is supplied to the top stage at a flow rate of 27,022 L/hr to remove the ethanol and water from the vapor phase. All of the ethanol is removed from the vapor phase and sent to the distillation tower in the absorber exit stream S-S-104. A hydrogen-rich gas stream leaves the absorber column from the top stage, and is sent to the furnace for subsequent burning to fuel the distillation tower D-1 reboiler. The absorber tower has no energy requirement. The tower has 7 stages calculated by Aspen. Assuming a tray efficiency of 0.40, 18 trays are used. The diameter calculated by Aspen is 5.5 ft. The height of the tower is 50 ft, and it uses sieve trays. The tower is made of 304 stainless steel. The pressure at the top of the tower is 16 psia and the pressure at the bottom of the tower is 20 psia.

Calculations on page 215.

Miscellaneous:

Reflux Accumulator: RA-1

Base Purchase Cost: $47,000

The reflux accumulator collects the liquid and vapor that have exited the distillation tower D-1 top stage condenser. The liquid collected is returned to the column in stream S-S-128 at a flow rate of 57,526 L/hr through pump P-S-106, and the hot vapor at 92% ethanol by mass (8% water) is sent to the molecular sieves for subsequent dehydration at a mass flow rate of 19,595 kg/hr. The volume of the reflux accumulator is 605 ft^3. The diameter is 11.6 ft and the height is 5.8 ft, for an aspect ratio (L/D) of ½. The residence time is 5 minutes.

Calculations on page 238.

FN-1 (Furnace)

Base Purchase Cost: $1,717,600

Re-boiling the bottoms of the distillation column is one of the largest energy consumptions of our process. In order to cut the cost of heating this stream, we designed a furnace to use the hydrogen being produced in the fermenters. This constitutes a heat duty of 76.9MMBTU/hr. The feed from the fermenters carries 392.2 kmol/hr of hydrogen. To reduce the burning temperature to 1100°F (the limit of the furnace) air is mixed in to this stream at a rate of 4687.4 kmol/hr. The temperature of the flue gas exiting is 121°C to maintain a 10°C temperature difference. The furnace is a fire heater made of 304 stainless steel.

Calculations on page 224.

Rotary Drum Vacuum Filter: RDF-1

Base Purchase Cost: $184,400

The rotary drum vacuum filter removes 90% of the deactivated biomass and corn steep liquor solids after the fermentation broth has been sterilized. The cake leaving the filter is 70% solids by mass, with a flow rate of 977 kg/hr. This cake is then sent to a landfill, as suggested by the problem statement. The remaining solution is then pumped to the distillation tower D-1 through pump P-S-101 at a flow rate of 174,995 L/hr. The filter uses a 2-4 inch pre-coating of diatomaceous earth as a filtration aid. The filter area is 113 ft^2 and the energy consumption is on average 11.8 HP.

Calculations on page 239.

Molecular Sieve : MS-1

Base Purchase Cost: $ 2,746,200

The molecular sieves system serves to separate the last 8% by weight of water from the ethanol vapor stream leaving the distillation tower. The system does this by absorbing the water into a resin. In order to purge this water, periodically 20% of the pure ethanol stream must be recirculated back to the molecular sieves to pull the water out of the resin. This regeneration results in an exit stream of 37% by weight water, the remainder ethanol, that must be fed back to the distillation tower (stream S-S-123). The pricing is based on flow rate of 99.5 % pure ethanol exiting the system, which is 18,036 kg/hr (39,800 lb/hr). The pricing and method of modeling were given to us by industrial consultant Mr. Bruce Vrana in the problem statement. The ethanol leaving the molecular sieves is at 78.4°C because ethanol is a liquid at this temperature at atmospheric pressure. Steam, electricity, and cooling water are used by the process, as described in the problem statement.

Calculations on page 232.

Electro-Dialysis : ED-1

Base Purchase Cost : $ 2,700,000.

Electro-dialysis is a system by which charged particles are transferred from low to high concentration by an applied electric field. Specific information pertaining to the design such as voltage necessary and transfer area were not available. Pricing was calculated by a general correlation from Perry's Chemical Engineering Handbook. For the modeling, an assumption of zero heat transfer with the mass transfer was used. This assumption will of course not be true, but it is used as a starting point. The effect of transferred heat is twofold, first it would decrease the temperature of the feed to HX-3. However, we anticipate there to be plenty of heat to preheat the distillation stream even with significant heat transfer. Additionally, an increase in the temperature of S-S-118 will increase the solubility of succinic acid. Depending how significant this effect is, chilled water may be needed to cool the crystallizer. In an article (Meynial-Salles et al.) on succinic acid separation by electro-dialysis, concentrations were increased from 20 g/L to 80 g/L by electro-dialysis. Because electro-dialysis is driven by electric potential, it is expected to be possible to achieve 80 g/L concentrations of succinic acid. However, as a conservative estimate, a much lower number of 10.4 g/L correlating to 4 fold concentration, similar to that in the report was used. From both Perry's and Meynial-Salles et al., electro-dialysis is used to completely remove ionic components, so no succinic acid is modeled as leaving in stream S-S-135. Accordingly, this hot stream can be sent to the ocean after being cooled in HX-3. Stream S-S-118, a concentrated stream of succinic acid in water, is sent to the crystallizer.

Calculations on page 218.

Crystallizer : C-1

Base Purchase Cost: $ 154,500

The crystallizer allows for the precipitation of the succinic acid out of the super-saturated solution down to the succinic acid solubility limit of 3 g/L, while recycling the succinic acid solution back to the electro dialysis as the feed for the concentrated stream so as to reduce loss of this valuable specialty chemical. As a very small quantity of corn steep liquor will also recirculate (primarily water, however), a water purge is performed in the amount of 10% by volume, exiting with the crystals. This is expected to be higher than necessary, however this purge stream was designed conservatively so as to predict the loss of the greatest amount of product. Process water of the volume of water purged is added in the feed to the concentrated stream of the electro-dialysis to make up for this. In the case that heat transfer is found to be significant in the electro dialysis, the crystallizer may need to be cooled. The purge stream contains a small quantity of organics, so it is sent for waste water treatment.

Calculations on page 214.

Dryer: DR-1

Base Purchase Cost: $ 22,200

The dryer takes the crystal product from C-1 and removes the water necessarily present. The amount of water is unknown, however we assumed no more than 25% by weight of the crystals could be water. This corresponds to 4.5 square feet of drying area. Because of the low cost and the highly unknown nature of this process, we have assumed a worst case scenario drying area of 45 square feet. Utility costs will depend on the amount of water that sticks to the crystals, however this calculates to 90 cents per hour at 25 mass percent water and therefore is nearly inconsequential. We have left this out and count the change in pricing as part of the sensitivity analysis.

Calculations on page 217.

Screw Conveyor: CB-1

Base Purchase Cost: $13,000

The Screw conveyor moves the solid succinic acid crystals in stream S-S-121 (459 kg/hr) to the succinic acid holding tank, T-110. The conveyor is made of 304 stainless steel. The conveyor is 24 feet long with a motor and power requirement of less than 1 HP.

Calculations on page 240.

Unit Specification Sheets

Section VIII

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Feed Preparation Section

Storage Tanks:

Holding Tank		
Identification	Item:	Holding Tank
	Item No.:	T-101
	No. Req'd:	1
Function	To hold 3 days worth of Crude Glycerol	
Operation	Continuous	
Materials Handled:		
	Stream out- S-FP-101	
Quantity(kg/hr)	43,370.1	
Temperature(C)	37.0	
Composition(kg/hr)		
Biomass	0.00	
Carbon Dioxide	0.00	
Corn Steep Liquor	0.00	
Ethanol	0.00	
Glycerol	36,855.87	
Hydrogen	0.00	
Succinic Acid	0.00	
Water	3,044.62	
Wastes (Salts, MONG)	3,469.61	
Design Data:	Volume (L)	3,165,300.00
	Working Volume	0.80
	Diameter (ft)	75.20
	Height (ft)	25.1
	Model	Floating Roof
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$564,600.00	
Utilities:		
Comments:		

Holding Tank

Identification	Item:	Holding Tank
	Item No.:	T-103
	No. Req'd:	1
Function	To hold 3 days worth of Corn Steep Liquor	
Operation	Continuous	
Materials Handled:		

	Stream out- S-FP-106
Quantity(kg/hr)	927.4
Temperature(C)	37.0
Composition(kg/hr)	
Biomass	0.0
Carbon Dioxide	0.0
Corn Steep Liquor	927.4
Ethanol	0.0
Glycerol	0.0
Hydrogen	0.0
Succinic Acid	0.0
Water	0.0
Wastes (Salts, MONG)	0

Design Data:	Volume (L)	83,500.00
	Working Volume	0.80
	Diameter (ft)	22.40
	Height (ft)	7.58
	Model	Cone Roof
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$49,600.00	
Utilities:		
Comments:		

Holding Tank

Identification	Item:	Holding Tank
	Item No.:	T-104
	No. Req'd:	1
Function	To hold 3 days worth of Brine before removal	
Operation	Continuous	
Materials Handled:		
	Stream in-S-FP-103	
Quantity(kg/hr)	6,567.1	
Temperature(C)	37.0	
Composition(kg/hr)		
Biomass	0.00	
Carbon Dioxide	0.00	
Corn Steep Liquor	0.00	
Ethanol	0.00	
Glycerol	0.00	
Hydrogen	0.00	
Succinic Acid	0.00	
Water	4,832.32	
Wastes (Salts, MONG)	1,734.80	
Design Data:	Volume (L)	145,000.00
	Working Volume	0.80
	Diameter (ft)	26.90
	Height (ft)	8.99
	Model	Cone Roof
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$65,700.00	
Utilities:		
Comments:		

Mixing Tank

Identification	Item:	Mixing Tank
	Item No.:	T-105
	No. Req'd:	1

Function	To combine the purified glycerol, water and CSL before sterilization in HX-2
Operation	Continuous

Materials Handled:

	Flow In	Flow In	Flow In	Flow Out
	S-FP-104	S-FP-105	S-FP-106	S-FP-107
Quantity(kg/hr)	39,900.5	151,104.8	927.4	191,932.7
Temperature(C)	25.00	25.00	25.00	25.0
Composition(kg/hr)				
Biomass	0.0	0.0	0.0	0.0
Carbon Dioxide	0.0	0.0	0.0	0.0
Corn Steep Liquor	0.0	0.0	927.4	927.4
Ethanol	0.0	0.0	0.0	0.0
Glycerol	36,855.9	0.0	0.0	36,855.9
Hydrogen	0.0	0.0	0.0	0.0
Succinic Acid	0.0	0.0	0.0	0.0
Water	3,044.6	151,104.8	0.0	154,149.4
Wastes (Salts, MONG)	0.0	0.0	0.0	0.0

Design Data:	Volume (L)	61,800
	Working Volume	0.50
	Diameter (ft)	20
	Height (ft)	6.75
	Residence Time (min)	10
	Model	Cone Roof
	Material of Construction:	304 stainless steel

Cost, C_{PB}	$42,500.00
Utilities:	
Comments:	

Agitator		
Identification	Item:	Agitator
	Used In	Storage Tank 105
	No. Req'd:	1
Function	Mixing freshwater, crude glycerol, and cornsteep liquor	
Operation	Continuous	
Design Data:	Electricity requirements (hp):	32.600
	Material of Construction:	304 Stainless Steel
Cost,C_{PB}	$29,900.00	
Utilities:	Electricity	
Comments:		

Holding Tank

Identification	Item:	Holding Tank
	Item No.:	T-106
	No. Req'd:	1
Function	To hold sterilized feed that is required for the fermentation stages	
Operation	Continuous/Batch	
Materials Handled:		
	Stream in-S-FP-112 (kg/hr)	Stream out(kg/batch)
Quantity(kg/hr)	43,370.1	43,370.1
Temperature(C)	37.0	37.0
Composition(kg/hr) /(kg/batch)		
Biomass	0.00	0.0
Carbon Dioxide	0.00	0.0
Corn Steep Liquor	0.00	0.0
Ethanol	0.00	0.0
Glycerol	36,855.87	36,855.9
Hydrogen	0.00	0.0
Succinic Acid	0.00	0.0
Water	3,044.62	3,044.6
Wastes (Salts, MONG)	3,469.61	3,469.6
Design Data:	Volume (L)	1,157,500.00
	Working Volume	0.80
	Diameter (ft)	53.80
	Height (ft)	17.9
	Model	Floating Roof
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$338,000.00	
Utilities:		
Comments:		

Heat Exchangers:

Heat Exchanger

Identification	Item:	Heat Exchanger
	Item No.:	HX-1
	No. Req'd:	1
Function	To preheat the feed S-FP-114 before sterilization and cool the hot sterilized feed(S-FP-109) to the fermentation temperature	
Operation	Continuous	

Materials Handled:	Shell Side		Tube Side	
	Stream In	Stream out	Stream in	Stream out
	S-FP-109	S-FP-112	S-FP-114	S-FP-108
Quantity(kg/hr)	191,932.7	191,932.7	191,932.7	191,932.7
Temperature(C)	121.0	37.0	25.0	111.0
Composition(kg/hr)				
Biomass	0.0	0.0	0.0	0.0
Carbon Dioxide	0.0	0.0	0.0	0.0
Corn Steep Liquor	927.4	927.4	927.4	927.4
Ethanol	0.0	0.0	0.0	0.0
Glycerol	36,855.9	36,855.9	36,855.9	36,855.9
Hydrogen	0.0	0.0	0.0	0.0
Succinic Acid	0.0	0.0	0.0	0.0
Water	154,149.4	154,149.4	154,149.4	154,149.4
Wastes (Salts, MONG)	0.0	0.0	0.0	0.0

Design Data:		
	Heat Duty(BTU)	59,665,811.0
	Overall Heat Coefficient (BTU/hr-ft^{2}°F)	250.0
	Heat Transfer Area (ft^{2})	12,042.0
	Type	Floating Head Shell/Tube
	Materials of Construction	
	Shell:	Tube:
	304 Stainless steel	304 Stainless steel

Cost,C$_{PB}$	$132,300.00
Utilities:	
Comments:	On start up, duty is provided by 50 psig steam 2470 kg of steam is required.

Heat Exchanger

Identification	Item:	Heat Exchanger
	Item No.:	HX-2
	No. Req'd:	1

Function	To preheat the feed S-FP-114 at 121°C to ensure sterilization
Operation	Continuous

Materials Handled:	Shell Side		Tube Side	
	Stream In	Stream out	Stream in	Stream out
	S-FP-110	S-FP-111	S-FP-08	S-FP-109
Quantity(kg/hr)	4,044.9	4,044.9	191,932.7	191,932.7
Temperature(C)	186.1	180.0	111.0	121.0
Composition(kg/hr)				
Biomass	0	0	0.0	0.0
Carbon Dioxide	0	0	0.0	0.0
Corn Steep Liquor	0	0	927.4	927.4
Ethanol	0	0	0.0	0.0
Glycerol	0	0	36,855.9	36,855.9
Hydrogen	0	0	0.0	0.0
Succinic Acid	0	0	0.0	0.0
Water	4044.94	4044.94	154,149.4	154,149.4
Wastes (Salts, MONG)	0	0	0.0	0.0

Design Data:

Heat Duty(BTU)	7,738,512.0
Overall Heat Coefficient (BTU/hr-ft^2°F)	200.0
Heat Transfer Area (ft^2)	321.0
Type	Floating Head Shell/ Tube
Materials of Construction	
Shell:	Tube:
carbon steel	304 Stainless steel

Cost,C_{PB}	$22,100.00
Utilities:	steam at 150 psig
Comments:	

Pumps:

Pump		
Identification	Item:	Pump
	Item No.:	P-FP-01
	No. Req'd:	1
Function	To bring crude glycerol form storage tank to the glycerol purification system	
Operation	Continuous	
Materials Handled:		
	Feed: S-FP-101	Exit: S-FP-101
Quantity(kg/hr)	43,370.1	43,370.1
Temperature(C)	25.0	25.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	0.000	0.000
Glycerol	36855.871	36855.871
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	3044.615	3044.615
Wastes	3469.608	3469.608
Design Data:	Density of Fluid (kg/l):	1.233
	Brake Power (hp):	7.663
	Pump Head (ft):	93.637
	Electricity requirements(kW):	6.962
	Material of Construction:	304 stainless steel
Cost,CPB	$4,500.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FP-02
	No. Req'd:	1
Function	To bring fresh water to mix with cornsteep liquor	
Operation	Continuous	
Materials Handled:		
	Feed: S-FP-105	Exit: S-FP-105
Quantity(kg/hr)	151,104.8	151,104.8
Temperature(C)	25.0	25.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	151104.765	151104.765
Wastes	0.000	0.000
Design Data:	Density of Fluid (kg/l):	1.000
	Brake Power (hp):	27.820
	Pump Head (ft):	122.106
	Electricity requirements(kW):	25.110
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$8,400.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FP-03
	No. Req'd:	1
Function	To bring cornsteep liquor to mix with fresh water	
Operation	Continuous	
Materials Handled:		
	Feed: S-FP-106	Exit: S-FP-106
Quantity(kg/hr)	927.4	927.4
Temperature(C)	25.0	25.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	927.419	927.419
Ethanol	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	0.000	0.000
Wastes	0.000	0.000
Design Data:	Density of Fluid (kg/l):	1.000
	Brake Power (hp):	0.111
	Pump Head (ft):	64.430
	Electricity requirements(kW):	0.109
	Material of Construction:	304 stainless steel
Cost, C_{PB}	$4,100.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FP-04
	No. Req'd:	1
Function	To bring purified glycerol to mix with cornsteep liquor and fresh water	
Operation	Continuous	
Materials Handled:		
	Feed: S-FP-104	Exit: S-FP-104
Quantity(kg/hr)	39,900.5	39,900.5
Temperature(C)	25.0	25.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	0.000	0.000
Glycerol	36855.871	36855.871
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	3044.615	3044.615
Wastes	0.000	0.000
Design Data:	Density of Fluid (kg/l):	1.233
	Brake Power (hp):	4.100
	Pump Head (ft):	53.525
	Electricity requirements(kW):	3.746
	Material of Construction:	304 stainless steel
Cost, C_{PB}	$3,900.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FP-05
	No. Req'd:	1
Function	To bring waste brine from glycerol purification system to storage	
Operation	Continuous	
Materials Handled:		
	Feed: S-FP-103	Exit: S-FP-103
Quantity(kg/hr)	6,567.1	6,567.1
Temperature(C)	25.0	25.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	4832.322	4832.322
Wastes	1734.804	1734.804
Design Data:	Density of Fluid (kg/l):	1.359
	Brake Power (hp):	1.228
	Pump Head (ft):	51.418
	Electricity requirements(kW):	1.141
	Material of Construction:	304 stainless steel
Cost, C_{PB}	$3,500.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FP-06
	No. Req'd:	1
Function	To bring glycerol/water/cornsteep liquor mixture through heat exchangers to holding tank	
Operation	Continuous	
Materials Handled:		
	Feed: S-FP-107	Exit: S-FP-114
Quantity(kg/hr)	191,932.7	191,932.7
Temperature(C)	25.0	25.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	927.419	927.419
Ethanol	0.000	0.000
Glycerol	36855.871	36855.871
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	154149.381	154149.381
Wastes	0.000	0.000
Design Data:	Density of Fluid (kg/l):	1.036
	Brake Power (hp):	37.549
	Pump Head (ft):	132.665
	Electricity requirements(kW):	33.880
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$10,100.00	
Utilities:	Electricity	
Comments:		

Miscellaneous:

Glycerol Purification System

Identification	Item:	Glycerol Purification System
	Item No.:	R-101
	No. Req'd:	1

Function: To purify the crude glycerol feed so that it only contains water and glycerol

Operation: Continuous

Materials Handled:

	Stream In S-FP-101	Stream in S-FP-102	Stream out S-FP-103	Stream out S-FP-104	Stream out S-FP-113
Quantity(kg/hr)	43,370.1	4,832.3	6,567.1	39,900.5	1,734.8
Temperature(C)	25.0	25.0	25.0	25.0	25.0
Composition(kg/hr)					
Biomass	0.0	0.0	0.0	0.0	0
Carbon Dioxide	0.0	0.0	0.0	0.0	0.00
Corn Steep Liquor	0.0	0.0	0.0	0.0	0.00
Ethanol	0.0	0.0	0.0	0.0	0.00
Glycerol	36,855.9	0.0	0.0	36,855.9	0.00
Hydrogen	0.0	0.0	0.0	0.0	0.00
Succinic Acid	0.0	0.0	0.0	0.0	0.00
Water	3,044.6	4,832.3	4,832.3	3,044.6	0.00
Wastes (Salts, MONG)	3,469.6	0.0	1,734.8	0.0	1,734.80

Design Data:

Processes : Reverse Osmosis
Electro-pressure membrane technology
Electro-dialysis

Cost,C_{BM} $430,800.00

Utilities:

Comments:

Seed Fermentation Section (Plant and Lab):

Fermenters:

Seed Fermenter

Identification

Item: Fermenter
Item No.: Seed 4A/4B
No. Req'd: 2

Function: To grow up Ecoli cells for 60 hours for innoculation in seed fermenter, Seed Ferm 5A or 5B

Operation: Batch

Materials Handled:	Stream In	Stream in	Stream out	Stream out
	S-105	S-101	S-109	S-106
Quantity(kg/hr)	7.6	160.9	16.4	152.1
Temperature(C)	37.00	37.00	37.00	37.00
Composition(kg/hr)				
Biomass	0.01	0.00	0.00	0.26
Carbon Dioxide	0.00	0.00	14.32	0.00
Corn Steep Liquor	0.04	0.78	0.00	0.82
Ethanol	0.76	0.00	0.74	15.17
Glycerol	0.00	30.90	0.00	0.00
Hydrogen	0.00	0.00	0.66	0.00
Succinic Acid	0.02	0.00	0.00	0.42
Water	6.79	129.25	0.71	135.45

Design Data:

Volume(L): 200
Working Vol initial (L) : 163.9 (82%)
Working Vol at end(L) : 157.7 (79%)
Height (ft) 3.3
Diameter (ft) 1.65
Material of Construction: 304 Stainless Steel

Cost: Insignificant
Utilities:
Comments:

Seed Fermenter

Identification	Item:	Fermenter		
	Item No.:	Seed 5A/5B		
	No. Req'd:	2		
Function	To grow up Ecoli cells for 60 hours for innoculation in seed fermenter, Seed Ferm 6A or 6B			
Operation	Batch			
Materials Handled:	Stream In	Stream in	Stream out	Stream out
	S-106	S-102	S-110	S-107
Quantity(kg/batch)	152.1	3,230.4	329.9	3,052.7
Temperature(C)	37.00	37.00	37.00	37.00
Composition(kg/batch)				
Biomass	0.26	0.00	0.00	5.25
Carbon Dioxide	0.00	0.00	287.55	0.00
Corn Steep Liquor	0.82	15.61	0.00	16.43
Ethanol	15.17	0.00	14.91	304.36
Glycerol	0.00	620.32	0.00	0.00
Hydrogen	0.00	0.00	13.31	0.00
Succinic Acid	0.42	0.00	0.00	8.37
Water	135.45	2594.50	14.13	2718.26
Design Data:	Volume(L):	4,500		
	Working Vol initial (L) :	3274.7 (73%)		
	Working Vol at end(L) :	3164.9 (70%)		
	Height (ft)	9.32		
	Diameter (ft)	4.6		
	Material of Construction:	304 Stainless Steel		
Cost, $C_{pb:}$	$30,700.00			
Utilities:				
Comments:				

Seed Fermenter

Identification	Item:	Fermenter		
	Item No.:	Seed 6A/6B		
	No. Req'd:	2		
Function	To grow up Ecoli cells for 60 hours for innoculation in seed fermenter, Seed Ferm 7A or 7B			
Operation	Batch			
Materials Handled:	Stream In	Stream in	Stream out	Stream out
	S-107	S-103	S-111	S-108
Quantity(kg/batch)	3,052.7	64,593.2	6,598.1	61,047.8
Temperature(C)	37.00	37.00	37.00	37.00
Composition(kg/batch)				
Biomass	5.25	0.00	0.00	104.89
Carbon Dioxide	0.00	0.00	5749.58	0.00
Corn Steep Liquor	16.43	312.11	0.00	328.54
Ethanol	304.36	0.00	298.82	6086.17
Glycerol	0.00	12403.51	0.00	0.00
Hydrogen	0.00	0.00	266.09	0.00
Succinic Acid	8.37	0.00	0.00	167.42
Water	2718.26	51877.60	283.60	54360.78
Design Data:	Volume(L):	8,500		
	Working Vol initial (L) :	65,490 (77%)		
	Working Vol at end(L) :	63,293 (75%)		
	Height (ft)	24.8		
	Diameter (ft)	12.4		
	Material of Construction:	304 Stainless Steel		
Cost, $C_{pb:}$	$100,900.00			
Utilities:				
Comments:				

Agitator		
Identification	Item:	Agitator
	Used In	Seed Fermenters 6 A/B
	No. Req'd:	2
Function	Mixing contents of seed fermenters 6 A and B	
Operation	Continuous	
Design Data:	Electricity requirements (hp):	2.200
	Material of Construction:	304 Stainless Steel
Cost, C_{PB}	$6,500.00	
Utilities:	Electricity	
Comments:		

Seed Fermenter

Identification	Item:	Fermenter		
	Item No.:	Seed 7A/7B		
	No. Req'd:	2		
Function	To grow up Ecoli cells for 60 hours for innoculation in main fermenters, Ferm 1-12			
Operation	Batch			
Materials Handled:	Stream In	Stream in	Stream out	Stream out
	S-108	S-104	S-112	S-114
Quantity(kg/batch)	61,047.8	423,410.3	43,596.3	440,861.8
Temperature(C)	37.00	37.00	37.00	37.00
Composition(kg/batch)				
Biomass	104.89	0.00	0.00	758.06
Carbon Dioxide	0.00	0.00	37688.68	0.00
Corn Steep Liquor	328.54	2045.92	0.00	2374.46
Ethanol	6086.17	0.00	2150.22	43794.61
Glycerol	0.00	81305.36	0.00	0.00
Hydrogen	0.00	0.00	1744.23	0.00
Succinic Acid	167.42	0.00	0.00	1209.97
Water	54360.78	340058.99	2013.16	392724.70
Design Data:	Volume(L):	650,000		
	Working Vol initial (L) :	471,835(73%)		
	Working Vol at end(L) :	457,030 (70%)		
	Height (ft)	48.9		
	Diameter (ft)	24.4		
	Material of Construction:	304 Stainless Steel		
Cost, $C_{pb:}$	$150,400.00			
Utilities:				
Comments:				

Agitator		
Identification	Item:	Agitator
	Used In	Seed Fermenters 7 A/B
	No. Req'd:	2
Function	Mixing contents of seed fermenters 7 A and B	
Operation	Batch	
Design Data:	Electricity requirements (hp):	17.171
	Material of Construction:	304 Stainless Steel
Cost, C_{PB}	$20,800.00	
Utilities:	Electricity	
Comments:		

Pumps:

Pump		
Identification	Item:	Pump
	Item No.:	P-101
	No. Req'd:	1
Function	To move sterilized feed from tank T-106 to either Seed Ferm 4A or 4B	
Operation	Batch	
Materials Handled:		
	Feed: S-101	Exit: S-101
Quantity(kg/hr)	2,682.08	2,682.08
Temperature(C)	37	37
Composition(kg/hr)		
Biomass	0.00	0.00
Carbon Dioxide	0.00	0.00
Corn Steep Liquor	12.96	12.96
Ethanol	0.00	0.00
Glycerol	515.03	515.03
Hydrogen	0.00	0.00
Succinic Acid	0.00	0.00
Water	2,154.09	2,154.09
Design Data:	Density of Fluid (kg/l):	1.03
	Brake Power (hp):	0.89
	Pump Head (ft):	59.21
	Electricity requirements(kW):	0.83
	Material of Construction:	304 stainless steel
Cost:	$3,700.00	
Utilities:	Electricity	
Comments:		

Pump

Identification	Item:	Pump
	Item No.:	P-102
	No. Req'd:	2
Function	To move sterilized feed from tank T-106 to either Seed Ferm 5A or 5B	
Operation	Batch	
Materials Handled:		
	Feed: S-102	Exit: S-102
Quantity(kg/batch)	3,230.4	3,230.4
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	0.0	0.0
Carbon Dioxide	0.0	0.0
Corn Steep Liquor	15.6	15.6
Ethanol	0.0	0.0
Glycerol	620.3	620.3
Hydrogen	0.0	0.0
Succinic Acid	0.0	0.0
Water	2,594.5	2,594.5
Design Data:	Density of Fluid (kg/l):	1.04
	Brake Power (hp):	6.41
	Pump Head (ft):	64.97
	Electricity requirements(kW):	5.59
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$4,400.00	
Utilities:	Electricity	
Comments:		

Pump

Identification	Item:	Pump
	Item No.:	P-103
	No. Req'd:	2
Function	To move sterilized feed from tank T-106 to either Seed Ferm 6A or 6B	
Operation	Batch	

Materials Handled:

	Feed: S-103	Exit: S-103
Quantity(kg/batch)	64,593.2	64,593.2
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	0.0	0.0
Carbon Dioxide	0.0	0.0
Corn Steep Liquor	312.1	312.1
Ethanol	0.0	0.0
Glycerol	12,403.5	12,403.5
Hydrogen	0.0	0.0
Succinic Acid	0.0	0.0
Water	51,877.6	51,877.6

Design Data:	Density of Fluid (kg/l):	1.04
	Brake Power (hp):	8.84
	Pump Head (ft):	80.46
	Electricity requirements(kW):	8.03
	Material of Construction:	304 stainless steel

Cost,C_{PB}	$4,900.00
Utilities:	Electricity
Comments:	

Pump

Identification	Item:	Pump
	Item No.:	P-104
	No. Req'd:	2
Function	To move sterilized feed from tank T-106 to either Seed Ferm 7A or 7B	
Operation	Batch	
Materials Handled:		
	Feed: S-104	Exit: S-104
Quantity(kg/batch)	423,410.3	423,410.3
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	0.0	0.0
Carbon Dioxide	0.0	0.0
Corn Steep Liquor	2,045.9	2,045.9
Ethanol	0.0	0.0
Glycerol	81,305.4	81,305.4
Hydrogen	0.0	0.0
Succinic Acid	0.0	0.0
Water	340,059.0	340,059.0
Design Data:	Density of Fluid (kg/l):	1.04
	Brake Power (hp):	16.7
	Pump Head (ft):	104.53
	Electricity requirements(kW):	15.10
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$6,400.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-105
	No. Req'd:	2
Function	To move products form seed fermenter 4A or 4B to seed fermenter 5A or 5B	
Operation	Batch	
Materials Handled:		
	Feed: S-106	Exit: S-106
Quantity(kg/batch)	152.12	152.1
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	10.667	10.667
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	8.186	8.186
Ethanol	329.217	329.217
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	3.533	3.533
Water	7518.970	7518.970
Design Data:	Density of Fluid (kg/l):	0.965
	Brake Power (hp):	0.975
	Pump Head (ft):	69.114
	Electricity requirements(kW):	0.909
	Material of Construction:	304 stainless steel
Cost,CPB	$3,600.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-106
	No. Req'd:	2
Function	To move products form seed fermenter 5A or 5B to seed fermenter 6A or 6B	
Operation	Batch	
Materials Handled:		
	Feed: S-107	Exit: S-107
Quantity(kg/batch)	3,052.7	3,052.7
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	5.246	5.246
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	16.428	16.428
Ethanol	304.361	304.361
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	8.371	8.371
Water	2718.259	2718.259
Design Data:	Density of Fluid (kg/l):	0.963
	Brake Power (hp):	7.600
	Pump Head (ft):	84.677
	Electricity requirements(kW):	6.905
	Material of Construction:	304 stainless steel
Cost,CPB	$4,700.00	
Utilities:	Electricity	
Comments:		

Pump

Identification	Item:	Pump
	Item No.:	P-107
	No. Req'd:	2
Function	To move products form seed fermenter 5A or 5B to seed fermenter 6A or 6B	
Operation	Batch	
Materials Handled:		
	Feed: S-108	Exit: S-108
Quantity(kg/batch)	61,047.8	61,047.8
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	104.891	104.891
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	328.543	328.543
Ethanol	6086.169	6086.169
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	167.417	167.417
Water	54360.776	54360.776
Design Data:	Density of Fluid (kg/l):	0.965
	Brake Power (hp):	11.262
	Pump Head (ft):	108.681
	Electricity requirements(kW):	10.204
	Material of Construction:	304 stainless steel
Cost,CPB	$5,300.00	
Utilities:		
Comments:		

Main Fermentation Section:

Fermenters:

Main Fermenter				
Identification	Item:	Fermenter		
	Item No.:	Ferm 1-Ferm 12		
	No. Req'd:	12		
Function	To produce ethanol through fermentation of glycerol in 60 hours .			
Operation	Batch			
Materials Handled:	Stream In	Stream in	Stream out	Stream out
	Sterilized Feed	Prod of Seed Ferm	Broth	Vapor
Quantity(kg/batch)	1,556,144.8	73,447.6	1,471,321.3	158,271.2
Temperature(C)	37.00	37.00	37.00	37.00
Composition(kg/batch)				
Biomass	0.00	126.29	2526.88	0.00
Carbon Dioxide	0.00	0.00	0.00	138515.88
Corn Steep Liquor	7519.29	395.59	7914.88	0.00
Ethanol	0.00	7296.18	146590.06	7197.25
Glycerol	298818.71	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	6410.52
Succinic Acid	0.00	201.58	4033.23	0.00
Water	1249806.82	65427.93	1310256.21	6147.61
Design Data:	Volume(L):	341,500		
	Working Vol initial (L) :	1,577,642 (79%)		
	Working Vol at end(L) :	1,525,404 (76%)		
	Height (ft)	71.1		
	Diameter (ft)	35		
	Material of Construction:	304 Stainless Steel		
Cost, $C_{pb:}$	$341,500.00			
Utilities:				
Comments:				

Agitator		
Identification	Item:	Agitator
	Used In	Fermenters 1-12
	No. Req'd:	12
Function	Denaturing ethanol with gasoline	
Operation	Continuous	
Design Data:	Electricity requirements (hp):	20.000
	Material of Construction:	304 Stainless Steel
Cost,C_{PB}	$44,200.00	
Utilities:	Electricity	
Comments:		

Storage Tanks:

Holding Tank		
Identification	Item:	Holding Tank
	Item No.:	T-107
	No. Req'd:	1
Function	To hold the product after the Main fermentation Process	
Operation	Batch	
Materials Handled:		
	Flow In	
Quantity(kg/batch)	1,471,321.3	
Temperature(C)	37.0	
Composition(kg/batch)		
Biomass	2,526.88	
Carbon Dioxide	0.00	
Corn Steep Liquor	7,914.88	
Ethanol	146,590.06	
Glycerol	0.00	
Hydrogen	0.00	
Succinic Acid	4,033.23	
Water	1,310,256.21	
Design Data:	Volume (L)	3,370,526.00
	Working Volume	0.80
	Diameter (ft)	76.90
	Height (ft)	25.6
	Model	Floating Roof
	Material of Construction:	304 stainless steel
Cost,CPB	$582,900.00	
Utilities:		
Comments:		

Agitator		
Identification	Item:	Agitator
	Used In	Storage Tank 107
	No. Req'd:	1
Function	Stir contents of broth storage tank	
Operation	Continuous	
Design Data:	Electricity requirements (hp):	20.000
	Material of Construction:	304 Stainless Steel
Cost, C_{PB}	$44,200.00	
Utilities:	Electricity	
Comments:		

Heat Exchangers:

Heat Exchanger

Identification	Item:	Heat Exchanger
	Item No.:	HX-FERM
	No. Req'd:	12

Function	To cool the contents of each 2,000,000 L fermentation tanks
Operation	Continuous

Materials Handled:	Shell Side		Tube Side	
	Stream In	Stream out	Stream in	Stream out
	S-143	S-FP-144	S-141	S-142
Quantity(kg/hr)	22,063.0	22,063.0	24,522.0	24,523.0
Temperature(C)	31.44	36.60	42.72	37.00
Composition(kg/hr)				
Biomass	0.00	0.00	42.11	42.11
Carbon Dioxide	0.00	0.00	0.00	1.00
Corn Steep Liquor	0.00	0.00	131.91	131.91
Ethanol	0.00	0.00	2443.17	2443.17
Glycerol	0.00	0.00	0.00	0.00
Hydrogen	0.00	0.00	0.00	0.00
Succinic Acid	0.00	0.00	67.22	67.22
Water	22063.00	22063.00	21837.60	21837.60

Design Data:		
	Heat Duty(BTU)	518,300.0
	Overall Heat Coefficient (BTU/hr-ft^2°F)	250.0
	Heat Transfer Area (ft^2)	197.6
	Type	Double Pipe
	Materials of Construction	
	Shell:	Tube:
	carbon steel	304 Stainless steel

Cost, C_{PB}	$4,200.00
Utilities:	A mixture of 95% cooling water is used in the shell
Comments:	5% chilled water

Pumps:

Pump		
Identification	Item:	Pump
	Item No.:	P-FA
	No. Req'd:	2
Function	To bring sterilized feed to main fermentation tanks	
Operation	Batch	
Materials Handled:		
	Feed: S-115 - S-120	Exit: S-115 - S-120
Quantity(kg/batch)	1,556,144.8	1,556,144.8
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	7519.292	7519.292
Ethanol	0.000	0.000
Glycerol	298818.709	298818.709
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	1249806.816	1249806.816
Design Data:	Density of Fluid (kg/l):	1.04
	Pressure Drop (Pa):	220400.00
	Brake Power (hp):	55.56
	Pump Head (ft):	126.75
	Electricity requirements(kW):	50.13
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$19,400.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FB
	No. Req'd:	2
Function	To bring seed train products to main fermentation tanks	
Operation	Batch	
Materials Handled:		
	Feed: S-121 - S-126	Exit: S-121 - S-126
Quantity(kg/batch)	73,447.6	73,447.6
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	126.293	126.293
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	395.585	395.585
Ethanol	7296.182	7296.182
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	201.580	201.580
Water	65427.934	65427.934
Design Data:	Density of Fluid (kg/l):	0.96
	Pressure Drop (Pa):	205200.00
	Brake Power (hp):	1.86
	Pump Head (ft):	130.89
	Electricity requirements(kW):	1.72
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$3,600.00	
Utilities:	Electricity	
Comments:		

Pump

Identification	Item:	Pump
	Item No.:	P-FC
	No. Req'd:	2
Function	To bring main fermentation tank products to broth storage tank	
Operation	Batch	
Materials Handled:		
	Feed: S-132 - S-137	Exit: S-132 - S-137
Quantity(kg/batch)	1,471,321.3	1,471,321.3
Temperature(C)	37.0	37.0
Composition(kg/batch)		
Biomass	2526.879	2526.879
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	7914.877	7914.877
Ethanol	146590.059	146590.059
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	4033.232	4033.232
Water	1310256.215	1310256.215
Design Data:	Density of Fluid (kg/l):	0.96
	Pressure Drop (Pa):	73900.00
	Brake Power (hp):	35.35
	Pump Head (ft):	85.41
	Electricity requirements(kW):	31.89
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$15,700.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FD
	No. Req'd:	1
Function	To bring broth from broth storage tank to separations section	
Operation	Continuous	
Materials Handled:		
	Feed: S-140	Exit: S-140
Quantity(kg/hr)	172,397.2	172,397.2
Temperature(C)	37.0	37.0
Composition(kg/hr)		
Biomass	296.079	296.079
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	927.400	927.400
Ethanol	17176.209	17176.209
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	472.581	472.581
Water	153524.971	153524.971
Design Data:	Density of Fluid (kg/l):	0.96
	Pressure Drop (Pa):	205200.00
	Brake Power (hp):	30.52
	Pump Head (ft):	119.59
	Electricity requirements(kW):	27.55
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$9,000.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-FE
	No. Req'd:	12
Function	To bring main fermenter contents through heat exchanger	
Operation	Continuous	
Materials Handled:		
	Feed: S-141	Exit: S-141
Quantity(kg/hr)	24522.02	24,522.0
Temperature(C)	37.0	37.0
Composition(kg/hr)		
Biomass	42.115	42.115
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	131.915	131.915
Ethanol	2443.168	2443.168
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	67.221	67.221
Water	21837.604	21837.604
Design Data:	Density of Fluid (kg/l):	0.96
	Pressure Drop (Pa):	205200.00
	Brake Power (hp):	2.97
	Pump Head (ft):	59.80
	Electricity requirements(kW):	32.66
	Material of Construction:	304 stainless steel
Cost, C_{PB}	$6,600.00	
Utilities:	Electricity	
Comments:		

Blower:

Blower		
Identification	Item:	Blower
	Item No.:	B-101
	No. Req'd:	1
Function	Bring waste gases from fermenters to furnace	
Operation	Continuous	
Materials Handled:		
	Feed: S-127 - S-131; S-138	Exit: S-139
Quantity(kg/[batch or hr])	158,271.2	19,524.7
Temperature(C)	37.0	37.0
Pressure (psi)	14.8	19.8
Composition(kg/[batch or hr])		
Biomass	0.000	0.000
Carbon Dioxide	138515.876	17084.349
Corn Steep Liquor	0.000	0.000
Ethanol	7197.246	888.991
Glycerol	0.000	0.000
Hydrogen	6410.517	790.664
Succinic Acid	0.000	0.000
Water	6147.606	760.731
Design Data:	Pressure Rise (psi):	5.000
	Brake Power (hp):	277.160
	Motor Power (hp):	300.652
	Electricity requirements(kW):	310.509
	Material of Construction:	Aluminum
Cost, C_{PB}	$70,800.00	
Utilities:	Electricity	
Comments:		

Separation Section:

Storage Tanks:

	Mixing Tank		
Identification	Item:	Mixing Tank	
	Item No.:	T-108	
	No. Req'd:	1	
Function	To mix the ethanol with gasoline to get the denatured ethanol product		
Operation	Continuous		
Materials Handled:			
	Flow In	Flow In	Flow Out
	S-S-124	S-S-125	S-S-126
Quantity(kg/hr)	18,035.8	360.7	18,396.5
Temperature(C)	50.0	25.0	50.0
Composition(kg/hr)			
Biomass	0.0	0.0	0.0
Carbon Dioxide	0.0	0.0	0.0
Corn Steep Liquor	0.0	0.0	0.0
Ethanol	18,035.8	0.0	18,035.8
Gasoline	0.0	360.7	360.7
Methane	0.0	0.0	0.0
Oxygen	0.0	0.0	0.0
Nitrogen	0.0	0.0	0.0
Glycerol	0.0	0.0	0.0
Hydrogen	0.0	0.0	0.0
Succinic Acid	0.0	0.0	0.0
	0.0	0.0	0.0
Design Data:	Volume (L)	8,020	
	Working Volume	0.50	
	Diameter (ft)	10	
	Height (ft)	3.4	
	Residence Time (min)	10	
	Model	Floating Roof	
	Material of Construction:	304 stainless steel	
Cost,C_{PB}	$26,800.00		
Utilities:			
Comments:			

Agitator

Identification	Item:	Agitator
	Used In	Storage Tank 108
	No. Req'd:	1
Function	Denature ethanol with gasoline	
Operation	Continuous	
Design Data:	Electricity requirements (hp):	4.000
	Material of Construction:	304 Stainless Steel
Cost,C_{PB}	$9,100.00	
Utilities:	Electricity	
Comments:		

Holding Tank

Identification	Item:	Holding Tank
	Item No.:	T-109
	No. Req'd:	1
Function	To hold 3 days worth of Gasoline	
Operation	Continuous	

Materials Handled:

	Stream out- S-S-125
Quantity(kg/hr)	360.7
Temperature(C)	37.0
Composition(kg/hr)	
Biomass	0.0
Carbon Dioxide	0.0
Corn Steep Liquor	0.0
Ethanol	0.0
Glycerol	0.0
Hydrogen	0.0
Succinic Acid	0.0
Water	0.0
Gasoline	360.72

Design Data:	Volume (L)	108,300.00
	Working Volume	0.80
	Diameter (ft)	24.59
	Height (ft)	8.20
	Model	Cone Roof
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$101,000.00	
Utilities:		
Comments:		

Holding Tank

Identification	Item:	Holding Tank
	Item No.:	T-110
	No. Req'd:	1
Function	To hold 3 days of succinic acid before shipment	
Operation	Continuous	
Materials Handled:		
	Stream in- S-S-121	
Quantity(kg/hr)	458.9	
Temperature(C)	37.0	
Composition(kg/hr)		
Biomass	0.0	
Carbon Dioxide	0.0	
Corn Steep Liquor	0.0	
Ethanol	0.0	
Gasoline	0.0	
Methane	0.0	
Oxygen	0.0	
Nitrogen	0.0	
Glycerol	0.0	
Hydrogen	0.0	
Succinic Acid	458.9	
Water	0	
Design Data:	Volume (L)	26,500.00
	Working Volume	0.80
	Diameter (ft)	8.41
	Height (ft)	16.82
	Model	Cone Roof
	Material of Construction:	304 stainless steel
Cost,CPB	$27,600.00	
Utilities:		
Comments:		

Holding Tank

Identification	Item:	Holding Tank
	Item No.:	T-111
	No. Req'd:	1

Function: To hold 3 days worth of Denatured Ethanol Product

Operation: Continuous

Materials Handled:

	Flow In
Quantity(kg/hr)	18,396.55
Temperature(C)	37.00
Composition(kg/hr)	
Biomass	0.00
Carbon Dioxide	0.00
Corn Steep Liquor	0.00
Ethanol	18,035.83
Gasoline	360.72
Methane	0.00
Oxygen	0.00
Nitrogen	0.00
Glycerol	0.00
Hydrogen	0.00
Succinic Acid	0.00

Design Data:	Volume (L)	2,057,300
	Working Volume	0.80
	Diameter (ft)	510
	Height (ft)	170
	Model	Floating Roof
	Material of Construction:	304 stainless steel

Cost,C_{PB} $453,300.00

Utilities:

Comments:

Heat Exchangers:

Heat Exchanger				
Identification	Item:	Heat Exchanger		
	Item No.:	HX-3		
	No. Req'd:	1		
Function	To deactivate E. coli in broth from fermentation prior to filtration			
Operation	Continuous			
Materials Handled:	Shell Side		Tube Side	
	Stream In	Stream out	Stream in	Stream out
	S-S-135	S-S-138	S-S-109	S-S-110
Quantity(kg/hr)	180,559.1	180,559.1	172,397.2	172,397.2
Temperature(C)	108.9	43.3	37.0	92.2
Pressure (psi)	21.0	21.0	14.8	14.8
Composition(kg/hr)				
Biomass	0	0	296.1	296.1
Carbon Dioxide	0	0	0.0	0.0
Corn Steep Liquor	0	0	927.4	927.4
Ethanol	0	0	17,176.2	17,176.2
Gasoline	0	0	0.0	0.0
Methane	0	0	0.0	0.0
Oxygen	0	0	0.0	0.0
Nitrogen	0	0	0.0	0.0
Glycerol	0	0	0.0	0.0
Hydrogen	0	0	0.0	0.0
Succinic Acid	0	0	472.6	472.6
Water	180559.1207	180559.1207	153,525.0	153,525.0
Design Data:				
	Heat Duty(BTU)		48,041,600.0	
	Overall Heat Coefficient (BTU/hr-ft^2°F)		250.0	
	Heat Transfer Area (ft^2)		9,996.6	
	Type		Floating Head Shell/Tube	
	Materials of Construction			
	Shell:		Tube:	
	carbon steel		304 Stainless steel	
Cost,C_{PB}	$113,900.00			
Utilities:				
Comments:				

Heat Exchanger

Identification	Item:	Heat Exchanger		
	Item No.:	HX-4		
	No. Req'd:	1		
Function	Partial condenser for Distillation Column			
Operation	Continuous			
Materials Handled:	Shell Side		Tube Side	
	Stream In	Stream out	Stream in	Stream out
	S-S-105	S-S-106	S-S-130	S-S-129
Quantity(kg/hr)	1,087,869.8	1,087,869.8	172,397.2	172,397.2
Temperature(C)	32.2	48.9	82.0	82.0
Pressure (psi)	25.0	20.0	17.0	17.0
Composition(kg/hr)				
Biomass	0	0	0.0	0.0
Carbon Dioxide	0	0	0.0	0.0
Corn Steep Liquor	0	0	0.0	0.0
Ethanol	0	0	174,279.2	174,279.2
Gasoline	0	0	0.0	0.0
Methane	0	0	0.0	0.0
Oxygen	0	0	0.0	0.0
Nitrogen	0	0	0.0	0.0
Glycerol	0	0	0.0	0.0
Hydrogen	0	0	0.0	0.0
Succinic Acid	0	0	0.0	0.0
Water	1087869.823	1087869.823	15,394.0	15,394.0
Design Data:				
	Heat Duty(BTU)		68,130,000	
	Overall Heat Coefficient (BTU/hr-ft^2°F)		200.0	
	Heat Transfer Area (ft^2)		4,635.8	
	Type		Floating Head Shell/Tube	
	Materials of Construction			
	Shell:		Tube:	
	carbon steel		304 Stainless steel	
Cost,C_{PB}	$65,900.00			
Utilities:	1087870 l/hr cooling water			
Comments:				

Heat Exchanger

Identification	Item:	Heat Exchanger		
	Item No.:	HX-5		
	No. Req'd:	1		
Function	Cooling ethanol product			
Operation	Continuous			
Materials Handled:	Shell Side		Tube Side	
	Stream In	Stream out	Stream in	Stream out
	S-S-136	S-S-137	S-S-122	S-S-124
Quantity(kg/hr)	23,766.1	23,766.1	18,035.8	18,035.8
Temperature(C)	32.2	48.9	78.4	50.0
Composition(kg/hr)				
Biomass	0	0	0.0	0.0
Carbon Dioxide	0	0	0.0	0.0
Corn Steep Liquor	0	0	0.0	0.0
Ethanol	0	0	18,035.8	18,035.8
Gasoline	0	0	0.0	0.0
Methane	0	0	0.0	0.0
Oxygen	0	0	0.0	0.0
Nitrogen	0	0	0.0	0.0
Glycerol	0	0	0.0	0.0
Hydrogen	0	0	0.0	0.0
Succinic Acid	0	0	0.0	0.0
Water	23766.1086	23766.1086	0.0	0.0
Design Data:				
	Heat Duty(BTU)		1,488,800	
	Overall Heat Coefficient (BTU/hr-ft^2°F)		150.0	
	Heat Transfer Area (ft^2)		238.2	
	Type		Floating Head Shell/Tube	
	Materials of Construction			
	Shell:		Tube:	
	carbon steel		304 Stainless steel	
Cost,C_{PB}	$21,200.00			
Utilities:	23766.11 l/hr cooling water			
Comments:				

Heat Exchanger

Identification	Item:	Heat Exchanger			
	Item No.:	HX-6			
	No. Req'd:	1			
Function	Supplement to furnace for reboiling bottoms of distillation column				
Operation	Continuous				
Materials Handled:	Shell Side		Tube Side		
	Stream In	Stream out	Stream in	Stream out 1 (l)	Stream out 2 (v)
	S-S-107	S-S-108	S-S-114	S-S-116	S-S-133
Quantity(kg/hr)	16,775.3	16,775.3	233,698.1	181,540.8	37,964.9
Temperature(C)	147.7	147.7	108.9	108.9	108.9
Pressure (psi)	64.7	64.7	21.5	21.5	21.5
Composition(kg/hr)					
Biomass	0	0	0.0	0.0	0.0
Carbon Dioxide	0	0	0.0	0.0	0.0
Corn Steep Liquor	0	0	509.3	509.3	0.0
Ethanol	0	0	1.5	0.5	1.0
Gasoline	0	0	0.0	0.0	0.0
Methane	0	0	0.0	0.0	0.0
Oxygen	0	0	0.0	0.0	0.0
Nitrogen	0	0	0.0	0.0	0.0
Glycerol	0	0	0.0	0.0	0.0
Hydrogen	0	0	0.0	0.0	0.0
Succinic Acid	0	0	472.4	472.4	0.0
Water	16775.34406	16775.34406	216,965.4	179,000.5	37,964.9
Design Data:					
	Heat Duty(BTU)		33,780,000		
	Heat Coefficient (BTU/hr-ft^2°F)		200.0		
	Heat Transfer Area (ft^2)		2,412.0		
	Type		Kettle Vaporizer Reboiler		
	Materials of Construction				
	Shell:		Tube:		
	carbon steel		304 Stainless steel		
Cost,CPB	$60,300.00				
Utilities:	16775 kg/hr 50 psig steam				
Comments:					

Pumps:

Pump		
Identification	Item:	Pump
	Item No.:	P-S-101
	No. Req'd:	1
Function	To bring solution from rotary drum filter to distillation column	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-112	Exit: S-S-112
Quantity(kg/hr)	171,420.7	171,420.7
Temperature(C)	92.2	92.2
Composition(kg/hr)		
Biomass	29.608	29.608
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	509.278	509.278
Ethanol	17146.882	17146.882
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	0.000	0.000
Nitrogen	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	472.356	472.356
Water	153262.613	153262.613
Design Data:	Density of Fluid (kg/l):	0.98
	Pressure Drop (Pa):	474600.00
	Brake Power (hp):	56.16
	Pump Head (ft):	220.84
	Electricity requirements(kW):	50.67
	Material of Construction:	304 stainless steel
Cost, C_{PB}	$13,100.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-S-102
	No. Req'd:	1
Function	To bring bottoms product from furnace to electrodialysis	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-116	Exit: S-S-116
Quantity(kg/hr)	181,540.8	181,540.8
Temperature(C)	111.3	111.3
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	509.278	509.278
Ethanol	0.000	0.000
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	0.000	0.000
Nitrogen	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	472.356	472.356
Water	180559.121	180559.121
Design Data:	Density of Fluid (kg/l):	1.005
	Pressure Drop (Pa):	50.000
	Brake Power (hp):	30.828
	Pump Head (ft):	114.845
	Electricity requirements(kW):	27.822
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$9,000.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-S-104
	No. Req'd:	1
Function	To bring liquid from crystallizer to electrodialysis	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-119	Exit: S-S-119
Quantity(kg/hr)	45,331.2	45,331.2
Temperature(C)	40.0	40.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	4583.503	4583.503
Ethanol	0.000	0.000
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	0.000	0.000
Nitrogen	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	121.877	121.877
Water	40625.802	40625.802
Design Data:	Density of Fluid (kg/l):	1.116
	Pressure Drop (Pa):	50.000
	Brake Power (hp):	8.605
	Pump Head (ft):	103.484
	Electricity requirements(kW):	7.807
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$4,700.00	
Utilities:		
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-S-105
	No. Req'd:	1
Function	To bring ethanol from absorber to distillation column	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-104	Exit: S-S-104
Quantity(kg/hr)	28,185.6	28,185.6
Temperature(C)	41.2	41.2
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	889.132	889.132
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	0.000	0.000
Nitrogen	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	27296.508	27296.508
Design Data:	Density of Fluid (kg/l):	0.959
	Pressure Drop (Pa):	50.000
	Brake Power (hp):	12.278
	Pump Head (ft):	222.340
	Electricity requirements(kW):	11.118
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$5,200.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-S-106
	No. Req'd:	1
Function	To bring reflux from distillate back to column	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-128	Exit: S-S-128
Quantity(kg/hr)	165,301.2	165,301.2
Temperature(C)	82.0	82.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	151734.448	151734.448
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	0.000	0.000
Nitrogen	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	13566.737	13566.737
Design Data:	Density of Fluid (kg/l):	0.80
	Pressure Drop (Pa):	389000.00
	Brake Power (hp):	56.43
	Pump Head (ft):	234.03
	Electricity requirements(kW):	50.92
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$13,500.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-S-107
	No. Req'd:	1
Function	To bring bottoms product to furnace	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-131	Exit: S-S-132
Quantity(kg/hr)	233,698.1	233,698.1
Temperature(C)	108.9	108.9
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	509.278	509.278
Ethanol	0.008	0.008
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	0.000	0.000
Nitrogen	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	472.364	472.364
Water	232716.491	232716.491
Design Data:	Density of Fluid (kg/l):	1.004
	Pressure Drop (Pa):	50.000
	Brake Power (hp):	38.689
	Pump Head (ft):	114.867
	Electricity requirements(kW):	34.906
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$15,700.00	
Utilities:	Electricity	
Comments:		

Pump		
Identification	Item:	Pump
	Item No.:	P-S-108
	No. Req'd:	1
Function	To bring clean water to absorber	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-101	Exit: S-S-101
Quantity(kg/hr)	27,022.5	27,022.5
Temperature(C)	25.0	25.0
Composition(kg/hr)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	0.000	0.000
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	0.000	0.000
Nitrogen	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	27022.500	27022.500
Design Data:	Density of Fluid (kg/l):	1.00
	Pressure Drop (Pa):	149700.00
	Brake Power (hp):	5.81
	Pump Head (ft):	107.81
	Electricity requirements(kW):	5.30
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$7,200.00	
Utilities:	Electricity	
Comments:		

Blowers:

Blower		
Identification	Item:	Blower
	Item No.:	B-102
	No. Req'd:	1
Function	Bring waste gases from fermenters to furnace	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-113	Exit: S-S-113
Quantity(kg/[batch or hr])	135,234.5	135,234.5
Temperature(C)	37.0	37.0
Pressure (psi)	14.7	18.7
Composition(kg/[batch or hr])		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	0.000	0.000
Gasoline	0.000	0.000
Methane	0.000	0.000
Oxygen	31498.339	31498.339
Nitrogen	103736.141	103736.141
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	0.000	0.000
Water	0.000	0.000
Design Data:	Pressure Rise (psi):	4.000
	Brake Power (hp):	1500.000
	Motor Power (hp):	1602.646
	Electricity requirements(kW):	1195.093
	Material of Construction:	Aluminum
Cost,C_{PB}	$264,200.00	
Utilities:	Electricity	
Comments:		

Columns:

Distillation Column

Identification	Item:	Distillation Column			
	Item No.:	D-1			
	No. Req'd:	1			
Function	Separate ethanol to it's azeotrope with water from water and succinic acid				
Operation	Continuous				
Materials Handled:	Feeds			Products	
	Stream In 1	Stream In 2	Stream In 3	Distillate	Bottoms
	S-S-104	S-S-123	S-S-112	S-S-115	S-S-116
Quantity(kg/hr)	28,185.6	6,336.0	171,420.7	24,372.1	181,540.8
Temperature(C)	41.2	82.0	37.0	82.0	108.9
Pressure (psi)	20.0	14.7	14.7	14.7	21.5
Composition(kg/hr)					
Biomass	0	0.0	29.6	0.0	0.0
Carbon Dioxide	0	0.0	0.0	0.0	0.0
Corn Steep Liquor	0	0.0	509.3	0.0	509.3
Ethanol	889.13	4,508.8	17,146.9	22,544.8	0.0
Gasoline	0	0.0	0.0	0.0	0.0
Methane	0	0.0	0.0	0.0	0.0
Oxygen	0	0.0	0.0	0.0	0.0
Nitrogen	0	0.0	0.0	0.0	0.0
Glycerol	0	0.0	0.0	0.0	0.0
Hydrogen	0	0.0	0.0	0.0	0.0
Succinic Acid	0	0.0	472.4	0.0	472.4
Water	27296.51	1,827.3	153,262.6	1,827.3	180,559.1
Design Data:					
	Stages		80.0		
	Diameter (ft)		12		
	Height (ft)		172.0		
	Shell Thickness (in)		0.5		
	Tray Type		Baffle tray		
	Materials of Construction		304 Stainless steel		
Cost,CPB	$798,000.00				
Utilities:					
Comments:	Biomass is periodically removed from a hopper in the bottom of the tower.				

Absorber Column

Identification	Item:	Absorber Column		
	Item No.:	AB-1		
	No. Req'd:	1		
Function	To capture the ethanol that escapes the fermenters as vapor			
Operation	Continuous			
Materials Handled:	Vapor		Liquid	
	Stream In	Stream out	Stream in	Stream out
	S-S-102	S-S-103	S-S-101	S-S-104
Quantity(kg/hr)	19,524.8	18,362.0	27,022.5	28,185.6
Temperature(C)	25.0	29.0	37.0	41.2
Pressure (psi)	16.0	16.0	14.8	20.0
Composition(kg/hr)				
Biomass	0	0	0.0	0.0
Carbon Dioxide	17084.2419	17084.24239	0.0	0.0
Corn Steep Liquor	0	0	0.0	0.0
Ethanol	889.1317	0.224366224	0.0	889.1
Gasoline	0	0	0.0	0.0
Methane	0	0	0.0	0.0
Oxygen	0	0	0.0	0.0
Nitrogen	0	0	0.0	0.0
Glycerol	0	0	0.0	0.0
Hydrogen	790.65504	790.6550493	0.0	0.0
Succinic Acid	0	0	0.0	0.0
Water	760.77345	486.9174262	27,022.5	27,296.5
Design Data:	Stages		18	
	Diameter (ft)		5.50	
	Height (ft)		50.00	
	Shell thickness (in)		0.31	
	Type		Bubble Cap Trays	
	Materials of Construction		304 Stainless steel	
Cost,C_{PB}	$117,100.00			
Utilities:				
Comments:				

Miscellaneous:

Reflux Accumulator

Identification	Item:	Reflux Accumulator		
	Item No.:	RA-1		
	No. Req'd:	1		
Function	Separates the Distillate vapor product from the liquid reflux			
Operation	Continuous			
Materials Handled:				
	Feed	Recycle	Product	
	S-S-129	S-S-128	S-S-115	
Quantity(kg/hr)	189,673.2	165,301.2	24,372.0	
Temperature(C)	82.0	82.0	82.0	
Pressure (psi)	17.0	17.0	17.0	
Composition(kg/hr)				
Biomass	0	0	0.0	
Carbon Dioxide	0	0	0.0	
Corn Steep Liquor	0	0	0.0	
Ethanol	174279.2349	151734.4484	22,544.8	
Gasoline	0	0	0.0	
Methane	0	0	0.0	
Oxygen	0	0	0.0	
Nitrogen	0	0	0.0	
Glycerol	0	0	0.0	
Hydrogen	0	0	0.0	
Succinic Acid	0	0	0.0	
Water	15393.99797	13566.73652	1,827.3	
Design Data:	Diameter (ft)		11.6	
	Length (ft)		6	
	Volume (cuft)		606.0	
	Materials of Construction		304 Stainless Steel	
Cost,C_{PB}	$47,000.00			
Utilities:				
Comments:				

Furnace

Identification	Item:	Furnace			
	Item No.:	FN-1			
	No. Req'd:	1			
Function	Burn hydrogen waste gas and reboil bottoms of distillation column				
Operation	Continuous				
Materials Handled:	Shell Side			Tube Side	
	Stream In 1	Stream In 2	Stream out	Stream in	Stream out
	S-S-113	S-S-103	S-S-117	S-S-132	S-S-114
Quantity(kg/hr)	135,234.5	18,362.0	153,597.3	217,948.5	217,948.5
Temperature(C)	37.0	29.0	121.0	108.9	108.9
Pressure (psi)	14.7	16.0	14.7	21.5	21.5
Composition(kg/hr)					
Biomass	0	0.0	0.0	0.0	0.0
Carbon Dioxide	0	17,084.2	17,084.7	0.0	0.0
Corn Steep Liquor	0	0.0	0.0	509.3	509.3
Ethanol	0	0.2	0.0	1.5	1.5
Gasoline	0	0.0	1.0	0.0	0.0
Methane	0	0.0	0.0	0.0	0.0
Oxygen	31498.33877	0.0	25,223.1	0.0	0.0
Nitrogen	103736.1414	0.0	103,736.1	0.0	0.0
Glycerol	0	0.0	0.0	0.0	0.0
Hydrogen	0	790.7	0.0	0.0	0.0
Succinic Acid	0	0.0	0.0	472.4	472.4
Water	0	486.9	7,552.4	216,965.4	216,965.4
Design Data:					
	Heat Duty(BTU)			76,910,000.0	
	Reactions			$2H_2 + O_2 \rightarrow 2H_2O$	
				$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$	
	Type			Fired Heater	
	Materials of Construction				
	Shell:			Tube:	
	304 Stainless steel			304 Stainless steel	
Cost, C_{PB}	$1,717,600.00				
Utilities:					
Comments:					

Rotary Drum Filter

Identification	Item:	Rotary Drum Filter	
	Item No.:	RDF-1	
	No. Req'd:	1	
Function	Separates Biomass from Distillation Column Feed		
Operation	Continuous		
Materials Handled:	Solutions		Waste
	Feed	Product	Biomass
	S-S-110	S-S-112	S-S-111
Quantity(kg/hr)	172,397.2	171,420.7	977.2
Temperature(C)	92.2	92.2	92.2
Pressure (psi)	14.7	14.7	14.7
Composition(kg/hr)			
Biomass	296.0787557	29.60787557	266.5
Carbon Dioxide	0	0	0.0
Corn Steep Liquor	927.3997293	509.2781511	418.1
Ethanol	17176.20898	17146.8818	29.4
Gasoline	0	0	0.0
Methane	0	0	0.0
Oxygen	0	0	0.0
Nitrogen	0	0	0.0
Glycerol	0	0	0.0
Hydrogen	0	0	0.0
Succinic Acid	472.5806935	472.356	0.8
Water	153524.9706	153262.6125	262.4
Design Data:			
	Materials of Construction		316 Stainless Steel
Cost,CPB	$184,400.00		
Utilities:	Electricity		
Comments:			

Molecular Sieve

Identification	Item:	Molecular Sieve	
	Item No.:	MS-1	
	No. Req'd:	1	
Function	Separate Water from azeotropic water ethanol mixture		
Operation	Continuous		
Materials Handled:	Shell Side		Tube Side
	Feed	Ethanol	Recirculation
	S-S-115	S-S-122	S-S-123
Quantity(kg/hr)	24,372.0	18,035.8	6,336.0
Temperature(C)	82.0	78.4	82.0
Pressure (psi)	17.0	17.0	17.0
Composition(kg/hr)			
Biomass	0	0	0.0
Carbon Dioxide	0	0	0.0
Corn Steep Liquor	0	0	0.0
Ethanol	22544.78653	18035.82922	4,508.8
Gasoline	0	0	0.0
Methane	0	0	0.0
Oxygen	0	0	0.0
Nitrogen	0	0	0.0
Glycerol	0	0	0.0
Hydrogen	0	0	0.0
Succinic Acid	0	0	0.0
Water	1827.26145	0	1,827.3
Design Data:			
	Type		Molecular Sieve
	Materials of Construction		Unknown
Cost,C_{PB}	$2,746,200.00		
Utilities:	Electricity	79.52318	kW
	Low P Steam	1590.4636	lb/hr
	Cooling Water	119284.77	gal/hr
Comments:	Black box design provided by Bruce Vrana		

Electro Dialysis

Identification	Item:	Electro Dialysis			
	Item No.:	ED-1			
	No. Req'd:	1			
Function	Transfer Succinic acid from the bottoms product to succinic acid recovery system				
Operation	Continuous				
Materials Handled:	Concentrating Side			Purifying Side	
	Fresh Water Feed	Recirc Feed	Conc. Stream	From Tower	Clean Out
	S-S-127	S-S-119	S-S-118	S-S-116	S-S-135
Quantity(kg/hr)	4,514.0	45,331.2	50,826.8	181,540.8	180,559.1
Temperature(C)	25.0	25.0	25.0	108.9	108.9
Pressure (psi)	14.7	14.7	14.7	21.5	21.5
Composition(kg/hr)					
Biomass	0	0.0	0.0	0.0	0.0
Carbon Dioxide	0	0.0	0.0	0.0	0.0
Corn Steep Liquor	0	4,583.5	5,092.8	509.3	0.0
Ethanol	0	0.0	0.0	0.0	0.0
Gasoline	0	0.0	0.0	0.0	0.0
Methane	0	0.0	0.0	0.0	0.0
Oxygen	0	0.0	0.0	0.0	0.0
Nitrogen	0	0.0	0.0	0.0	0.0
Glycerol	0	0.0	0.0	0.0	0.0
Hydrogen	0	0.0	0.0	0.0	0.0
Succinic Acid	0	121.9	594.2	472.4	0.0
Water	4513.978016	40,625.8	45,139.8	180,559.1	180,559.1
Design Data:					
	Type			Electro Dialysis	
	Materials of Construction			Unknown	
Cost,CPB	$2,700,000.00				
Utilities:	$190,200.00	/year			
Comments:					

Crystalizer

Identification	Item:	Crystalizer		
	Item No.:	C-1		
	No. Req'd:	1		
Function	Precipitates the supersaturated succinic acid into crystals			
Operation	Continuous			
Materials Handled:	Solutions		Product	
	Recycle In	Recycle Out	Crystals & Purge	
	S-S-118	S-S-119	S-S-120	
Quantity(kg/hr)	50,826.8	45,331.2	5,495.6	
Temperature(C)	25.0	25.0	25.0	
Pressure (psi)	14.7	14.7	14.7	
Composition(kg/hr)				
Biomass	0	0	0.0	
Carbon Dioxide	0	0	0.0	
Corn Steep Liquor	5092.781511	4583.50336	509.3	
Ethanol	0	0	0.0	
Gasoline	0	0	0.0	
Methane	0	0	0.0	
Oxygen	0	0	0.0	
Nitrogen	0	0	0.0	
Glycerol	0	0	0.0	
Hydrogen	0	0	0.0	
Succinic Acid	594.2334064	121.8774064	472.4	
Water	45139.78016	40625.80215	4,514.0	
Design Data:				
	Materials of Construction		316 Stainless Steel	
Cost, C_{PB}	$154,500.00			
Utilities:				
Comments:				

Dryer

Identification	Item:	Dryer	
	Item No.:	DR-1	
	No. Req'd:	1	
Function	Dryes the crystals from C-1		
Operation	Batch		
Materials Handled:	Solutions		Product
	Feed	Waste	Succinic Acid
	S-S-120	S-S-134	S-S-121
Quantity(kg/hr)	5,495.6	5,036.8	458.8
Temperature(C)	25.0	25.0	100.0
Pressure (psi)	14.7	14.7	14.7
Composition(kg/hr)			
Biomass	0	0	0.0
Carbon Dioxide	0	0	0.0
Corn Steep Liquor	509.2781511	509.2781511	0.0
Ethanol	0	0	0.0
Gasoline	0	0	0.0
Methane	0	0	0.0
Oxygen	0	0	0.0
Nitrogen	0	0	0.0
Glycerol	0	0	0.0
Hydrogen	0	0	0.0
Succinic Acid	472.356	13.54193405	458.8
Water	4513.978016	4513.978016	0.0
Design Data:			
	Materials of Construction		316 Stainless Steel
Cost,CPB	$22,200.00		
Utilities:			
Comments:			

Screw Conveyor		
Identification	Item:	Screw Conveyor
	Item No.:	CB-1
	No. Req'd:	1
Function	To cary Succinic acid crystals to storage tank	
Operation	Continuous	
Materials Handled:		
	Feed: S-S-121	Exit: S-S-121
Quantity(kg/batch)	458.8	458.8
Temperature(C)	100.0	100.0
Composition(kg/batch)		
Biomass	0.000	0.000
Carbon Dioxide	0.000	0.000
Corn Steep Liquor	0.000	0.000
Ethanol	0.000	0.000
Glycerol	0.000	0.000
Hydrogen	0.000	0.000
Succinic Acid	458.814066	458.814066
Water	0.000	0.000
Design Data:	Density of Crystals (kg/l):	1.600
	Pressure Drop (Pa):	0.000
	Brake Power (hp):	1.000
	Pump Head (ft):	0.000
	Electricity requirements(kW):	0.750
	Material of Construction:	304 stainless steel
Cost,C_{PB}	$13,000.00	
Utilities:	Electricity	
Comments:		

Alternate Units and Considerations

Section IX

Alternate Process Units and Considerations

Succinic Acid Separation:

Numerous methods of separation were considered for succinic acid, the most promising of which was ion exchange chromatography. During the initial investigation phase, however, it was noted that the resin exhibited significant loss of functionality over time, as some succinic acid would not desorb during washing. The loss of useful resin would have cost $14MM per year minimum, as a small quantity of resin would have to be continually replenished. Electrodialysis was found to be a cost effective alternative, even before pricing equipment.

Absorber Column vs. Ethanol Burning:

At 37 ^{o}C, the vapor pressure of ethanol is high enough for a significant portion to escape as vapor with the hydrogen and carbon dioxide gases emitted during fermentation. Since the hydrogen-rich stream is sent to the furnace in order to recover the heat of combustion for use in the reboiler, burning the vaporized ethanol rather than absorbing it was considered. Steam, however, has a cost of 3.3 cents per 10,000 BTU, while burning ethanol would result in a 33 cent loss per 10,000 BTU. It was therefore financially advantageous to capture the vaporized ethanol and recover it in an absorption column.

Natural Gas vs. Steam for Reboiler Heat Duty:

Natural gas and steam were the two main choices for supplying the remainder of the heat duty for the reboiler not supplied by the hydrogen combustion. The cost of energy from natural gas was $3.69 per MMBTU while steam cost $3.30 per MMBTU. Furthermore, the installation cost of a steam-powered heat exchanger is significantly lower than the installation cost of another furnace, or the redesigning of the furnace for higher heat duty. Ultimately steam heat was more cost effective.

Glycerol Feed Purchase:

Glycerol feedstock from the biodiesel industry is available in two main forms: crude and partially refined. Although the partially refined glycerol feed would have eliminated the need for the glycerol purification system, suppliers could not confirm the availability of the partially refined product for the quantity of glycerol required for the process. Additionally, the partially refined glycerol is typically $0.15/lb more expensive than the crude glycerol (Gallagher et al.), which, given the sensitivity of the process to glycerol, would be prohibitively expensive. The choice was made to use the crude glycerol feedstock, although a purification unit operation is now required. The added benefit of the glycerol purification system from EET Corporation is its ability to process a feedstock with a variety of compositions. The plant flexibility is advantageous, because the least expensive glycerol can be purchased at a given time.

Clarifying/Settling Tank vs. Storage Tank with Agitator

The broth leaving the fermenters to be stored in T-107 must be continually agitated to prevent the settling of cells in the storage tank prior to transportation to the separation process. As an alternative to agitation, a settling clarifier tank similar to those used in waste water treatment was researched and priced. According to Perry's Chemical Engineering Handbook, clarifiers with dilute concentrations of solids typically have underflow solids weight percents of 8-15%. At this percentage, two streams with low solids mass percentages would need to be sterilized and filtered rather than one (the overflow and the underflow from the clarifier). The clarifier does not work in this case to separate any solids, so it has no benefit, and essentially functions as an agitator.

Other Considerations

Section X

Other Considerations

Plant Layout

The few interconnected steps in the process should be placed near each other. The molecular sieve regeneration stream recirculates into the distillation column, and therefore these units should be placed near one another. The electro-dialysis feeds water into HX-3 and therefore, these units should be placed together. The furnace should be placed far away from the succinic acid separation section as well as the pure ethanol and gasoline streams due to flammability.

Storage tanks (T-101, T-103, T-109, T-110, T-111) should be placed outside the plant for easy loading and unloading, preferably next to railroad tracks for easy transport.

Health and Safety Considerations

The presence of hydrogen in this process posses the largest safety concern. The process has been designed with this in mind, so 304 stainless steel has been used for all components coming into contact with hydrogen to protect against hydrogen embrittlement (Gallagher et al.). Positive pressure is used to decrease the likelihood of oxygen seeping into the system. Special care will be taken with regard to sealing the system in the presence of hydrogen. Special fittings will be designed for this purpose.

Several of the process components are flammable. The explosion limits on hydrogen, ethanol, and gasoline are 4-75%, 3.3-19% and 1.4-7.6% respectively. Oxygen sensors will be necessary within hydrogen containing vessels and piping, and sensors will be necessary to ensure that no buildup of hydrogen, ethanol, or gasoline occurs.

The fermentation is exothermic, but reactor runaway is not a large concern. Due to the high volume of the reactors, even under adiabatic conditions, there is only a small 5.8°C temperature increase over the course of the fermentation cycle. Automatic shut down will be necessary within the furnace. Should there be a breakdown of blower B-102, the combustion temperature could skyrocket to higher than 2000°F, which would damage the furnace and possibly lead to explosion.

There will also be large quantities of succinic acid in some areas of the plant. Succinic acid is a hazardous chemical which can cause skin and eye irritation, as well as breathing difficulties in the case of ingestion. Showers and eyewash stations will be placed frequently around the plant in case of human contact with succinic acid.

Basic safety equipment such as eye protection and hard hats will be worn at all times around the plant. The MSDS sheets for all of the components in our process have been included in the appendix of the report.

The *E. coli* to be used in this process is not a genetically modified organism, and poses no health threats to humans as per the design problem statement. As such, it does not fall under governmental regulation. Nonetheless, it is prudent to deactivate the organisms before disposal, and this is completed in HX-3 for the broth stream and in the furnace FN-1 for the vapor stream. Any small spills can be sent to an empty (off-line) seed fermentation train unit for sterilization with caustic solution.

Plant Start-Up Considerations

The main start-up considerations are heat related, as the heat exchangers HX-1 (in the feed preparation section) and HX-3 (in the separation section) require streams that have already been heated in the process. Steam can be used in both heat exchangers for the start-up period. By the time the separation processing section is reached, after ~100 hours, enough hydrogen will have been generated to fuel the reboiler, which has the largest heat requirement.

Process Control

The major section of the plant that must be monitored and controlled is the main large-scale fermentation section. The 14.8 psia positive pressure must be maintained in the fermenters at all times. This can be accomplished with a pressure-monitoring system and a valve controlling the release of fermentation gases to the piping connected to the blower system. Additionally, the temperature of the fermentation units must be controlled. The temperature must be monitored, and a valve is installed to control the amount of the cooling water/chilled water mixture that is sent to the twelve HX-FERM units to control the amount of heat transferred from the fermentation broth to the cooling water during fermentation.

Additionally, level controllers should be installed in the tanks T-106 and T-107, which are the intermediate sterilized feed and fermentation broth holding tanks, functioning as the transition point from continuous to batch processing and vice versa. These tanks have been designed with a working volume of 80%, and the levels should be monitored to prevent any overflows or empty tanks. With the current schedule, these problems should be avoided, but these tanks need to be monitored for the duration of the process to ensure safety and steady-state processing in the continuous sections of the plant.

Environmental Considerations

Section XI

Environmental Considerations

The main impact on the environment is from the waste carbon dioxide that is released from the fermentation process. The chemical reaction produces approximately 150,000 tons/year of carbon dioxide waste. The disposal of carbon dioxide has become a controversial topic in recent years as the exact environmental impact of a certain amount of carbon dioxide is still unknown. There are three options for dealing with this waste in accordance with the main systems in place and with pending legislation in the different government systems around the world.

One option that is popular within industry is carbon offsetting. A carbon offset program attempts to make up for carbon dioxide waste produced, by taking a secondary action that consumes carbon dioxide. In that case, this plant would have to invest in a reforestation plan that would consume, once fully mature, the same amount of CO_2 per year that is produced by the plant. The plant will produce 150,000 tons of Carbon Dioxide per year. Approximately 120 fully-mature trees can sequester 5 tons of CO_2 per year (Botanical Society of America). The average cost to plant an acre of trees is $500, and in the current climate conditions the one can expect 35% of the planted trees to survive to maturity. Therefore for the reforestation plan, if 200 pine trees are planted per acre, 70 will survive, so to be safe, for every 5 tons of CO_2, two acres of trees need to be planted. Therefore, to offset all of the carbon output from the plant, it will take 60,000 acres of pine trees, costing $30 million (SRP.net).

Recent research has looked into carbon capture and sequestration technologies as a means of lowering carbon dioxide emissions. Carbon sequestering is an expensive option that can at best eliminate 80% of the carbon dioxide produced (National Mining Association). The best method seems to be with a solid absorbent-magnesium oxide absorber to capture the carbon dioxide and then using a 3 stage compressor to bring it to its supercritical phase so as to be transported (Czarniak et al). Besides the cost of bringing the carbon dioxide into a supercritical phase and pumping into storage, sequestering would also require the extra step of separating the gaseous carbon dioxide and hydrogen gas wastes.

However, while this process incurs large startup costs, the cost of capturing and sequestering the CO_2 is on the order of $31.80 per ton of CO_2 (Czarniak et al). Since in 2030, it is likely that some sort of CCS (carbon capture and storage) technology will be required of all industries that produce large amounts of CO2, it may be required that the plant add in this process when it is necessary (McKinsey). With 150,000 tons being produced per year, the annual cost of CO_2 capture and sequester is $4,741,300.

However, since the process of producing the ethanol uses a feed of glycerol which is produced from biodiesel production, this process can be considered to be carbon neutral. Biofuels are carbon neutral even though the production of them produces carbon dioxide. This is because the carbon in the biofuel comes from a plant source. As such, the carbon dioxide produced can be released to the atmosphere without any carbon offsetting or sequestration technologies.

This release may be legal for only a few years depending on United States governmental policy regarding CO_2 emissions. Many of the potential laws set the maximum allowable emissions levels at 250 tons per year (Efstathiou Jr.) (See Carbon Dioxide Legislation Appendix E on page 265). Whenever this happens, the CCS technology option will have to be reexamined and, at that point, the cost will be lower since a lot of research is currently focusing in that area.

Economic Analysis

Section XII

Economic Analysis

Equipment Cost Estimates

The equipment purchase costs were computed using the specifications and correlations outlined in Product and Process Design Prinicples by Seider, Seader, Lewin, and Widagdo. The base purchase costs included with the unit descriptions, C_{PB} for the Method of Guthrie equation for installation cost, are based on carbon steel construction. However, most of our plant equipment is made of 304 stainless steel . To account for the difference in material, the Guthrie correlation was used to determine the bare module cost of the equipment, where the Guthrie material factors F_M for 304 Stainless Steel were obtained from Perry's Chemical Engineering Handbook.

Guthrie correlation: $C_{BM=}C_{PB}(I/I_B)[F_{BM}+(F_dF_PF_M-1)]$,

Where: F_{BM}= bare module factor

F_d= equipment design factor

F_p= pressure factor

F_m= material factor

The material factors from Perry's Handbook for 304 stainless steel construction were 1.7 for pumps and 2.8 for other equipment. For heat exchangers, the factor was 1.67 if the tubes were 304 stainless and the shell was carbon steel, and 2.86 if both shell and tubes were 304 stainless steel.

The summary of the calculated equipment costs is shown below in Table E-1.

Process Equipment												
		Unit		No. Units		C_{PB} (one unit)		C_{PB} (all units)	F_M	F_{BM}		C_{BM}
	Pumps	Pump	P-101	2	$	3,700	$	7,400	1.70	3.30	$	29,600
		Pump	P-102	2	$	4,400	$	8,800	1.70	3.30	$	35,200
		Pump	P-103	2	$	4,900	$	9,800	1.70	3.30	$	39,200
		Pump	P-104	2	$	6,400	$	12,800	1.70	3.30	$	51,200
		Pump	P-105	2	$	3,600	$	7,200	1.70	3.30	$	28,800
		Pump	P-106	2	$	4,700	$	9,400	1.70	3.30	$	37,600
		Pump	P-107	2	$	5,300	$	10,600	1.70	3.30	$	42,400
		Pump	P-FA	2	$	19,400	$	38,800	1.70	3.30	$	155,200
		Pump	P-FB	2	$	3,600	$	7,200	1.70	3.30	$	28,800
		Pump	P-FC	2	$	15,700	$	31,400	1.70	3.30	$	125,600
		Pump	P-FD	1	$	9,000	$	9,000	1.70	3.30	$	36,000
		Pump	P-FE	12	$	6,600	$	79,200	1.70	3.30	$	316,800
		Pump	P-FP-01	1	$	4,500	$	4,500	1.70	3.30	$	18,000
		Pump	P-FP-02	1	$	8,400	$	8,400	1.70	3.30	$	33,600
		Pump	P-FP-03	1	$	4,100	$	4,100	1.70	3.30	$	16,400
		Pump	P-FP-04	1	$	3,900	$	3,900	1.70	3.30	$	15,600
		Pump	P-FP-05	1	$	3,500	$	3,500	1.70	3.30	$	14,000
		Pump	P-FP-06	1	$	10,100	$	10,100	1.70	3.30	$	40,400
		Pump	P-S-101	1	$	13,100	$	13,100	1.70	3.30	$	52,400
		Pump	P-S-102	1	$	9,600	$	9,600	1.70	3.30	$	38,400
		Pump	P-S-104	1	$	4,700	$	4,700	1.70	3.30	$	18,800
		Pump	P-S-105	1	$	5,200	$	5,200	1.70	3.30	$	20,800
		Pump	P-S-106	1	$	13,500	$	13,500	1.70	3.30	$	54,000
		Pump	P-S-107	1	$	15,700	$	15,700	1.70	3.30	$	62,800
		Pump	P-S-108	1	$	7,200	$	7,200	1.70	3.30	$	28,800
	Blowers	Blower	B-101	1	$	70,793	$	70,793	1.00	2.15	$	152,204
		Blower	B-102	1	$	264,200	$	264,200	1.00	2.15	$	568,030
						Total	$	670,093		Total	$	2,060,634

Table E-1 : Equipment Cost Sheet for the Process (1 of 2)

Fabricated Equipment												
		Unit		No. Units		Cpb (one unit)		Cpb (all units)	F_M	F_{BM}		C_{BM}
	Vessels	Fermenter	Ferm 1	12	$	341,500	$	4,098,000	2.80	4.16	$	24,424,080
		Fermenter	Seed Ferm 5A/B	2	$	30,700	$	61,400	2.80	4.16	$	365,944
		Fermenter	Seed Ferm 6A/B	2	$	100,900	$	201,800	2.80	4.16	$	1,202,728
		Fermenter	Seed Ferm 7A/B	2	$	150,400	$	300,800	2.80	4.16	$	1,792,768
		Distillation Column	D-1	1	$	798,000	$	798,000	2.80	4.16	$	4,756,080
		Absorber Column	AB-1	1	$	117,100	$	117,100	2.80	4.16	$	697,916
		Reflux Accumulator	RA-1	1	$	47,000	$	47,000	2.80	3.05	$	227,950
	Agitators	Agitator	for Ferm 1	12	$	44,200	$	530,400	2.80	3.21	$	2,657,304
		Agitator	for T-107	1	$	44,200	$	44,200	2.80	3.21	$	221,442
		Agitator	for Seed 6A/B	2	$	6,500	$	13,000	2.80	3.21	$	65,130
		Agitator	for Seed 7A/B	2	$	20,800	$	41,600	2.80	3.21	$	208,416
		Agitator	for T-105	1	$	29,900	$	29,900	2.80	3.21	$	149,799
		Agitator	for T-108	1	$	9,100	$	9,100	2.80	3.21	$	45,591
	Heat Exchangers	HX-FERM	for Ferm 1	12	$	4,200	$	50,400	1.67	1.80	$	124,488
		Heat Exchanger	HX-1	1	$	132,300	$	132,300	2.86	3.17	$	665,469
		Heat Exchanger	HX-2	1	$	22,049	$	22,049	1.67	1.80	$	54,461
		Heat Exchanger	HX-3	1	$	113,900	$	113,900	1.67	3.17	$	437,376
		Heat Exchanger	HX-4	1	$	65,900	$	65,900	1.67	3.17	$	253,056
		Heat Exchanger	HX-5	1	$	21,200	$	21,200	1.67	3.17	$	81,408
		Heat Exchanger	HX-6	1	$	60,237	$	60,237	1.67	3.17	$	231,310
	Furnace	Furnace	FN-1	1	$	1,717,600	$	1,717,600	2.80	1.86	$	6,286,416
						Total	$	8,475,886		Total	$	44,949,132
Storage												
		Unit		No. Units		Cpb (one unit)		Cpb (all units)	F_M	F_{BM}		C_{BM}
	Storage Tanks	Broth Storage Tank	T-107	1	$	582,900	$	582,900	2.80	3.05	$	2,827,065
		Glycerol Storage	T-101	1	$	564,600	$	564,600	2.80	3.05	$	2,738,310
		CSL Storage	T-103	1	$	49,600	$	49,600	2.80	3.05	$	240,560
		Brine Storage	T-104	1	$	65,700	$	65,700	2.80	3.05	$	318,645
		Feed Mixing Tank	T-105	1	$	42,500	$	42,500	2.80	3.05	$	206,125
		Sterilized Feed Tank	T-106	1	$	338,000	$	338,000	2.80	3.05	$	1,639,300
		Denatured Ethanol Ho	T-111	1	$	453,300	$	453,300	2.80	3.05	$	2,198,505
		Succinic Acid Storage	T-110	1	$	27,600	$	27,600	2.80	4.16	$	164,496
		Mixing Tank	T-108	1	$	26,800	$	26,800	2.80	3.05	$	129,980
		Gasoline Storage Tank	T-109	1	$	101,000	$	101,000	1.00	3.05	$	308,050
						Total	$	2,252,000.00		Total	$	10,771,036.00
Miscellaneous												
		Unit		No. Units		Cpb (one unit)		Cpb (all units)	F_M	F_{BM}		C_{BM}
	Spray Nozzles	Spray Nozzles	For FERM 1-12	48	$	10,000	$	480,000	1.00	1.00	$	480,000
		Spray Nozzles	for Seed 7A/B	6	$	10,000	$	60,000	1.00	1.00	$	60,000
	Reverse Osmosis	Glycerol Pur. Sys.	R-101	1	$	--	$	--			$	430,800
	Rotary Drum Filte	Rotary Drum Filter	RDF-1	1	$	184,400	$	184,400	1.00	2.32	$	427,808
	Electrodialysis	Electrodialysis	ED-1	1		--		--			$	2,700,000
	Crystallizer	Crystallizer	C-1	1	$	154,500	$	154,500	1.00	2.06	$	318,270
	Dryer	Dryer	DR-1	1	$	22,200	$	22,200	1.00	2.06	$	45,732
	Screw Conveyor	Screw Conveyor	CB-1	1	$	13,000	$	13,000	1.00	1.61	$	20,930
	Molecular Sieves	Molecular Sieves	MS-1	1	$	2,746,200	$	2,746,200	1.00	1.00	$	2,746,200
						Total	$	3,660,300.00		Total	$	7,229,740.00
											$	65,010,542

Table E-1 : Equipment Cost Sheet for the Process (2 of 2)

Utility Requirements

The utility cost for the entire plant includes costs for electricity, steam, water (cooling and process), waste water treatment, and landfill. These costs are summarized in Table E-2. Prices for utilites were obtained using the 3rd Edition of Product and Process Design Principles by Seider, Seader, Lewin, and Widagdo.

Utility						
Process Water	Stream	L/hr	m^3/ hr	cost ($/ m^3)	cost/hr	cost/yr
	S-FP-102	4832.30	4.83	$0.20	$0.97	$7,654.36
	S-FP-105	151105.00	151.11	$0.20	$30.22	$239,350.32
	S-S-127	4514	4.51	$0.20	$0.90	$7,150.18
	S-S-101	27022.50	27.02	$0.20	$5.40	$42,803.64
						$296,958.50
Waste Water	Stream	kg/hr		cost ($/kg)		cost/yr
	S-S-134	13.40		$0.33	$4.42	$35,022.24
						$35,022.24
Steam - 150 psig	Equipment	kg/hr		cost($/1000 kg)		cost/yr
	HX-2	4044.94		$10.50	$42.47	$336,377.21
						$336,377.21
Steam - 50 psig	Equipment	kg/hr		cost($/1000 kg)	cost/hr	cost/yr
	HX-6	16775		$6.60	$110.72	$876,862.80
	MS-1				$4.77	$37,789.41
						$914,652.21
cooling water	Stream	l/hr	m^3/hr	$/m^3	cost/hr	cost/yr
	HX-4	1087870.00	1087.87	$0.02	$21.76	$172,318.61
	HX-5	23766.11	23.77	$0.02	$0.48	$3,764.55
	MS-1				$8.95	$70,855.17
	HX-FERM	21003.00	21.00	$0.02	$0.42	$2,015.78
						$248,954.11
chilled water	Stream	BTU/HR	BTU/day	$/btu	$/day	$/yr
	HX-FERM	298539.57	7164949.62	$0.00	$29.85	$9,851.81
						$9,851.81
Landfill	Stream	kg/hr		cost ($/kg)		
	Biomass cake	505.47		$0.17	$85.93	$680,564.81
						$680,564.81
Electricity	Stream	HP	Kw	cost($ / kW-hr)	cost/hr	cost/yr
	P-S-101	67.95	50.67	$0.06	$3.04	$24,078.53
	P-S-102	37.31	27.82	$0.06	$1.67	$13,221.04
	P-S-104	10.47	7.81	$0.06	$0.47	$3,710.11
	P-S-105	14.91	11.12	$0.06	$0.67	$5,283.46
	P-S-106	68.28	50.92	$0.06	$3.05	$24,195.47
	P-S-107	46.81	34.91	$0.06	$2.09	$16,587.43
	P-S-108	7.10	5.30	$0.06	$0.32	$2,516.47
	CB-1	1.00	0.75	$0.06	$0.04	$354.36
	RDF-1	11.78	8.78	$0.06	$0.53	$4,173.26
	Agitator for T-10	4.00	2.98	$0.06	$0.18	$1,417.43
	ED-1					$190,200.00
	B-102	1602.65	1195.09	$0.06	$71.71	$567,908.07
	MS-1				$4.77	$37,789.41
	P-FA A	67.22	50.13	$0.06	$3.01	$1,202.75
	P-FA B	67.22	50.13	$0.06	$3.01	$1,202.75

	P-FB A	2.31	1.72	$0.06	$0.10	$445.47
	P-FB B	2.31	1.72	$0.06	$0.10	$445.47
	P-FC A	42.77	31.89	$0.06	$1.91	$4,591.53
	P-FC B	42.77	31.89	$0.06	$1.91	$4,591.53
	P-FD	36.94	27.55	$0.06	$1.65	$13,089.93
	B-101	300.00	223.71	$0.06	$13.42	$64,412.36
	Agitators Ferm 1-	240.00	178.97	$0.06	$10.74	$51,529.89
	Agitator for T-107	20.00	14.91	$0.06	$0.89	$7,087.13
	P-FE(1-12)	43.80	32.66	$0.06	$1.96	$9,404.20
	P-101A	1.12	0.83	$0.06	$0.05	$0.13
	P-101B	1.12	0.83	$0.06	$0.05	$0.13
	P-102A	7.49	5.59	$0.06	$0.34	$8.93
	P-102B	7.49	5.59	$0.06	$0.34	$8.93
	P-103A	10.76	8.03	$0.06	$0.48	$12.84
	P-103B	10.76	8.03	$0.06	$0.48	$12.84
	P-104A	20.25	15.10	$0.06	$0.91	$96.62
	P-104B	20.25	15.10	$0.06	$0.91	$96.62
	P-105A	1.22	0.91	$0.06	$0.05	$0.15
	P-105B	1.22	0.91	$0.06	$0.05	$0.15
	P-106A	9.26	6.91	$0.06	$0.41	$1.10
	P-106B	9.26	6.91	$0.06	$0.41	$1.10
	P-107A	13.68	10.20	$0.06	$0.61	$16.32
	P-107B	13.68	10.20	$0.06	$0.61	$16.32
	Agitator for Ferm	2.25	1.67	$0.06	$0.10	$482.12
	Agitator for Ferm	2.25	1.67	$0.06	$0.10	$482.12
	Agitator for Ferm	17.17	12.80	$0.06	$0.77	$3,686.79
	Agitator for Ferm	17.17	12.80	$0.06	$0.77	$3,686.79
	P-FP-01	9.34	6.96	$0.06	$0.42	$3,308.48
	P-FP-02	33.68	25.11	$0.06	$1.51	$11,934.38
	P-FP-03	0.15	0.11	$0.06	$0.01	$51.66
	P-FP-04	5.02	3.75	$0.06	$0.22	$1,780.29
	P-FP-05	1.53	1.14	$0.06	$0.07	$542.02
	P-FP-06	45.43	33.88	$0.06	$2.03	$16,099.56
	Agitator for T-105	32.60	24.31	$0.06	$1.46	$11,552.02
						$1,103,316.45
					Total	$3,625,697.34

Table E-2: Utility cost Per Year

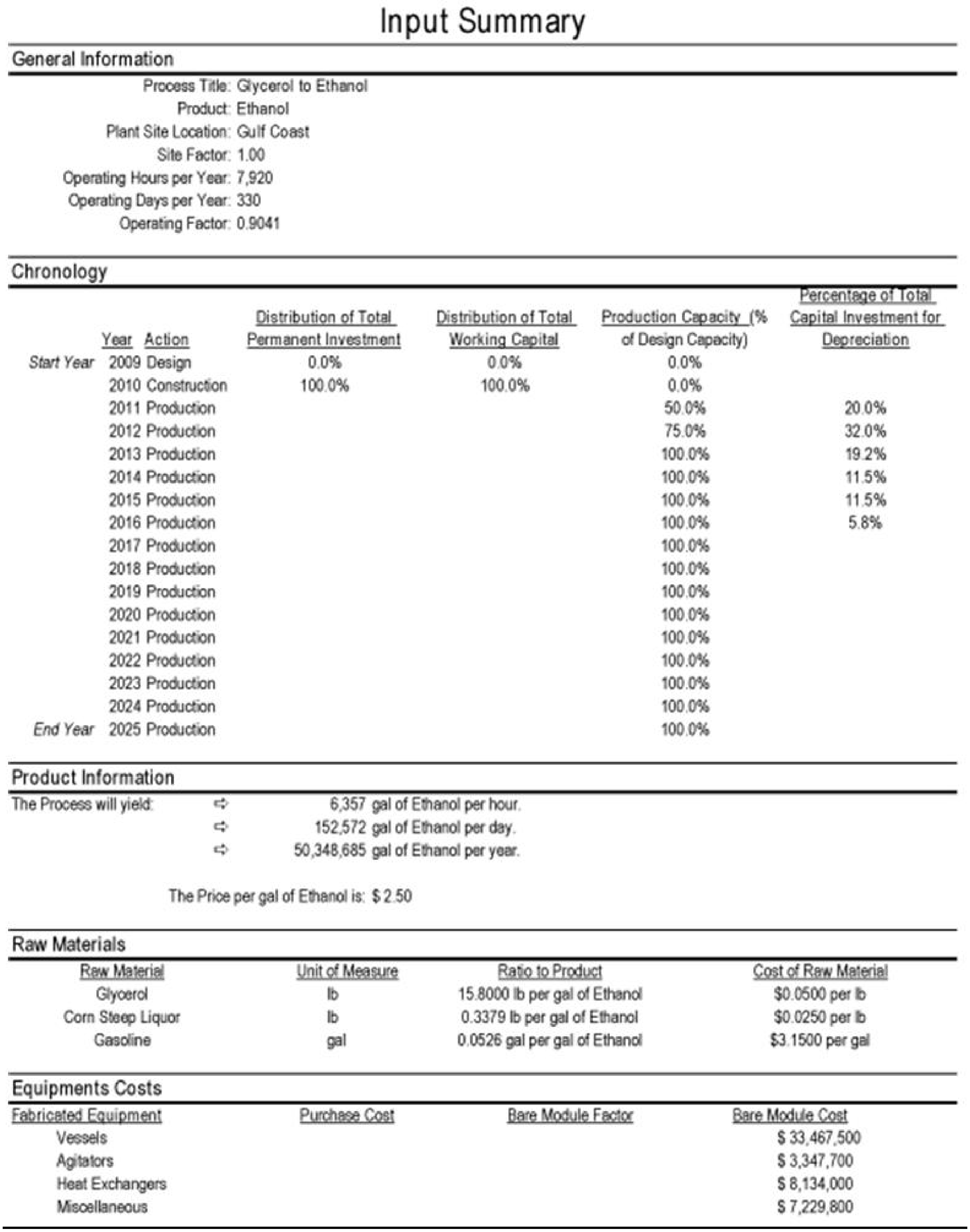
	$/year	$/units	units/year	units	units/gallon ethanol
Process Water	$296,958	$0.20	1,484,792	m^3	0.02949
Waste Water	$35,022	$0.33	106,128	kg	0.00211
150 psig Steam	$336,377	$0.01	32,035,925	kg	0.63628
50 psig Steam	$914,652	$0.01	138,583,668	kg	2.75248
Cooling Water	$248,954	$0.02	12,447,706	m^3	0.24723
Chilled Water	$9,852	$0.0000041667	2,364,414,458	BTU	46.96080
Landfill	$680,565	$0.17	4,003,322	kg	0.07951
Electricity	$1,103,316	$0.06	18,388,608	kW-hr	0.36523

Table E-3 : Utility cost per unit product

Operating Costs

The process has three main sections, glycerol purification, fermentation, and separation. For continuous processes with solids, it is advised to have 2 operators on hand (Seider) while 3 are recommended for batch systems with solids. Therefore, we have assumed 7 operators at all times, paid $35/hour.

It is assumed that the plant will be in operation for 15 years after construction, and that design and construction take one year each. The plant will be located on the Gulf Coast and will operate 330 days per year as recommended in Product and Process Design Prinicples by Seider, Seader and Lewin. The working capital assumes 3 days of inventory and 30 days of receivables.



Input Summary

General Information

Process Title: Glycerol to Ethanol
Product: Ethanol
Plant Site Location: Gulf Coast
Site Factor: 1.00
Operating Hours per Year: 7,920
Operating Days per Year: 330
Operating Factor: 0.9041

Chronology

	Year	Action	Distribution of Total Permanent Investment	Distribution of Total Working Capital	Production Capacity (% of Design Capacity)	Percentage of Total Capital Investment for Depreciation
Start Year	2009	Design	0.0%	0.0%	0.0%	
	2010	Construction	100.0%	100.0%	0.0%	
	2011	Production			50.0%	20.0%
	2012	Production			75.0%	32.0%
	2013	Production			100.0%	19.2%
	2014	Production			100.0%	11.5%
	2015	Production			100.0%	11.5%
	2016	Production			100.0%	5.8%
	2017	Production			100.0%	
	2018	Production			100.0%	
	2019	Production			100.0%	
	2020	Production			100.0%	
	2021	Production			100.0%	
	2022	Production			100.0%	
	2023	Production			100.0%	
	2024	Production			100.0%	
End Year	2025	Production			100.0%	

Product Information

The Process will yield: ➪ 6,357 gal of Ethanol per hour.
➪ 152,572 gal of Ethanol per day.
➪ 50,348,685 gal of Ethanol per year.

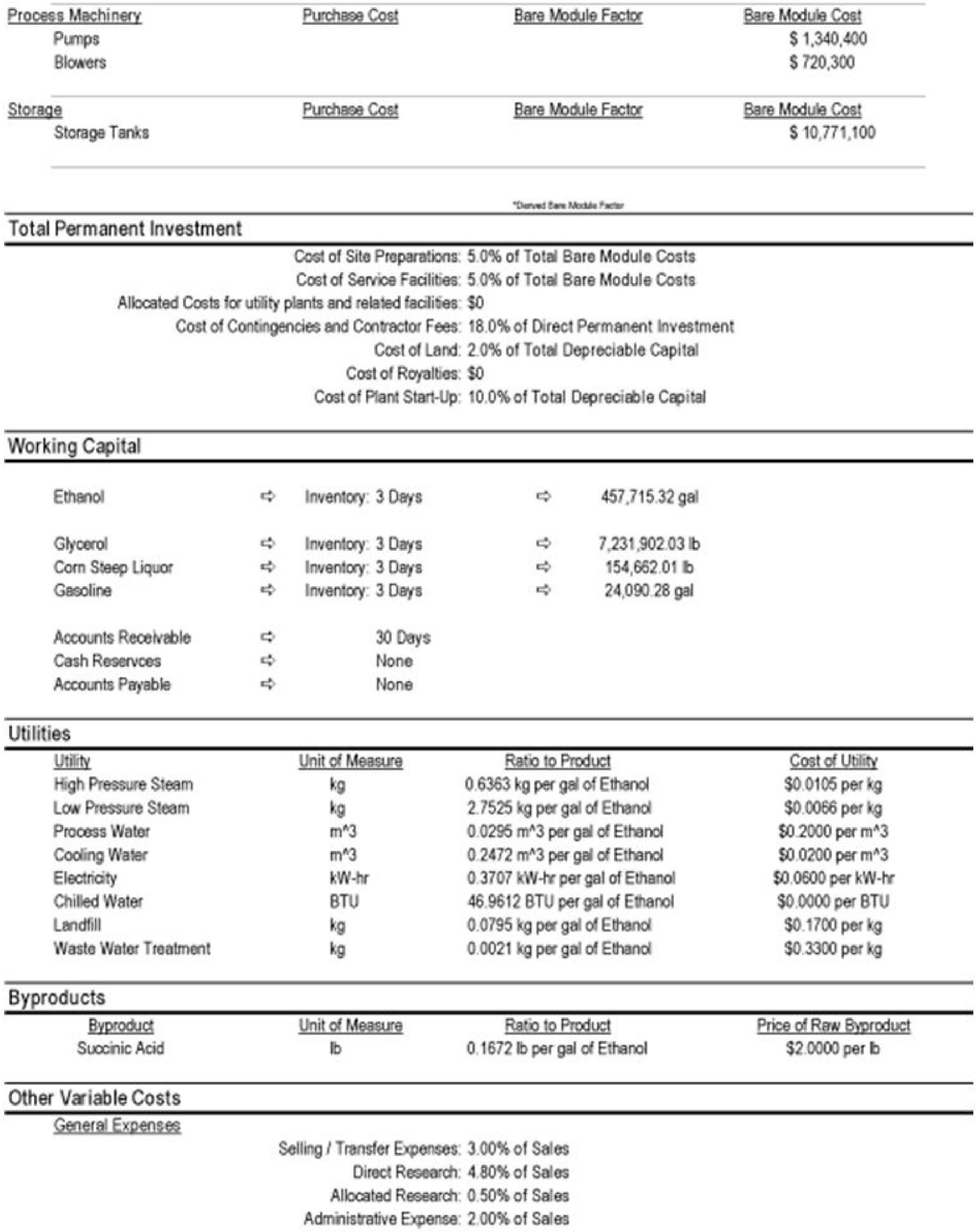
The Price per gal of Ethanol is: $ 2.50

Raw Materials

Raw Material	Unit of Measure	Ratio to Product	Cost of Raw Material
Glycerol	lb	15.8000 lb per gal of Ethanol	$0.0500 per lb
Corn Steep Liquor	lb	0.3379 lb per gal of Ethanol	$0.0250 per lb
Gasoline	gal	0.0526 gal per gal of Ethanol	$3.1500 per gal

Equipments Costs

Fabricated Equipment	Purchase Cost	Bare Module Factor	Bare Module Cost
Vessels			$ 33,467,500
Agitators			$ 3,347,700
Heat Exchangers			$ 8,134,000
Miscellaneous			$ 7,229,800



Process Machinery	Purchase Cost	Bare Module Factor	Bare Module Cost
Pumps			$ 1,340,400
Blowers			$ 720,300

Storage	Purchase Cost	Bare Module Factor	Bare Module Cost
Storage Tanks			$ 10,771,100

*Derived Bare Module Factor

Total Permanent Investment

Cost of Site Preparations: 5.0% of Total Bare Module Costs
Cost of Service Facilities: 5.0% of Total Bare Module Costs
Allocated Costs for utility plants and related facilities: $0
Cost of Contingencies and Contractor Fees: 18.0% of Direct Permanent Investment
Cost of Land: 2.0% of Total Depreciable Capital
Cost of Royalties: $0
Cost of Plant Start-Up: 10.0% of Total Depreciable Capital

Working Capital

Ethanol	⇨	Inventory: 3 Days	⇨	457,715.32 gal
Glycerol	⇨	Inventory: 3 Days	⇨	7,231,902.03 lb
Corn Steep Liquor	⇨	Inventory: 3 Days	⇨	154,662.01 lb
Gasoline	⇨	Inventory: 3 Days	⇨	24,090.28 gal
Accounts Receivable	⇨	30 Days		
Cash Reservces	⇨	None		
Accounts Payable	⇨	None		

Utilities

Utility	Unit of Measure	Ratio to Product	Cost of Utility
High Pressure Steam	kg	0.6363 kg per gal of Ethanol	$0.0105 per kg
Low Pressure Steam	kg	2.7525 kg per gal of Ethanol	$0.0066 per kg
Process Water	m^3	0.0295 m^3 per gal of Ethanol	$0.2000 per m^3
Cooling Water	m^3	0.2472 m^3 per gal of Ethanol	$0.0200 per m^3
Electricity	kW-hr	0.3707 kW-hr per gal of Ethanol	$0.0600 per kW-hr
Chilled Water	BTU	46.9612 BTU per gal of Ethanol	$0.0000 per BTU
Landfill	kg	0.0795 kg per gal of Ethanol	$0.1700 per kg
Waste Water Treatment	kg	0.0021 kg per gal of Ethanol	$0.3300 per kg

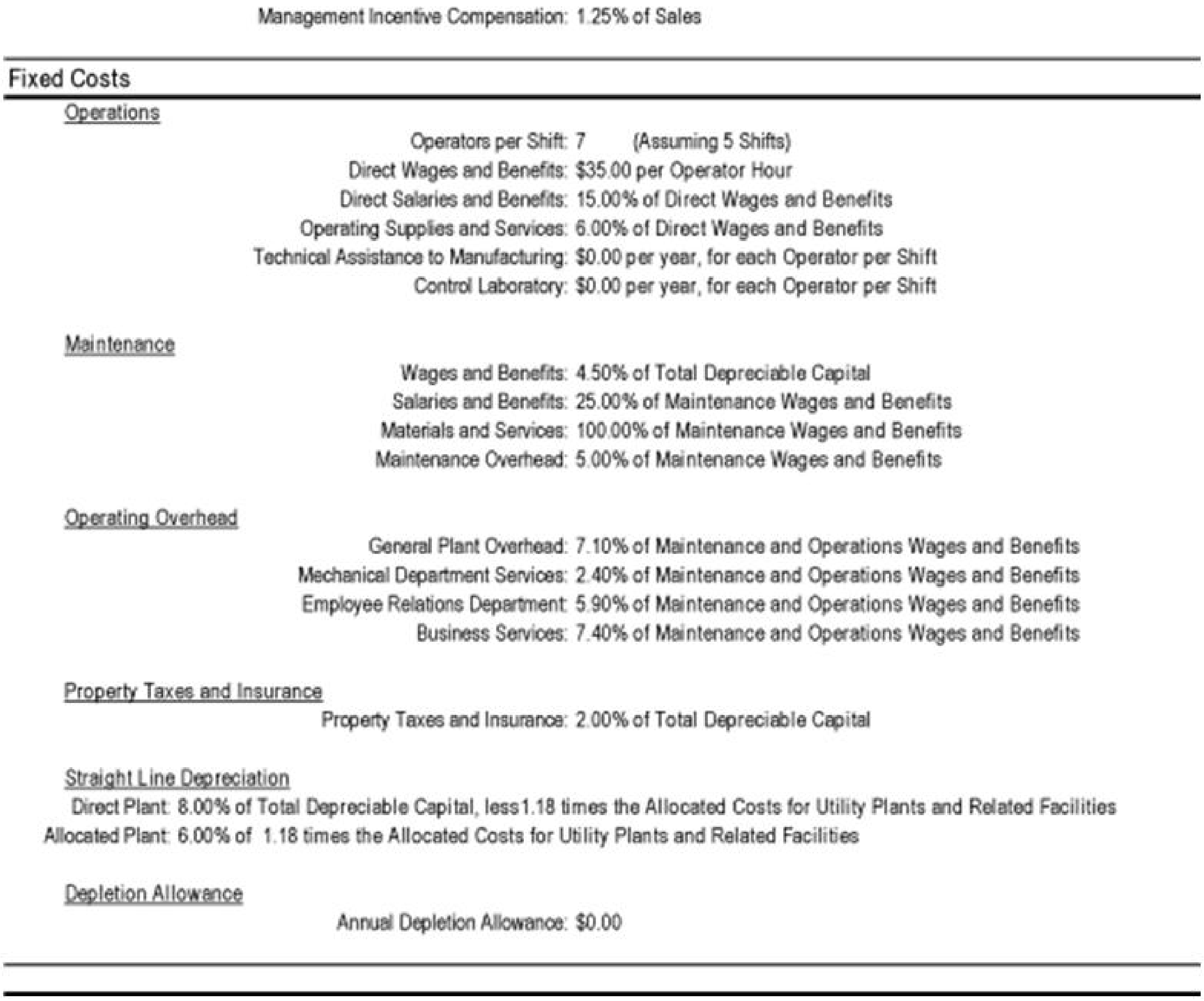
Byproducts

Byproduct	Unit of Measure	Ratio to Product	Price of Raw Byproduct
Succinic Acid	lb	0.1672 lb per gal of Ethanol	$2.0000 per lb

Other Variable Costs

General Expenses

Selling / Transfer Expenses: 3.00% of Sales
Direct Research: 4.80% of Sales
Allocated Research: 0.50% of Sales
Administrative Expense: 2.00% of Sales



Management Incentive Compensation: 1.25% of Sales

Fixed Costs

Operations

Operators per Shift: 7 (Assuming 5 Shifts)
Direct Wages and Benefits: $35.00 per Operator Hour
Direct Salaries and Benefits: 15.00% of Direct Wages and Benefits
Operating Supplies and Services: 6.00% of Direct Wages and Benefits
Technical Assistance to Manufacturing: $0.00 per year, for each Operator per Shift
Control Laboratory: $0.00 per year, for each Operator per Shift

Maintenance

Wages and Benefits: 4.50% of Total Depreciable Capital
Salaries and Benefits: 25.00% of Maintenance Wages and Benefits
Materials and Services: 100.00% of Maintenance Wages and Benefits
Maintenance Overhead: 5.00% of Maintenance Wages and Benefits

Operating Overhead

General Plant Overhead: 7.10% of Maintenance and Operations Wages and Benefits
Mechanical Department Services: 2.40% of Maintenance and Operations Wages and Benefits
Employee Relations Department: 5.90% of Maintenance and Operations Wages and Benefits
Business Services: 7.40% of Maintenance and Operations Wages and Benefits

Property Taxes and Insurance

Property Taxes and Insurance: 2.00% of Total Depreciable Capital

Straight Line Depreciation

Direct Plant: 8.00% of Total Depreciable Capital, less 1.18 times the Allocated Costs for Utility Plants and Related Facilities
Allocated Plant: 6.00% of 1.18 times the Allocated Costs for Utility Plants and Related Facilities

Depletion Allowance

Annual Depletion Allowance: $0.00

As the investment summary shows below, an investment of $107.6MM will be required to begin this process. With the initial process equipment priced at $65MM, the standard cost of land, contractors and services for construction workers, site preparation, et cetera, account for nearly half the total investment.

Investment Summary

April, 2009

Glycerol to Ethanol

				TOTAL
Bare Module Costs				
Fabricated Equipment				
Vessels		$33,467,500		
Agitators		$3,347,700		
Heat Exchangers		$8,134,000		
Miscellaneous		$7,229,800		
Total Fabricated Equipment:		$52,179,000		
Process Machinery				
Pumps		$1,340,400		
Blowers		$720,300		
Total Process Machinery:		$2,060,700		
Storage				
Storage Tanks		$10,771,100		
Total Storage:		$10,771,100		
Total Bare Module Costs:				$65,011,000
Direct Permanent Investment				
Cost of Site Preparation:		$3,250,600		
Cost of Service Facilities:		$3,250,600		
Allocated Costs for utility plants and related facilities:		$0		
Direct Permanent Investment:				$71,512,000
Total Depreciable Capital				
Cost of Contigencies and Contractor Fees:		$12,872,200		
Total Depreciable Capital:				$84,384,000
Total Permanent Investment				
Cost of Land:		$1,687,700		
Cost of Royalties:		$0		
Cost of Plant Start-Up:		$8,438,400		
Total Permanent Investment:				$94,510,000
Working Capital				
Inventory				
Ethanol	a 458,000 gal		$1,144,300	
Glycerol	a 7,232,000 lb		$361,600	
Corn Steep Liqu	a 155,000 lb		$3,900	
Gasoline	a 24,000 gal		$75,900	
Total Inventory:			$1,585,600	
Accounts Receivable:			$11,442,900	
Cash Reservces:			$0	
Accounts Payable:			$0	
Total Working Capital:			$13,028,500	
TOTAL CAPITAL INVESTMENT				$107,538,500

Variable Cost Summary

April, 2009

Glycerol to Ethanol

		Per gal Ethanol		TOTAL
Raw Materials				
	Glycerol	$0.79 per gal of Ethanol	$39,775,500	
	Corn Steep Liquor	$0.01 per gal of Ethanol	$425,300	
	Gasoline	$0.17 per gal of Ethanol	$8,347,300	
	Total Raw Materials:	$0.96 per gal of Ethanol	$48,548,100	$48,548,100
Utilties				
	High Pressure Steam	$0.01 per gal of Ethanol	$336,400	
	Low Pressure Steam	$0.02 per gal of Ethanol	$914,700	
	Process Water	$0.01 per gal of Ethanol	$297,000	
	Cooling Water	$0.00 per gal of Ethanol	$249,000	
	Electricity	$0.02 per gal of Ethanol	$1,119,900	
	Chilled Water	$0.00 per gal of Ethanol	$9,900	
	Landfill	$0.01 per gal of Ethanol	$680,600	
	Waste Water Treatment	$0.00 per gal of Ethanol	$35,000	
	Total Raw Materials:	$0.07 per gal of Ethanol	$3,642,300	$52,190,400
Byproducts				
	Succinic Acid	-$0.33 per gal of Ethanol	-$16,835,400	
	Total Byproducts:	-$0.33 per gal of Ethanol	-$16,835,400	$35,355,000
General Expenses				
	Selling / Transfer:	$0.08 per gal of Ethanol	$3,776,200	
	Direct Research:	$0.12 per gal of Ethanol	$6,041,800	
	Allocated Research:	$0.01 per gal of Ethanol	$629,400	
	Administrative Expense:	$0.05 per gal of Ethanol	$2,517,400	
	Management Incentives:	$0.03 per gal of Ethanol	$1,573,400	
	Total Byproducts:	$0.29 per gal of Ethanol	$14,538,200	$49,893,200
TOTAL		$0.99 per gal of Ethanol	$49,893,200	$49,893,200

From the Variable Cost Summary, we can see that this process has a low utility cost and suggests that we have optimized the utility usage. Glycerol makes up 60% of the variable costs when counting succinic acid as revenue. (On the above spreadsheet, succinic acid revenue is shown as negative cost rather than as revenue, so glycerol appears to make up 80% of the variable cost.) Succinic acid produces revenues of $16.8MM per year, composing 12% of total revenue. Total variable costs per gallon of ethanol are $1.32, and total revenues are $2.83 at the base case.

Fixed Cost Summary

April, 2009

Glycerol to Ethanol

			TOTAL
Operations			
	Direct Wages and Benefits:	$2,548,000	
	Direct Salaries and Benefits:	$382,200	
	Operating Supplies and Services:	$152,880	
	Technical Assistance to Manufacturing:	$0	
	Control Laboratory:	$0	
	Total Operations:	$3,083,080	$3,083,080
Maintenance			
	Wages and Benefits:	$3,797,280	
	Salaries and Benefits:	$949,320	
	Materials and Services:	$3,797,280	
	Maintenance Overhead:	$189,864	
	Total Maintenance:	$8,733,744	$11,816,824
Operating Overhead			
	General Plant Overhead:	$545,053	
	Mechanical Department Services:	$184,243	
	Employee Relations Department:	$452,931	
	Business Services:	$568,083	
	Total Operating Overhead:	$1,750,310	$13,567,134
Property Insurance and Taxes			
	Total Property Insurance and Taxes:	$1,687,680	$15,254,814
TOTAL			$15,254,814

The largest fixed cost the plant will have is maintenance. Maintenance is calculated as a percentage of installed costs, and therefore, changes in installed costs will affect profitability two fold in the investment, and in increased fixed costs. Seven operators cost $2.5MM and require $400K in management.

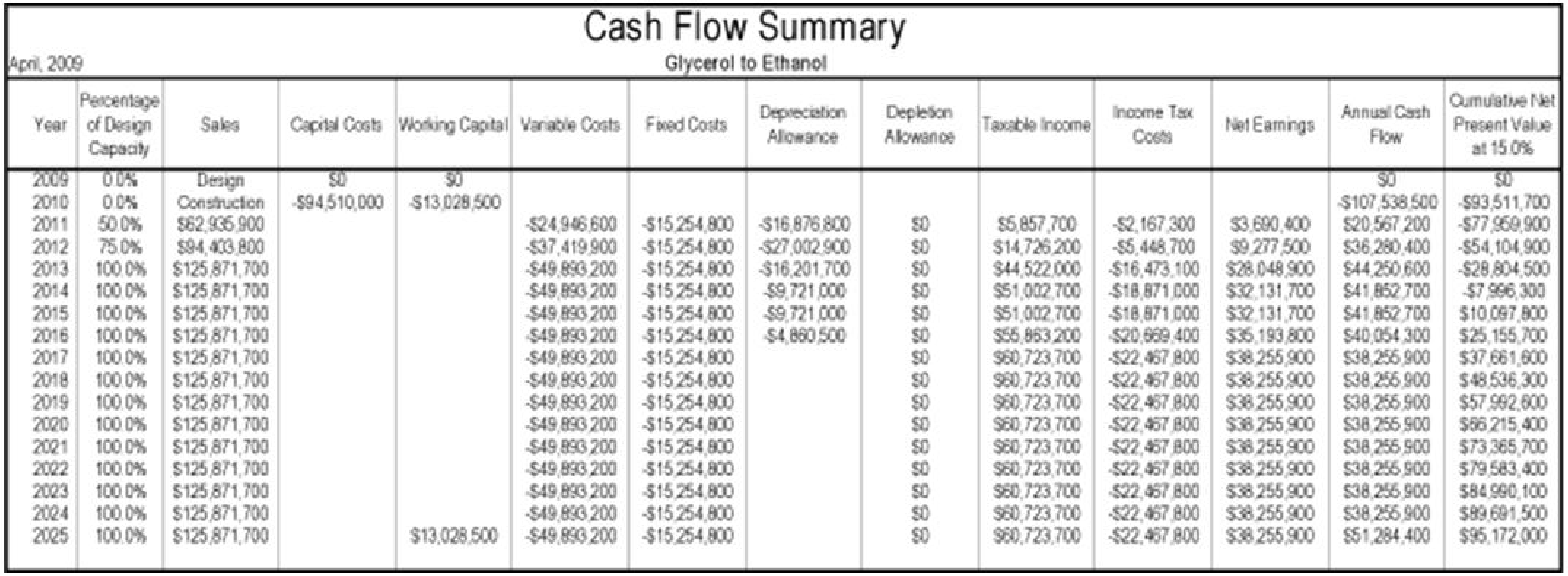
Profitability Measures

April, 2009

Glycerol to Ethanol

The Investor's Rate of Return (IRR) for this Project is: **32.24%**

The Net Present Value (NPV) at 15% for this Project is: **$95,172,000**



Cash Flow Summary

Glycerol to Ethanol

April, 2009

Year	Percentage of Design Capacity	Sales	Capital Costs	Working Capital	Variable Costs	Fixed Costs	Depreciation Allowance	Depletion Allowance	Taxable Income	Income Tax Costs	Net Earnings	Annual Cash Flow	Cumulative Net Present Value at 15.0%
2009	0.0%	Design	$0	$0								$0	$0
2010	0.0%	Construction	-$94,510,000	-$13,028,500								-$107,538,500	-$93,511,700
2011	50.0%	$62,935,900			-$24,946,600	-$15,254,800	-$16,876,800	$0	$5,857,700	-$2,167,300	$3,690,400	$20,567,200	-$77,959,900
2012	75.0%	$94,403,800			-$37,419,900	-$15,254,800	-$27,002,900	$0	$14,726,200	-$5,448,700	$9,277,500	$36,280,400	-$54,104,900
2013	100.0%	$125,871,700			-$49,893,200	-$15,254,800	-$16,201,700	$0	$44,522,000	-$16,473,100	$28,048,900	$44,250,600	-$28,804,500
2014	100.0%	$125,871,700			-$49,893,200	-$15,254,800	-$9,721,000	$0	$51,002,700	-$18,871,000	$32,131,700	$41,852,700	-$7,996,300
2015	100.0%	$125,871,700			-$49,893,200	-$15,254,800	-$9,721,000	$0	$51,002,700	-$18,871,000	$32,131,700	$41,852,700	$10,097,800
2016	100.0%	$125,871,700			-$49,893,200	-$15,254,800	-$4,860,500	$0	$55,863,200	-$20,669,400	$35,193,800	$40,054,300	$25,155,700
2017	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$37,661,600
2018	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$48,536,300
2019	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$57,992,600
2020	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$66,215,400
2021	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$73,365,700
2022	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$79,583,400
2023	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$84,990,100
2024	100.0%	$125,871,700			-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$38,256,900	$89,691,500
2025	100.0%	$125,871,700		$13,028,500	-$49,893,200	-$15,254,800		$0	$60,723,700	-$22,467,800	$38,255,900	$51,284,400	$95,172,000

At a glycerol price of $0.05 /lb, an ethanol price of $2.50/gallon, a gasoline price of $2.00/ gallon and a succinic acid price of $2.00/ lb, our process has a very high IRR of 32.24%. This makes the investment opportunity outlined in this report highly favorable. Taking into account fluctuations in the prices of these commodities as shown in the sensitivity analysis, given current global and national trends, this process seems to only get more profitable over time. As can be seen in the cash flow summary, a shortened depreciation schedule of 5 years increases the profitability of the plant in the first few years of operation. This results in a higher IRR because the time value of money severely reduces present value of profits later on. The plant reaches positive cash flow in its first year of operation, and reaches an annual profit , after taxes, of $38MM. The economic analysis of this process is highly favorable, and suggests that further research be performed.

Sensitivity Analysis

Section XIII

Sensitivity Analysis

Because the process is connected with the price of oil, both by the price of the feedstock gasoline (for denaturing) and through the prices of ethanol and glycerol (the connections of which will be covered shortly), the economics of the plant will likely vary significantly over the projected 15 years of operation. This likelihood necessitates analyzing the effect of projected trends on the profitability of the plant. Furthermore, it is important to know what costs and prices significantly affect profitability, and which affect it less.

The process's main factors for determining profitability are the price of glycerol, the price of succinic acid, the price of ethanol, and the price of gasoline. In the base case of $0.05/lb for glycerol, $2.00/lb for succinic acid, $2.50/gallon ethanol, and $3.15/gallon gasoline, glycerol comprises 60% of the variable costs of the process while gasoline comprises another 12%. 88% of revenues are provided by ethanol while the remaining 12% are from succinic acid. Interestingly, there is a significant correlation between ethanol prices and crude oil prices, along with the more obvious correlation between gasoline prices and crude oil prices. For this reason a sensitivity analysis was performed on crude oil instead of both gasoline and ethanol to reduce the number of independent variables. Glycerol prices are indirectly dependent on crude oil prices because higher crude oil prices drive up biodiesel production, which increases the glycerol supply, reducing glycerol prices. Quantitative analysis of this relationship however is not reliable so this correlation is not taken into account in this analysis.

Crude Oil

At the base case, ethanol sales amount to $125MM per year, which is 88% of the annual revenue. Naturally, profitability is closely related to the price of ethanol. Today wholesale ethanol is priced at $1.59/gallon. Oil shortages similar to those in the summer of 2008 are predicted by the United States Department of Energy to drive the price of oil up to close to $125/barrel by 2025. At this price of oil, correlations predict ethanol prices to be near $2.60/gallon. Further details of this prediction are available in the competitive and market analysis section.

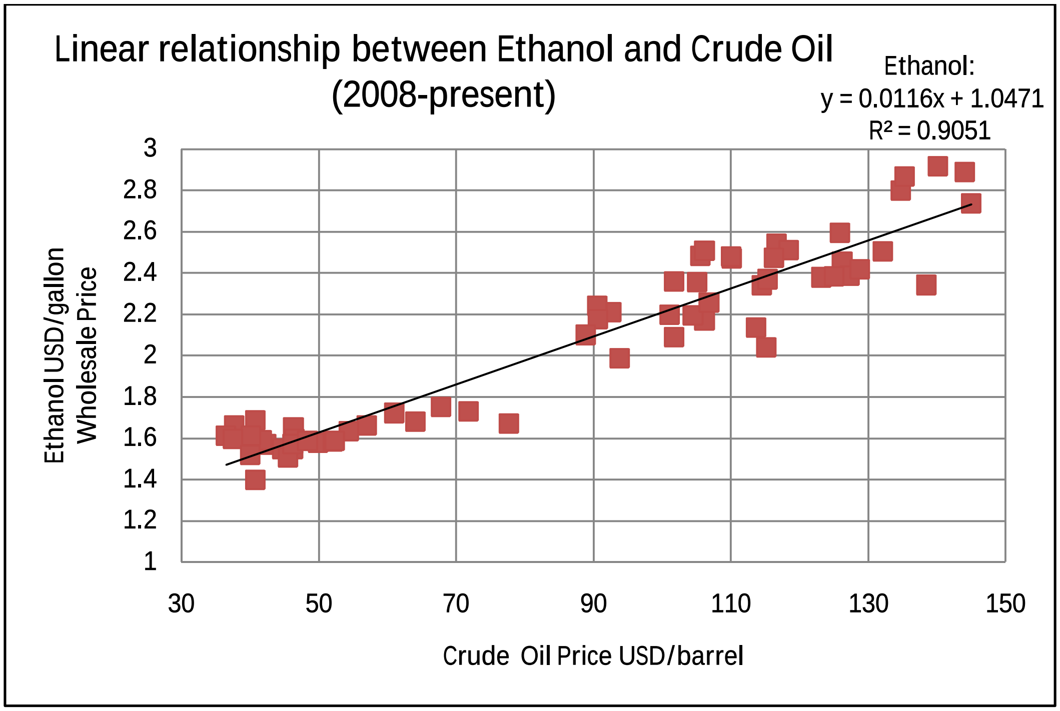


Figure SA-1: Ethanol price ($/gallon) vs. Crude Oil Price ($/barrel). Data from Interactive Data Corporation.

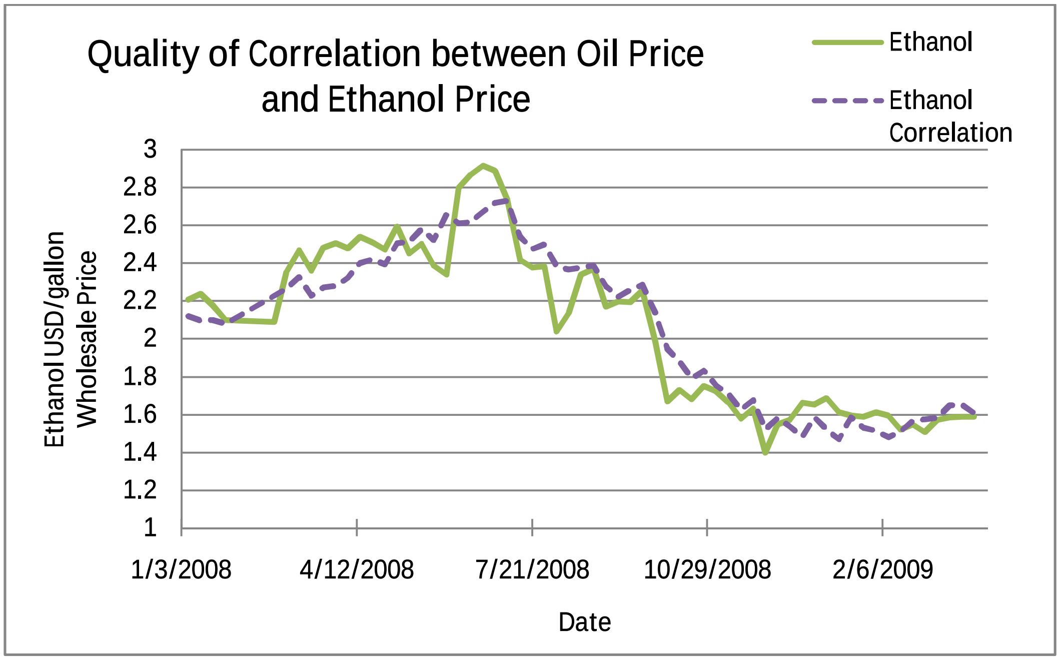
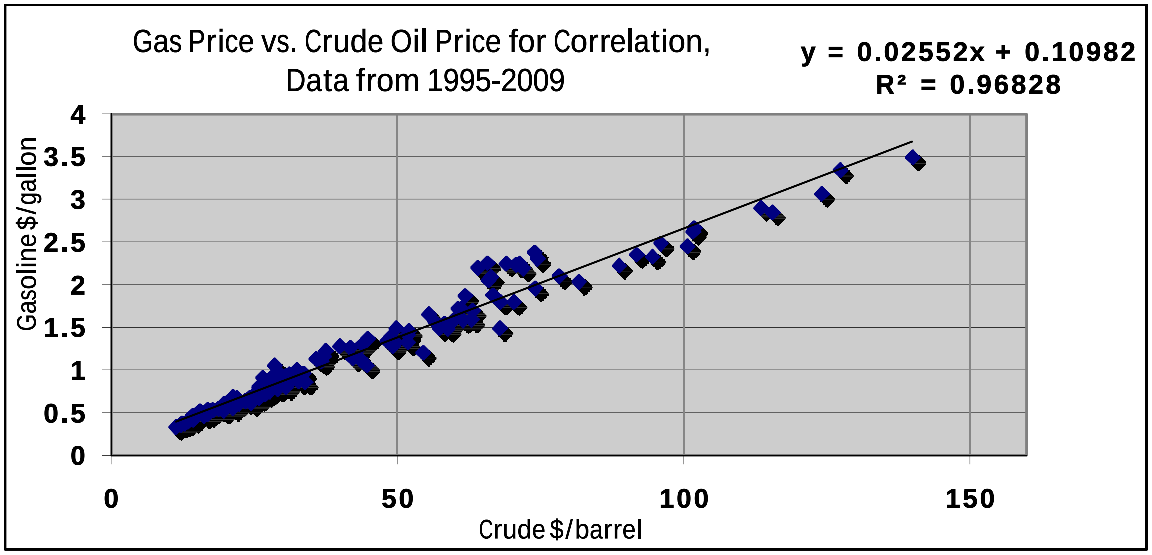


Figure SA-2: Testing the linear regression correlation from Fig. SA-1. Comparison of actual Ethanol price with price predicted from correlation. Data from Interactive Data Corporation.

While this correlation between ethanol prices and gasoline prices does show imperfections, it is significant. This correlation is valid for the time period since ethanol has been significantly used as a retail fuel (2008) and is caused by the substitute role of ethanol for gasoline. We anticipate the correlation to remain relevant so long as both gasoline and ethanol share the fuel market.

A similar, but much stronger, correlation exists between oil and gasoline, as would be expected. Oil is the feed for gasoline and therefore, oil almost completely predicts the price of gasoline. Furthermore, to ensure that the correlation is not changing, in Figure SA-3, a correlation was calculated for the prices of oil and gasoline between 1995 and 2000 then projected forward. As can be seen below, there is almost no difference between this earlier correlation and the long term correlation, suggesting this correlation will hold for some time.

At the base case, gasoline costs for denaturing ethanol are $8.3MM/year and constitute 12% of the variable costs of the plant. Variations in the price of gasoline have less effect on the profitability of the plant than ethanol or glycerol prices; however they are still significant. According to the correlations, at $2.50/gallon ethanol, gasoline will cost $3.15/gallon. In the crude oil sensitivity analysis, both the gasoline price and the ethanol price are varied with the use of these correlations with crude oil.



SA-3: Gasoline Price vs. Crude Oil Price. Data for linear regression pricing correlation. Data from Interactive Data Corporation.

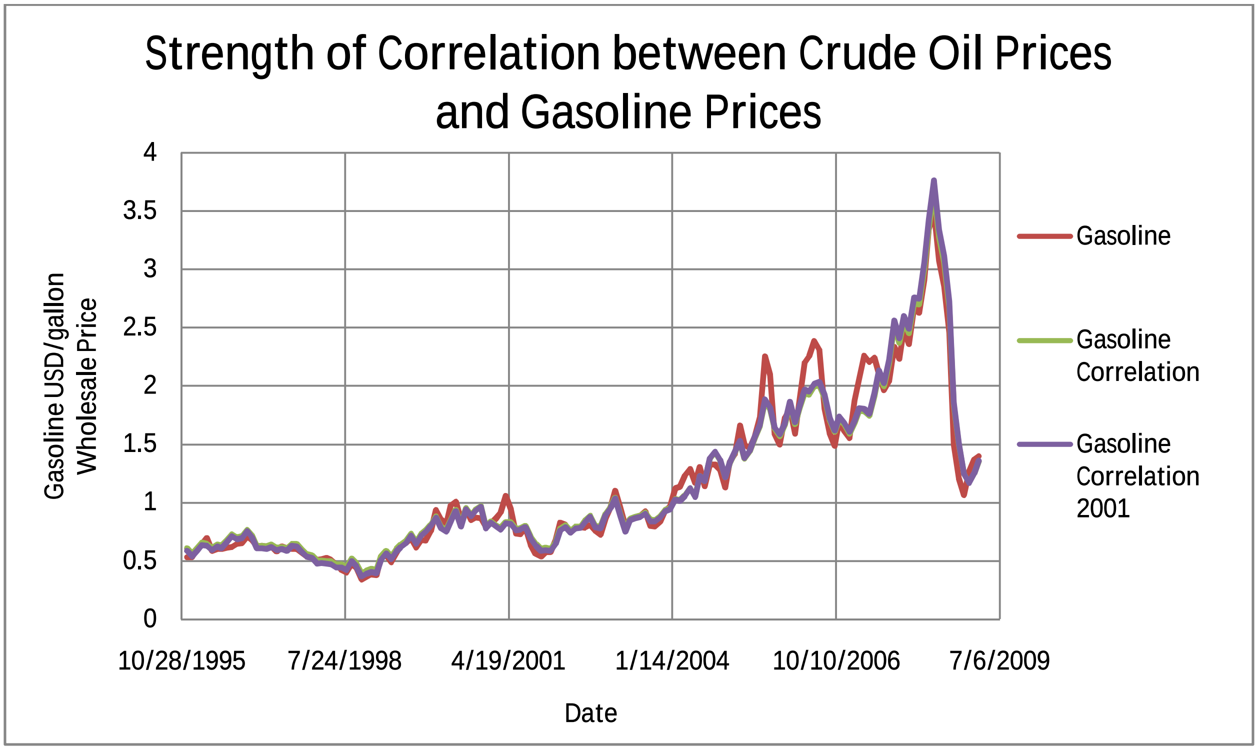


Figure SA-4: Testing two linear regression correlations for the price of gasoline as a function of the cost of oil. One linear regression is based on data from 2001 to present, and another linear regression is based on data from 1995 to present. Both correlations accurately predict the cost of gasoline from the cost of oil. The actual pricing of gasoline is shown for comparison. Data was collected by Interactive Data Corporation.

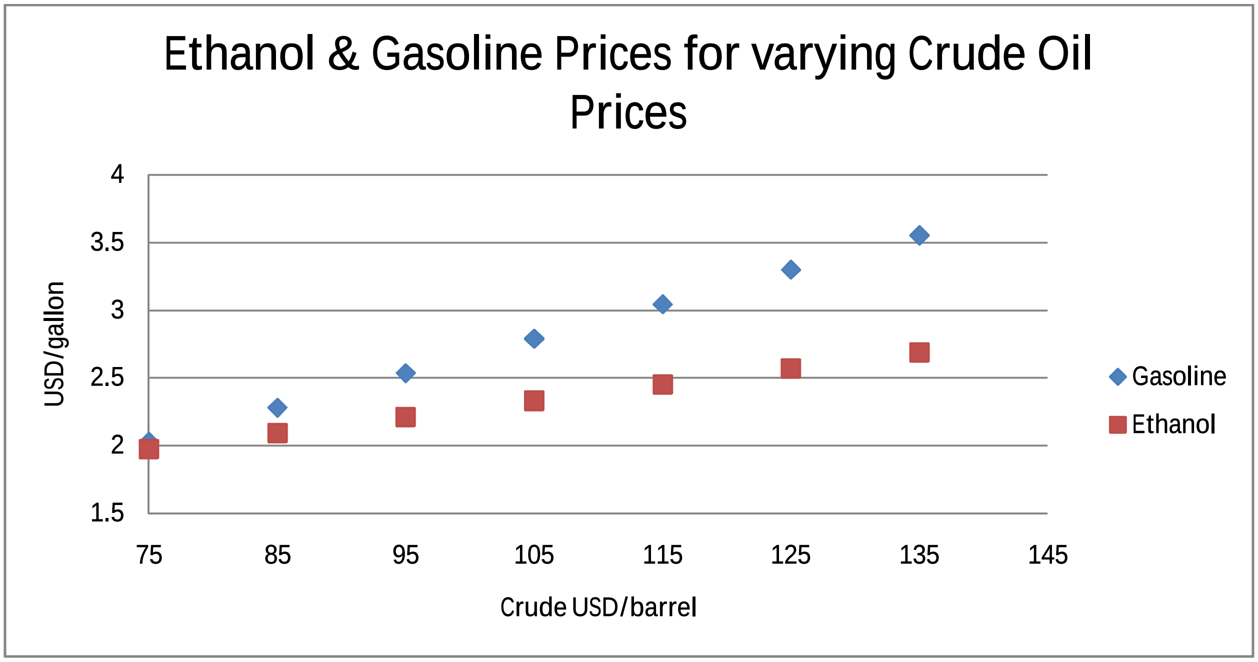


Figure SA-5: Price of gasoline and price of ethanol in $/gallon as predicted by the price of crude oil in $/barrel , using correlations determined from Fig. SA-1 and SA-3.

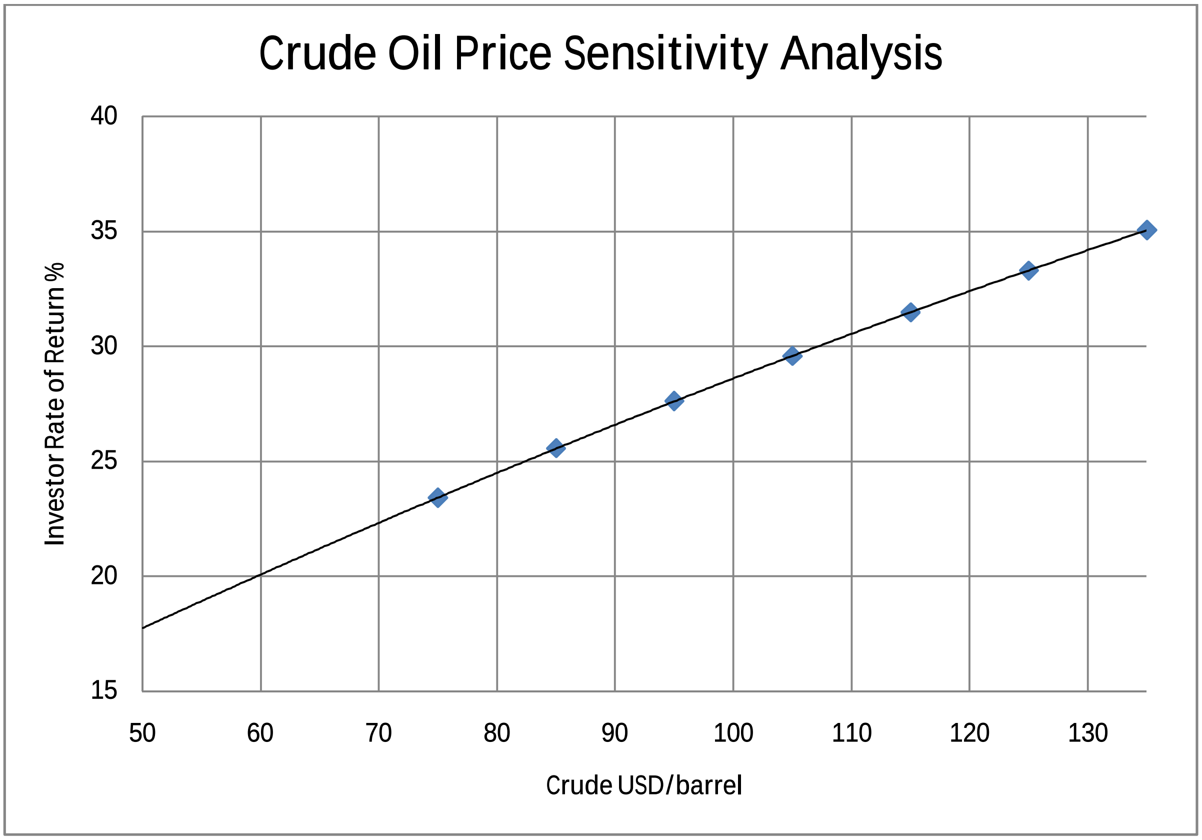


Figure SA-6: Process sensitivity analysis: The IRR as a function of the price of crude oil.

In the crude oil sensitivity analysis, the cost of ethanol and the cost of gasoline are varied in tandem, using the values shown in Fig. SA-5, and the glycerol price is kept constant at $0.05/lb. The results of the crude oil sensitivity analysis clearly show that the economics of the plant become significantly better as the price of oil increases. In our base case, the predicted crude oil price from the DOE is near $125/barrel and ethanol is priced at $2.50/gallon (see Fig. SA-5). As the process is highly profitable with high prices for crude oil, it is useful to look at profitability with low prices for crude oil. In Fig. SA-6 the worst case scenario of low crude oil prices is presented. Even if oil stays at present day values of $50/barrel, the IRR will be at 17.7% (with the price of glycerol at $0.05/lb). This eventuality is however unlikely. The plant is very well positioned to become more profitable as the price of oil increases. As the price of oil rises following the current recession, the plant will just be starting production.

Glycerol

The price of glycerol has been steadily decreasing over the last few years as the production of glycerol increases in the biodiesel industry. At the moment, very few processes are able to take advantage of the glycerol glut. As new processes like this process start up and demand begins to increase, price may vary significantly until the market reaches equilibrium. Profitability is highly dependent on glycerol price, if the price of glycerol is above 9.4 cents/lb, the process IRR decreases to below 15%. If however glycerol continues to be overproduced in comparison to demand, we have the opportunity to earn an IRR of above 40% at low glycerol prices. The plant is designed to handle crude glycerol, the cheapest possible glycerol source, to improve profitability. The plant is well placed, as biodiesel production is growing rapidly (meaning that glycerol production is increasing rapidly as well). We anticipate a continued glut in the glycerol market making this plant highly profitable.

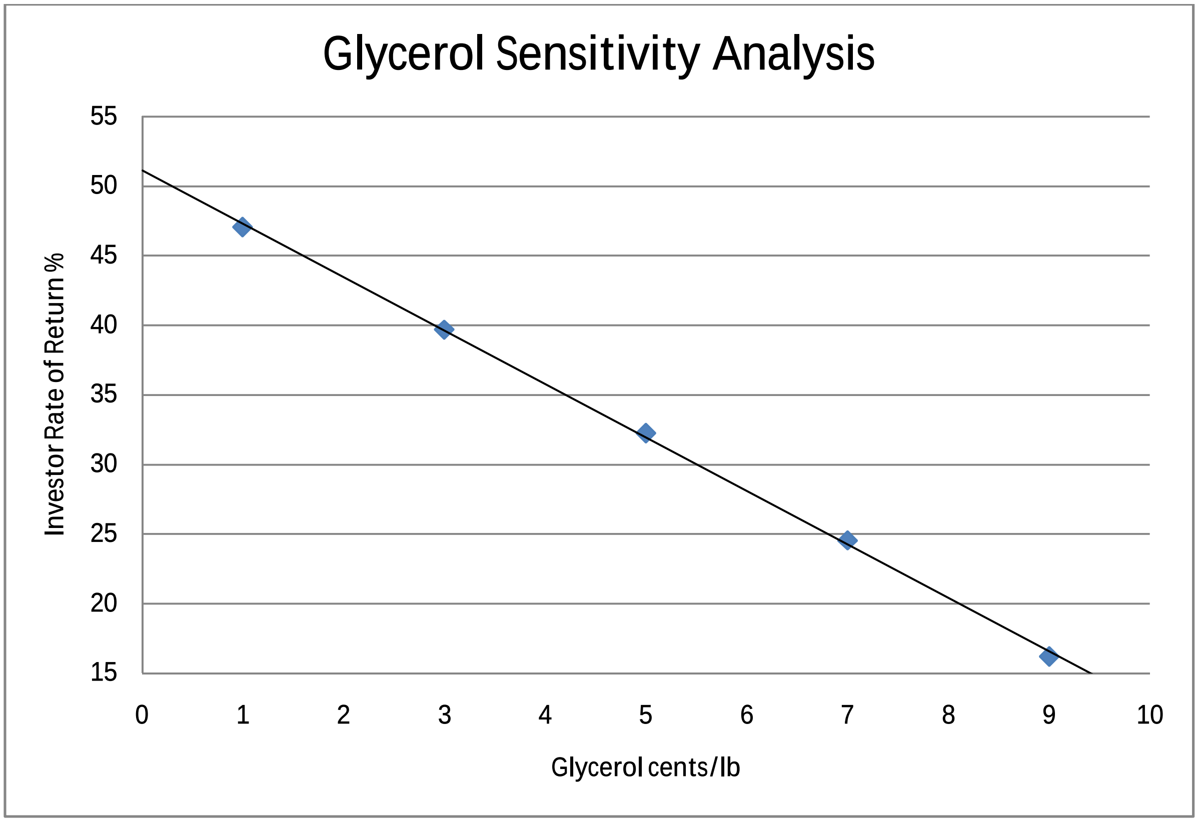


Figure SA-7: Process sensitivity analysis: The IRR as a function of the price of crude glycerol.

Succinic Acid

Succinic acid is a byproduct of the fermentation of glycerol; however it provides a significant portion of our annual revenue. At the base case, sales of succinic acid are predicted to amount to \$16.6MM/year. Since this is 12% of annual revenue, changes in the price of succinic acid do significantly alter profitability. The separation for succinic acid still needs to be fine tuned, and production levels may shift by several percent when completely understood, so we have taken a wide variance in succinic acid price to account for this. While higher succinic acid prices would be desirable for our process, our sensitivity analysis shows that succinic acid cannot make the plant unprofitable. In the worst case scenario of \$0/lb succinic acid, the IRR will not be reduced to below 25% assuming base case prices for other chemicals.

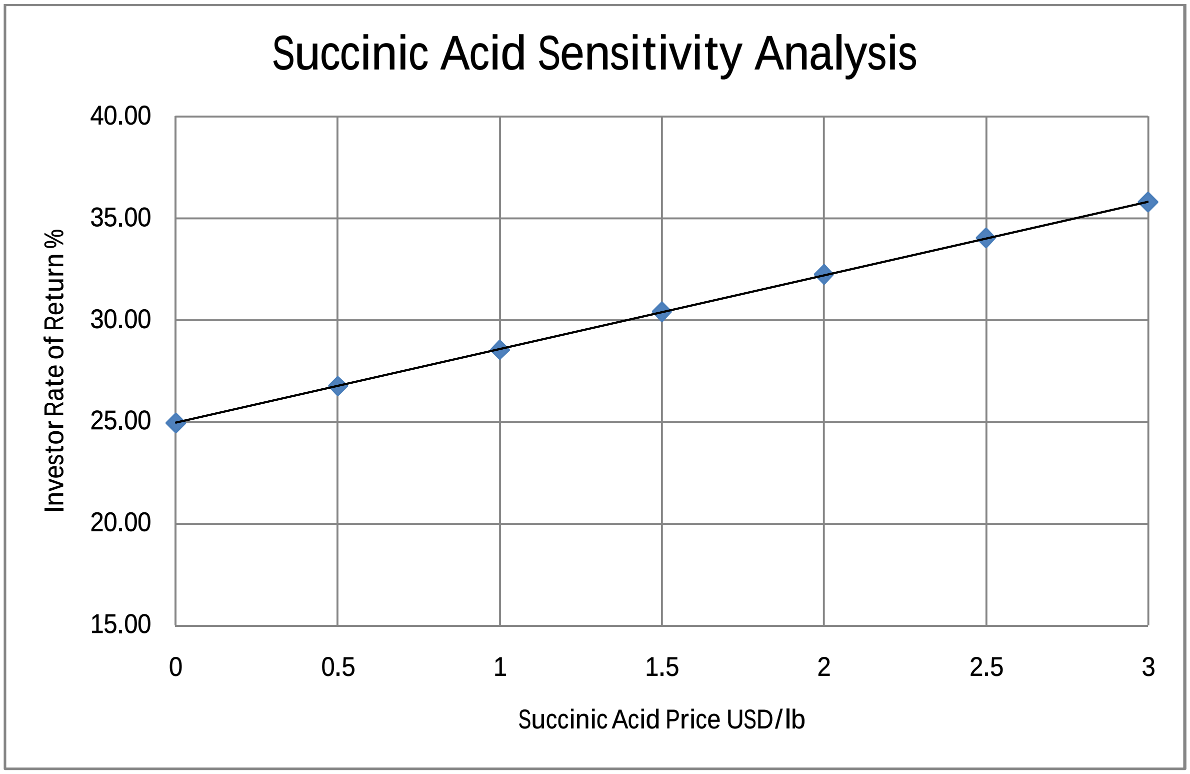


Figure SA-8: Process sensitivity analysis: The IRR as a function of the price of succinic acid.

Conclusion

Section XIV

Conclusions

The report contained herein is an exciting and comprehensive first look at the economic viability and design of an ethanol plant with a succinic acid byproduct. The economics of this process appear exceedingly favorable at this time with an IRR of 32.24% and NPV of $95MM in our base case, and with possibility to be even more lucrative. Furthermore, the process has little risk of being unprofitable, with the only concern being the unlikely scenario that the price of crude glycerol rises above $0.094/lb.

Further research is needed in laboratory experimentation with the succinic acid separation, as well as arranging for use of the patent-pending licensed glycerol purification system. Both of these non-traditional separation systems will require further information, and it is likely that the purchase and utilities costs will change based on further information and study. Utilities for the glycerol purification system have been ignored, with the exception of estimation for process water usage. Due to the highly profitable nature of this plant, the further research and necessary clarifications to the design have little chance of turning the proposal unprofitable. We find that this is an exciting opportunity deserving of further resources and attention, particularly with the insight that although our process design made use of a hypothetical microorganism, existing *E. coli* have been grown in favorable conditions to ferment glycerol to ethanol.

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Section XV

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Acknowledgements

Section XVI

Acknowledgements

We would like to thank Professor Warren D. Seider for the direction he gave our group, his ideas, and his patience over the course of this project. To Professor Leonard Fabiano, we thank you for your assistance with the design of agitators and distillation columns, as well as the ideas and support you provided.

We would like to thank all the industrial consultants, especially Mr. Bruce Vrana, who not only provided the problem statement, but who served as a sounding board for all our ideas (whether smart or not).

To our entire class who suffered with us, we thank you for the late nights, the support you provided, the food and drinks we shared, and the memories of the late nights in the fishbowl. We will look back on one day with unfounded nostalgia.

Appendices

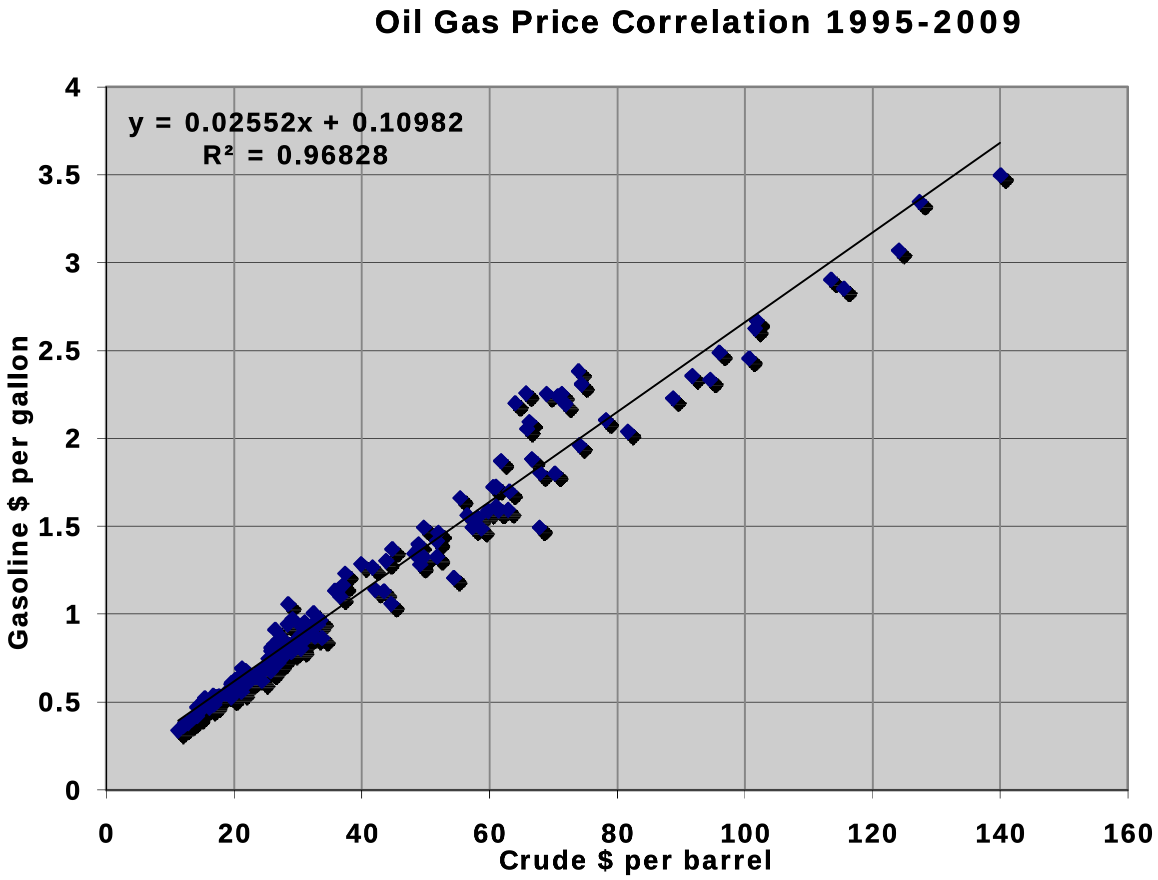
Section XVII

Appendix A.

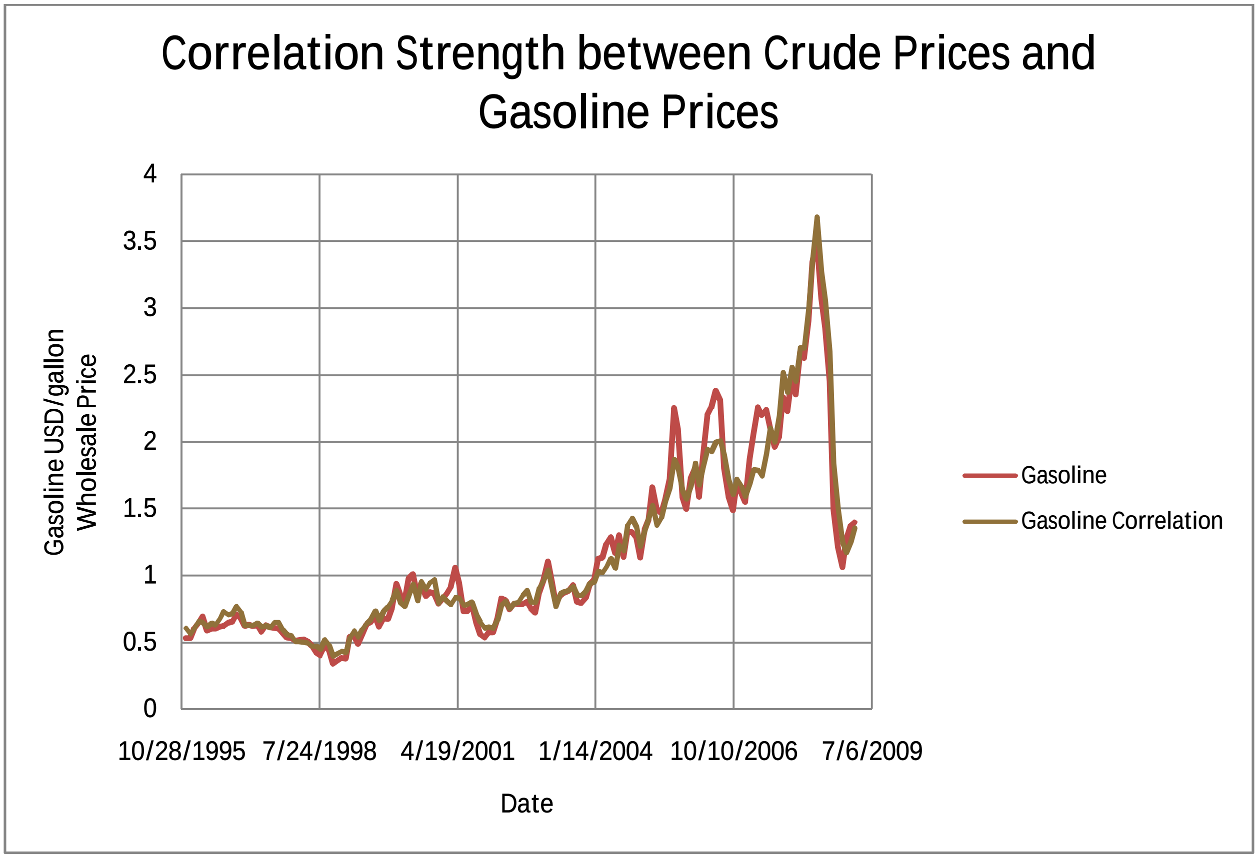
Sensitivity Analysis Correlation Example

Appendix A. Sensitivity Analysis Correlation Example

Correlations between ethanol, gasoline, and oil prices were developed in the following manner. First, the closing prices of commodities were taken and plotted against each other as in the graph below. Strong linear relationships are obvious at first glance. Using excel, a linear trend line is inserted and the equation is shown as below.



Now, going back to the closing prices, the equation found from the graph above is applied to each closing oil price to find a correlation price of gasoline. This is graphed chronologically with the actual closing price of gasoline to determine how exact the correlation is. The graph below is such a graph, and as can be seen, the correlation is exceptional.


Correlation Strength between Crude Prices and Gasoline Prices
4
3.5
3
2.5
2
1.5
1
0.5
0
Gasoline USD/gallon Wholesale Price
10/28/1995
7/24/1998
4/19/2001
1/14/2004
10/10/2006
7/6/2009
Date
Gasoline
Gasoline Correlation

Appendix B.

Equipment Costing and Sizing Calculations

Appendix B. Equipment Costing and Sizing Calculations

Agitators:

Agitators for 2,000,000 L tanks FERM1 (through FERM12) and Broth Storage Tank T-107 are priced and designed based on quotes from supplier The Kahl Company, Inc. (See following page).

Industrial consultant Mr. Bruce Vrana recommended the power requirement factor of 0.1 HP/1,000 gallons of fluid in the tank for the specific application, and this factor was applied to determine the energy requirements and costs of agitators for Seed Ferm 6A/B and Seed Ferm 7A/B. For the mixing agitators (for T-105 and T-108), 2 HP/1,000 gallons of fluid is estimated as an approximation (in range provided in Seider 537). These power requirements are used in tandem with the following equation (for turbine-powered agitators on enclosed tanks) for pricing, including the costs of the motors and shafts (Seider 553). Since the price quote for the agitators is given for 304 stainless steel and the Method of Guthrie for determining installation cost assumes a base cost of equipment in carbon steel, a materials factor of 1.7 was used to determine the carbon steel cost of agitators for Ferm 1-12 and T-107.

$$C_P = \left(\frac{566}{394}\right) 2850\, S^{0.57}$$

Where S is the motor power requirement, in HP.

Agitator for use in:	Ferm 1-12	T-107	T-105	Seed Ferm 7A/B	Seed Ferm 6A/B	T-108
Volume (L)	2,000,000	3,254,965	62,731	650,000	85,000	7,619
Volume (gal)	528,344	859,870	16,307	171,711	22,454	2,012
Power req. (HP)	20.0	20.0	32.6	17.2	2.2	4.0
C_P (CE = 394)	--	--	$13,992	$14,410	$4,519	$6,303
C_P (2009)	$75,000	$75,000	$29,900	$20,800	$6,500	$9,100
C_{PB} (2009, for Guthrie)	$ 44,200	$ 44,200	$29,900	$20,800	$6,500	$9,100

E-mail communication:

Hello Mr. Kahl,
I am a chemical engineering student at the University of Pennsylvania designing a chemical plant for my senior design project that uses 2,000,000 L fermenter tanks. Professor Len Fabiano recommended that I ask you about the costs and energy requirements associated with the agitation to be used in these tanks.

We are looking for mild agitation, our volume of liquid in the tank is about 1,500,000 L/batch, and the fluid is mostly water. We want to suspend E coli (~0.5 um particles) in the solution and ensure an even temperature distribution in the tanks. The solids content is about .4 % by mass. We are also generating gas in the anaerobic fermentation reaction, at a flow rate of 2415 kg/hr, which we believe will aid in the agitation process. The tanks have a 2:1 aspect ratio, with a height of ~72 ft and a diameter of ~36 ft.

I would greatly appreciate any suggestions or help you may be able to provide.

Thank you for your time,
Chloe LeGendre

Chloe,

I got some information for you for your project that I hope helps.

For this application, using some similar agitators we have sold in the past, you would be looking at a mixer with a 20hp motor, running at about 30 RPM. It would use three 88” hydrofoil impellers. If the shaft and impellers were made out of 304 stainless steel, a rough price of about 75000/each would be right in the ballpark. I hope this helps!

Best Regards,

Nicholas Clucas

The Kahl Company, Inc

Tel: 302-478-8450

Cell: 302-353-7317

Fax: 302-478-4826

Blowers:

Modeled as Centrifugal (Turbo) Blower

(Seider, 510, 518-519)

$C_P = F_M C_B$

$F_M = 0.6$, for Aluminum

$C_B = (566/394)\exp\{6.6547 + 0.7900[\ln(P_C)]\}$

P_C , Power Consumption (HP) = P_B/η_M

P_B, Brake Horsepower $= 0.00436(\frac{k+1}{k})\frac{Q_I P_I}{h_B}[(\frac{P_O}{P_I})^{\frac{k-1}{k}} - 1]$

η_B, Mechanical Efficiency = 0.75

k, Constant specific heat ratio = 1.4

η_M, Electric Motor Efficiency = $0.8 + 0.0319(\ln P_B) - 0.00182(\ln P_B)^2$

	B-101	B-102
Q(ft^3/min)	12,522.00	70,214.00
k	1.40	1.40
ηb	0.75	0.75
Pi (psi)	14.80	14.70
Po (psi0	19.00	18.71
Po/Pi	1.28	1.27
Pb (HP)	278.97	1,500.00
ηm	0.92	0.94
Pc (HP)	300.65	1,602.65
Cb(base cost)	$ 70,800	$ 264,200

Crystallizer (C-1)

Crystallizers are sized by the amount of crystals produced. The process produces 12.23367 tons per day. Price is calculated by the equation from Table 16.32 in Seider (Draft-tube baffled crystallizer), where W is tons of crystals produced per day:

$$C_P = \left(\frac{566}{394}\right) \$22{,}200(W)^{0.63}$$

C_P= $ 107,526

C_{PB}(2009) = $154,500

Distillation Towers:

The cost of a tower is found using the following equation (Seider 528):

$$C_V = \exp\left[7.0374 + 0.018255(\ln(W)) + 0.02297((\ln(W))^2\right]$$

Where W= weight of the distillation column (lbs)

$$W = \pi(D_i + t_s)(L + 0.8D_i)t_s\rho$$

Where D_i = the diameter of the distillation column in inches, L = the length of the distillation column in inches, T_s = the wall thickness of the distillation column in inches, ρ = the density of steel, 0.284 lb/ in^3.

To find the Length (L):

The number of theoretical stages is 32 as reported by ASPEN simulation (RADFRAC). The length for the distillation column was calculated using spacing of 2 feet between each tray, as well as an extra 10 feet at the bottom and 4 feet at the top of the column for the reboiler and condenser. The efficiency is assumed to be 40% per suggestion by industrial consultant Mr. Bruce Vrana.

$N_{(theoretical)}$ = 32 stages
$N_{(actual) =}$ 32/.4 = ≈ 80 stages
L = 79*2 + 10 + 4 = 172 ft
One stage is subtracted because the reboiler acts as a stage while not actually requiring space for a tray.

To find the thickness t_s:

D_i = 12 ft
L = 172 ft
Therefore,

$$W = \pi\left(12ft\frac{12in}{1\,ft} + \frac{1}{2}in\right)\left(172ft\frac{12in}{1\,ft} + 0.8(12ft)\frac{12in}{1\,ft}\right)\left(\frac{1}{2}in\right)\left(\frac{0.284lb}{in^3}\right)$$

W =140,476 lbs
Therefore,

$$C_V = \exp\left[7.0374 + 0.018255(\ln(140{,}476)) + 0.02297((\ln(140{,}476))^2\right]$$

C_V= $ 249,734

Cost of Platforms & Ladders (Seider 528):

$$C_{PL} = 237.1(D_i)^{0.63616}(L)^{0.80161}$$
$$C_{PL} = 237.1(11)^{0.63616}(162)^{0.80161}$$

C_{PL}= $ 70,835

Cost of Trays (Seider 532):

The costs of the trays are determined by the following equation:

$$C_T = N_T F_{NT} F_{TT} F_{TM} C_{BT}$$

Where:

$$C_{BT} = 369 \exp(0.1739D_i)$$

C_{BT} = $ 2,973
N_T = 79

F_{NT} = 1 (for > 20 trays)
F_{TT} = 1 (for Sieve Trays. Industrial Consultant Mr. Bruce Vrana recommends Baffle Trays for the distillation tower, but indicated that this pricing correlation would be conservative, as Baffle Trays are mechanically simpler than Sieve Trays)

$$F_{TM} = 1\ (Carbon\ Steel)$$

$$C_T = 74(1)(1)(2.197)(\$2973) = \$234{,}930$$

C_T= $234,930
C_P = total cost of column

$$C_P = \left(\frac{566}{394}\right)(F_M C_V + C_{PL} + C_T)$$

F_M=Function of Materials
F_M= 1 for Carbon Steel
C_P(2009) = $ 798,000

	Distillation Column D-1	Absorber AB-1
Theoretical Stages	32	7
Efficiency	0.4	0.4
Actual Stages	80	17.5
Stages used	80	18
Diameter (Aspen)	12	5.46
Diameter Used (ft)	12	5.5
Length (ft)	172	50
Shell Thickness (in)	0.5	0.3125
Weight (lb)	140,476	12,069
Cost of Vessel	$249,734	$48,148
Cost of Platforms & Ladders	$70,835	$16,055
Base Cost of Trays	$2,973	$960
F_{TM}	1	1
C_T	$234,930	$17,285
C_{PB} (2009, for Guthrie)	$798,000	$117,100

Dryer:

Assuming no more than 25Wt% water in the crystals, the dryer needs to vaporize, at most, 114.7 kg/hr of water, requiring a heat duty of 273,651 BTU/hr. Because of the low temperature needed, 212 °F, we selected an indirect-heat steam-tube rotary dryer, heated by steam at 298 °F. As per Philip A. Schweitzer, dryers are quite complex and unpredictable, however the best general modeling of a dryer is as a heat exchanger. So, to calculate the area of the dryer we used the standard heat exchanger formula:

$$A = \frac{Q}{U\Delta T_{LM}}$$

ΔT = 86 °F
U = 700 BTU/(°F-ft^2-hr) (Seider Table 13.5 for water/steam heat exchanger)
A= (273,651 Btu/hr)/[(86 °F)*(700 BTU/(°F-ft^2-hr))]
A= 4.5 ft^2
Assume 45 ft^2 just to be extra safe given the number of unknowns
A= 45 ft^2
The purchase cost is found using the formula for indirect-heat steam-tube rotary dryer (Seider 553), where A is area in ft^2.

$$C_P = \left(\frac{566}{394}\right)3500(A)^{0.32}$$

C_P (2009) = $22,200

Electro-dialysis:

According to Perry's Chemical Engineering Handbook, the price of an electro dialysis plant with a flow rate of 2000 m^3/day has a cost of $665,000 in 1993, and that this price is scalable at a 0.7 power. According to the plant cited, the equipment price was $1,210,000 while installation was $600,000, yielding a Bare Module factor of 1.5. Flow rate for electro-dialysis is based on the volume of clean water produced in m^3/day.

C_{ED}=(4,333 m^3/2000 m^3) $^{(0.7)}$ *$665,000
C_{ED}=$1,142,500
Adjusted by the CE index:
C_{ED} (2009) =C_{ED} (1993)/CE (1993)*CE (2009) = $1,142,500/359*566
C_{ED} (2009)=$1,801,000
C_{BM} (2009) = $1,801,000 * 1.5 = $2,700,000

Daily Incremental Cost:
Perry's cites typical operating costs of electro dialysis as $133 per 1000 m^3 in 1993 dollars
Operating Cost = ($133/1000 m^3)*(4,333 m^3/day)*(330 days/year)
Operating Cost = $190,200/year

External Heat Losses from FERM1-12

Since the majority of the plant equipment will be outdoors, additional calculations need to be done to estimate the heat required to replace any heat lost to the atmosphere by the fermentation tanks.

The average temperature of the Gulf Coast was approximated to be the average temperature of Louisiana which is 58 °F .The air velocity was also estimated to be that of Louisiana and that was reported to be 10 MPH.

The heat loss from one of the 2,000,000 L fermenters was approximated to be that of a cylinder in cross flow. The Reynolds number was calculated using tabulated values for air at the reported temperatures and velocities using

$$\mathrm{Re}_D = \frac{\rho \overline{V} D}{\mu}$$

Where ρ- density of the fluid (kg/m^3)
D - diameter of the cylinder (m)
$\overline{V}$- average velocity of the fluid (m/s)
μ- viscosity of the fluid (Pa-s)

The heat transfer coefficients may be determined by correlations obtained from dimensional analysis (Incropera & Dewitt).

$$Nu = \frac{hd}{k} = 0.3 + \frac{0.62Re^{1/2}Pr^{1/3}}{\left(1 + \left(\frac{0.4}{\mathrm{Pr}}\right)^{\frac{2}{3}}\right)^{\left(\frac{1}{4}\right)}}\left[1 + \left(\frac{Re}{28200}\right)^{\frac{5}{8}}\right]^{\frac{4}{5}}$$

Where h-heat transfer coefficient (SI units: W/(m^2K))
d-Diameter of the cylinder (m)
Pr-Prandtl number
k- thermal conductivity, (SI units : W/(m-K))

With the heat transfer coefficient calculated the heat dissipation can be calculated from Newton's Law of cooling. That is

$Q= h A_S(T_s-T_{inf})$

Where A_s – Surface Area of Cylinder(πDL)(in m^2)
T_{inf} –Temperature of Air

Air							
Temp (K)	Film Temp(K)	Density (kg/m^3)	**μ** x 10^7(N/m^2)	k x 10^3 (W/m-K)	Pr		
287.4	298.7	1.1614	184.6	26.3	0.707		
	Diameter	Length	Re	Nu	h	Q(kW)	Q(BTU/hr)
Ferm 1	10.820	21.671	3043875.897	3272.024	7.953	58.588	55.529
Seed 6	3.781	7.563	1063748.065	1297.874	9.027	8.110	7.687
Seed 7	7.450	14.900	2095737.894	2339.798	8.260	28.805	27.301

Fermenter Tanks:

Determination of required Volumes
Total Ethanol produced per year = 50 MM gallons (denatured with gasoline)
Operation for 330 days/yr
50 MM gallons/yr ≈ 23,897 L/hr (denatured with gasoline)
Denatured ethanol is 2-5% gasoline by volume.
Pure ethanol produced per year = 22,703 L/hr to 23,420 L/hr
Cycle Time = 297 hr/cycle (for 3 full fermentation periods) (see below)
100 g Ethanol/ L of reaction (end ethanol titer specified by problem statement)

$$\left(\sim 22{,}900\,\frac{L}{hr}\right)\left(297\,\frac{hr}{cycle}\right)\left(0.79\,\frac{g\ Ethanol}{cm^3}\right)\left(\frac{1\ cm^3}{0.001\ L}\right)\left(\frac{1\ L\ of\ reaction}{100\ g\ Ethanol}\right)$$

$$= 53{,}495{,}640\,\frac{L\ of\ reaction}{cycle}$$

One cycle is 3 fermentation periods (see below)
Maximum volume for fermentation tank = 2,000,000 L (Shuler & Kargi), with suggested working volume from 70% (Shuler & Kargi) to 83% (Kwiatkowski). 1,500,000 L is 75% working volume.

$$53{,}495{,}640\,\frac{L\ of\ reaction}{cycle}\left(\frac{1\ cycle}{3\ reaction\ periods}\right)\left(\frac{1}{1{,}500{,}000\ L}\right) \approx 12\ tanks$$

Twelve (12) 2,000,000 L tanks at a working volume of about 75% are required for operation at the current schedule posted below.

Cycle based on largest fermenters (bottleneck):	time (hr)
Charge with biomass from Seed 7A/B	=27 (stagger time)
Charge with glycerol feed from T-106	=5
Ferment/React	=60
Drain to T-107 (95%)	=5
Charge with glycerol feed	=5
Ferment/React	=60
Drain to T-107 (95%)	=5
Charge with glycerol feed	=5
Ferment/React	=60
Drain to T-107 (100%)	=5
Clean-in-Place	=60
Total	=297 hours

Initial stagger time S (27 hours) determined using:
S + 4(60 hr) +3(5 hr) + 3(5 hr) = 11 S
(For 12 tanks, need 11 staggered start times after first for fully staggered configuration)

One cycle consists of three fermentation/ reaction periods or batches, as seen above. All flow rate values in the batch material balance blocks refer to the flow requirements for one batch within each three-batch cycle.

The problem statement gives 1.6 g Ethanol formed per L reaction volume per hour, with an end concentration of 100 g Ethanol / L. The 60 hour fermentation time was determined by dimensional analysis: (100 g/L)/(1.6 g/L-hr) = 62.5 hours. However, a small portion of ethanol is fed to each reactor during the seed fermentation seed (5%, or 1/20), and 62.5 * 0.95 ≈ 60 hours. The exception to this is the first stage seed fermenter 1A/B, which is fed only biomass (containing no ethanol) and therefore requires 62.5 hours to reach the required ethanol titer.

Glycerol added beyond what could stoichimetrically react to form 100 g ethanol /L would not be consumed, because at higher ethanol concentrations, *E. Coli* are killed. Accordingly, the design problem statement required that a stoichiometric amount of glycerol be added to form 100 g Ethanol / L of solution. Some of the ethanol produced is vaporized and leaves in the vapor exit streams. The quantity of water and ethanol leaving as vapor are determined using Aspen in a Flash calculation at 37 °C. Approximately 4.9% by mass of the ethanol produced is vaporized, and 0.49 % by mass of the water contents is vaporized, using NRTL property estimations. These figures are calculated using the final contents of the reactions, so they represent a worst case scenario of ethanol and water removed from the liquid phase (as less ethanol exists in solution for the majority of the reaction time). Accordingly, dilute glycerol feed was added to stoichiometrically react to form the 100 g Ethanol / L of solution as if none were to evaporate, since the evaporation quantity was an estimate. The liquid exit streams, as a result of the evaporation calculations, appear to have ~95 g Ethanol/ L.

The process begins with 1 mL of biomass/ *E. coli* cells, specified in the design problem statement, referred to as the inoculum from the laboratory. The problem states that each successive reactor can be 20 times as large as the previous reactor, so the first stage of fermentation (Seed Ferm. 1A/1B) has a working volume of about 20 mL. (19.1 mL of glycerol feedstock is added to the 1 mL inoculum, but the volume at the end of the 62.5 hour period is ~ 19.4 mL). Seed Ferm 1A is charged with a 1 mL inoculum sample, as is Seed Ferm 1B. Each starts a separate seed fermentation train (Train A and Train B). The reaction occurs, and as per the problem statement, 98% of the glycerol reacts to form ethanol, while 1% reacts to form succinic acid and 1% reacts to form biomass. The reactions were entered into SuperPro designer for the mass balance information, with 98% glycerol conversion for the ethanol reaction. This reaction was first in series with the two parallel reactions of 50% conversion of the remaining glycerol to succinic acid and 50% conversion of the glycerol to biomass.

Glycerol **à** CO_2 + H_2 + Ethanol
CO_2 + Glycerol **à** Succinic Acid + H_2O
Glycerol **à** 3.0075(Biomass) + H_2O

(Biomass has a molecular weight of 24.63 g/mol)

The contents of Seed Fermenter 1A is then transferred to Seed Fermeter 2A. Seed Fermenters 2A/B have working volumes of approximately (20 mL *20) = 400 mL. The appropriate stoichiometric quantity of glycerol was determined using SuperPro designer for all stages. After the next 60 hours of reaction, the contents of Seed Ferm 2A/B are transferred to Seed Ferm 3A/B, with a working volume of about (400 L)*20 = 8 L. Following this trend, seed Fermenters 4A/B have working volumes of about (8 L *20) =

160 L, seed Fermenters 5A/B have working volumes of about (160 L *20) = 3200 L, and seed Fermenters 6A/B have working volumes of about (3,200 L *20) = 64,000 L.

The precise working volume of the final large scale fermenter is 1,577,642 L upon charging, and 1,525,404 L at the end of the reaction. The portion of seed volume required to charge these large scale fermentation tanks (1/20) of this volume, is therefore between 76,270 and 78,882 L. A value of 77,090 L was chosen to represent the required charging volume per tank, and 12 seed portions of this size were required, six for each fermentation train. Accordingly, 77,090 x 6 = 460,000 L was chosen as the approximate working volume of seed fermenters 7A/B, even though this volume only represents a multiplication factor of about 7 from the scaling up to 7A/B from 6A/B. (The initial working volume of seed fermenters 7A/B is 471,800 L, and the final working volume is 457,000 L). The alternative of having one fermentation train with Seed 7A as 77,090 L x 12 portions was not selected, as the draining from this tank to the twelve larger tanks followed by a significant cleaning time of ~60 hours represented a bottleneck in the process. The addition of a second seed fermentation train, with the final volume of seed fermenter 7A/B split into six portions for charging the main fermenters, removed this bottleneck.

Fermenter Tank Costs

Tanks Seed 1A/B, Seed 2A/B, Seed 3A/B, and Seed 4A/B are considered too small to contribute to the overall cost estimate.

L/D Aspect Ratio for all tanks = 2:1 (Shuler & Kargi). L and D are determined by volume requirement (formula for volume of cylinder is used).

The SuperPro Designer "Ethanol Dry Grind Process Model" (Kwiatkowski et al.) includes cost estimates "based on equipment and operating costs and descriptions obtained from industry sources" for 304 Stainless Steel Fermentation tanks of 1.9 MM L volume (≈ volume of FERM1) and 650,000 L (≈ volume of Seed Ferm 7A/B) volumes with 3:1 or 2:1 aspect ratios. These figures are used to estimate the costs of units FERM1 (through FERM-12) and Seed Ferm 7A/B, as the heights and diameters of these vessels are outside the boundaries for applying cost estimation formulas found in many resources. The value for (F_MC_V) from the Kwiatkowski model for the 1.9 MM L 304 Stainless steel tank was $470,000 (CE index = 526). The value for (F_MC_V) for the 650,000 L 304 Stainless steel tank was $197,000 (CE index = 526). The carbon steel value for the base cost of the vessels (for input into the Guthrie Model to determine the installation cost) was determined by dividing the cost of the stainless tower by 1.7, the materials factor for 304 Stainless Steel for vertical vessels.

Tanks Seed Ferm 5A/B and Seed Ferm 6A/B were estimated by methods in Seider (527-529) as vertical pressure vessels:

$$C_P = F_M C_V + C_{PL}$$

$$C_V = \exp\left[7.0374 + 0.018255(\ln(W)) + 0.02297((\ln(W))^2\right]$$

$$W = \pi(D_i + t_i)(L + 0.8D_i)t_s\rho$$

$$C_{PL} = 237.1(D_i)^{0.63316}(L)^{0.80161} \quad (for\ 3 < D < 24\ ft, 27 < L < 170\ ft, typically\ towers)$$

$$C_{PL} = 285.1(D_i)^{0.73960}(L)^{0.70684} \quad (for\ 3 < D < 21\ ft, 12 < L < 40\ ft, typically\ vessels)$$

Where W is weight of the vessel in lb, D_i is the diameter of the vessel, and L is the height or length of the vessel. ρ was taken as 0.284 lb/in^3 for steel, and t_s was found using the table for minimum wall thickness at the top of page 530 (Seider). F_M was taken as 1, as the Guthire Model requires costs of vessels made of carbon steel.

	Ferm 1 (-- Ferm 12)	Seed Ferm 7A/B	Seed Ferm 6A/B	Seed Ferm 5A/B
Diameter Used (ft)	35.55	24.44	12.41	4.66
Length (ft)	71.10	48.88	24.81	9.32
Shell Thickness (in)	--	--	0.25	0.25
Weight (lb)	--	--	13,865.04	1,960.18
Cost of Vessel	$470,000.00	$197,000.00	$52,453.33	$17,006.02
C_{PL}	$69,397.61	$40,541.47	$17,768.47	$4,308.41
Cost of Tower (Stainless Steel)	$539,397.61	$237,541.47	--	--
C_P (2009, for Guthrie)	$341,500	$150,400	$100,900	$30,700

Furnace:

Heat duty requirement for reboiler (from Aspen)
Q = 76,910,000 BTU/hr
Supplied with hydrogen from fermentation process

Modeled as Fired heater (Seider 526) with F_M = 1 for Carbon Steel, F_P = 1 for atmospheric pressure

$$C_p = \left(\frac{566}{394}\right) F_p F_M C_B$$

$$C_B = \exp\left[0.08505 + 0.766(\ln(Q))\right]$$

Q	76,910,000
C_B	$1,195,638
F_M	1
C_{PB} (2009, for Guthrie)	$1,717,600

Glycerol Purification System:

Although the glycerol purification system is a combination of reverse osmosis, electro/pressure membrane separation, and electro-dialysis, and is a licensed unit available for purchase from EET Corporation, a price is estimated for the system first as reverse osmosis and then as electro-dialysis. A price quote from the company was unavailable.

As Reverse Osmosis:
Stream S-FP-104 is the “purified stream” with flow rate = 32,356 L/hr = 205,142 gal/day
Approximated as Brackish Water purification (Seider 554):
C_{BM} = 2.1*Q
With Q in gal/day.
C_{BM} = $ 430,800

As Electro-dialysis (using equations above):
Stream S-FP-104
Q = 205,142 gal/day = 776 m^3/day
C_{ED}= $ 178,300
C_{ED} (2009)=$281,100
C_{BM} (2009)=$421,700

The larger of the costs, that for Reverse Osmosis, was chosen as a starting value for the glycerol purification system installation cost. However, these correlations are provided for purifying water, not a glycerol/water solution.

Heat Exchangers

HX-1 (Feed Sterilization Pre-Heater) (Floating Head Shell/Tube Heat Exchanger)

Mass flow rate of Glycerol, Water, Corn Steep Liquor
= 191,924 kg/hr (S-FP-114)

5 psi pressure drop across both sides of Heat Exchanger. Feed enters at 45 psia to avoid vaporization of feed. Modeled in Aspen as Glycerol/Water Mixture (CSL mass assumed to be water mass).

Hot Sterile Feed (S-FP-109) cooled from:
121 °C to 37 °C (or 250 °F to 98.6 °F)

Heat from Hot Sterile Feed preheats Cold Unsterile Feed (S-FP-114) from
25 °C to 111 °C (or 77 °F to 231.86 °F)

Exchanger Duty Q calculated from Aspen
= 59,665,811 BTU/hr.

Upon plant start up, the duty will be provided using 50 psig steam because the hot sterile feed will not yet be available. 2470 kg of 50 psig steam (298 °F) will be condensed over a period of five minutes to provide this duty. The sterilized feed will then wait until a valve allows the steam utility to be turned off and the hot sterile feed will then begin to pre-heat the cold unsterile feed as described above. The exchanger area requirement for the start-up will be less, as the value for the heat transfer coefficient for the steam/feed configuration is greater than for the feed/feed configuration.

Steam ΔH_{vap} = 2013.164 Btu/ kg (at 298 °F, Perry's Chemical Engineering Handbook).
$Q = m*\Delta H_{vap}$
$Q/\Delta H_{vap}$ = 29,637.84 kg /hr steam flow rate
29,637.84 kg/hr * 5 min * (60 min/1 hr)
= 2470 kg of steam for start up.

HX-2 (Sterilizer) (Double Pipe Heat Exchanger)

Mass flow rate of Glycerol, Water, Corn Steep Liquor
= 191,924 kg/hr (S-FP-108)

5 psi pressure drop across both sides of Heat Exchanger. Feed enters at 40 psia to avoid vaporization of feed stream. Model in Aspen as Glycerol/Water Mixture (CSL mass assumed to be water mass).

150 psig steam (367 °F) with mass flow rate 4045 kg/hr (S-FP-110) is condensed.

Pre-heated Feed (S-FP-108) is heated further by steam from
111 °C to 121 °C (or from 231.86 °F to 250 °F).
This is sterilization temperature (for all organisms, spores).

Exchanger Duty Q calculated from Aspen
= 7,738,512 BTU/hr.

HX-3 (Post-Fermentation Sterilizer) (Floating Head Shell/Tube Exchanger)
Mass flow rate of Fermentation Broth
= 172,397 kg/hr (S-140)

Broth (S-S-109) is heated from
37 °C to 92.2 °C (or from 98.6 °F to 198 °F).
(past 62.2 °C deactivation temperature for *E. Coli*)

21 psi Water (S-S-135) leaving ED-1 (Electrodialysis) is cooled from
109 °C to 43.3 °C (or from 228 °F to 110.4 °F)

Exchanger Duty Q calculated from Aspen
= 48,041,600 BTU/hr

HX-4 (Partial Condenser for Tower D-1) (Floating Head Shell/Tube Heat Exchanger)
Mass flow rate of Vapor stream (S-S-130) leaving Tower
= 189,673 kg/hr
at 82 °C (179.5 °F)

Vapor is partially condensed to liquid using
1,087,869 kg/hr cooling water (S-S-106)
heated from 32.2 °C to 48.9 °C (90 °F to 120 °F)

Exchanger Duty Q calculated from Aspen
= 68,130,000 BTU/hr

HX-5 (Ethanol Cooler) (Floating Head Shell/Tube Exchanger)
Mass flow rate of ethanol stream (S-S-122) = 19,594.03 kg/hr.

Ethanol is cooled from its boiling point (exit temperature of liquid ethanol from MS-1)
78.4 °C to 50 °C (173 °F to 122 °F)

Cooling water is warmed from
32.2 °C to 48.9 °C (90 °F to 120 °F)
At a flow rate of 23,766.11 kg/hr (S-S-136)
Exchanger Duty Q calculated from Aspen
=1,488,726.2 BTU/hr

HX-Ferm (Exchanger to Maintain T = 98.6 °F in Fermenter tanks) (Double Pipe Heat Exchanger)
As suggested by the heats of formation calculation, one heat exchanger is provided to cool the contents of each 2,000,000 L fermentation tank. The fluid is circulated over a period of 60 hours (one fermentation period) through a heat exchanger, and the heat duty corresponds to the amount of heat required to cool the contents of one reactor from 109 °F to 98.6 °F (42.72 °C to 37 °C)

Cooling water at a mass flow rate of 22,063 kg/hr (calculated by Aspen) enters at 87.6 °F (30.9 °C) and leaves at 99 °F (37.2 °C) (to maintain a minimum temperature approach of 10 °F). In summer months, when cooling water may not be available at 87.6 °F, cooling water and chilled water may be combined.

Heat Duty Q calculated by Aspen
= 518,297 BTU/hr.

Assuming cooling water is available at 90°F, it makes up 95% of the heat duty, at a flow rate of 21,003 kg/hr per heat exchanger. The remaining 5% of the heat duty is made up using chilled water (40 °F).

HX-6 (Supplement to Furnace for D-1 Tower Partial Reboiler, Kettle Vaporizer Reboiler)

Mass flow rate of mixed stream (S-S-114) entering HX-6 = 217,948 kg/hr

The reboiler duty is calculated by subtracting the heat duty given by burning the fermentation-produced hydrogen in the furnace (Q_{furn} = 76,910,000 BTU/hr) from the total tower reboiler heat duty requirement as determine by Aspen (Q_{tower} = 110,690,000 BTU/hr).

HX-6 heat exchanger duty Q
= 33,780,000 BTU/hr

This duty is provided by condensing 50 psig steam (298 °F)
ΔH_{vap} = 2013.16 BTU/kg (steam at 298 °F, Perry's Chemical Engineering Handbook)
$Q = m^*\Delta H_{vap}$
$Q/\Delta H_{vap}$ = 16,780 kg /hr steam flow rate

Costs for Heat Exchangers

Heat Exchangers HX -1, HX-3, HX-4, and HX-5 are modeled as Floating Head Shell and Tube Heat Exchangers (Seider 523).

$$C_p = \left(\frac{566}{394}\right) F_p F_M F_L C_B$$

$$F_M = 1 \ (for\ Carbon\ Steel - Carbon\ Steel)$$

$$C_B = \exp\left[11.667 - 0.8709(\ln(A)) + 0.09005(\ln(A))^2\right]$$

$$A = \frac{Q}{U\Delta T_{LM}}$$

A is exchanger area in ft^2. The values for U, the heat transfer coefficient estimates in Btu/(ft^2 hr °F), were obtained from Table 13.5 (Seider 431).

F_p = 1 (for pressures < 100 psi)

F_L = 1 (for tube length = 20 ft).

Heat Exchangers	HX-1	HX-2	HX-3	HX-4	HX-5
Q (BTU/hr)	59,665,811	7,738,512	48,041,600	68,130,000	1,488,726
U (BTU/(hr-ft^2-°F)	250	200	250	200	150
ΔT_{LM} (°F)	19.82	120	19.22	73.48	41.66
A (ft^2)	12,042	321	9,997	4,636	239
C_B	$ 92,061	$ 15,348	$ 79,269	$45,808	$ 14,734
F_M	1	1	1	1	1
C_{PB} (2009, for Guthrie)	$ 132,300	$ 22,100	$ 113,900	$ 65,900	$ 21,200

Heat Exchanger HX-Ferm is modeled as a Double Pipe Heat Exchanger (Seider 524) due to smaller exchanger area requirements. It is modeled as carbon steel shell side / carbon steel tube side for placement into the Guthrie method. This gives $F_M = 1$. For pressures less than 600 psig, $F_P = 1$. The value for U is given in Table 13.5 (Seider 431).

$$C_p = \left(\frac{566}{394}\right) F_p F_M C_B$$

$$C_B = \exp\,[7.1248 + 0.16(\ln(A))]$$

$$A = \frac{Q}{U \Delta T_{LM}}$$

Heat Exchangers	HX-FERM
Q (BTU/hr)	518,297
U (BTU/(hr-ft^2-°F)	250.00
ΔT_{LM} (°F)	10.49
A (ft^2)	197.635
C_B	$ 2,894
F_M	1
C_{PB} (2009, for Guthrie)	$4,200

Heat Exchanger HX-6 is modeled as a Kettle Vaporizer type Heat Exchanger (Seider 523) due to its functionality as the supplement to the partial reboiler for the distillation column D-1. The value for U, the heat transfer coefficient estimates in Btu/(ft^2 hr °F), was obtained from Table 13.5 (Seider 431).

$$C_p = \left(\frac{566}{394}\right) F_p F_M F_L C_B$$

$$F_M = 1\ (for\ Carbon\ Steel - Carbon\ Steel)$$

$$C_B = \exp\,[11.967 - 0.8709(\ln(A)) + 0.09005(\ln(A))^2]$$

$$A = \frac{Q}{U\Delta T_{LM}}$$

F_p = 1 (for pressures < 100 psi)
F_L = 1 (for tube length = 20 ft).

Heat Exchanger	HX-6
Q (BTU/hr)	33,780,000
U (BTU/(hr-ft^2-°F)	200
ΔT_{LM} (°F)	70
A (ft^2)	689
C_B	$41,931
F_M	1
C_P (2009, for Guthrie)	$60,300

Heat of Reaction Calculation for determining Temperature Change in Reactors

Glycerol Heat of Formation = -655.9 kJ/mol
Ethanol Heat of Formation =-277.63 kJ/mol
Carbon Dioxide Heat of Formation =-393.5 kJ/mol
Hydrogen Heat of Formation =0 kJ/mol

Primary Reaction
Glycerol **à** Ethanol + CO_2 + H_2

ΔH_{rxn} = -5.23 kJ/mol of Ethanol formed (exothermic reaction)
Ethanol formation rate in largest reactor: 3,181.96 kmol over 60 hours = 53,032.79 mol/hr
= -277,361 kJ/hr

$Q = C_PmT$
Q = -277,361 kJ/hr
C_P = 38.08 kJ/kmol-K (mostly water in solution)
m = 76129.39 kmol in reactor (water, ethanol, glycerol) (S-132)
T = -0.095 K/hr (Temperature rise)
Over 60 hours, corresponds to adiabatic temperature rise of 5.74 K =
Change from 37 °C to 42.74 °C (or from 98.6 °F to 109 °F)
(This temperature rise is used to determine the heat duty for HX-FERM)

Molecular Sieves:

According to the problem statement, a packaged unit for drying ethanol with molecular sieves costs \$2.5 million for a 34,000 lb/hr pure ethanol basis, with a scaling exponent of 0.6. Our flow rate of ethanol is 39,761.59 lb/hr so:

$$C_P = \left(\frac{39{,}761.59}{34{,}000}\right)^{0.6} (\$2{,}500{,}000)$$

C_P=\$2,746,200

Incremental costs suggested by the problem statement are below:

Incremental Electricity = (.002 kWhr/lb)*(\$.060/kWhr)*(39761.59 lb/hr)

Incremental Electricity = \$4.77139/hr

Incremental Steam =(.04lb/lb)*(\$3.00/1000lb)*(39761.59 lb/hr)

Incremental Steam =\$4.77139/hr

Incremental Cooling Water = (3 gal/lb)*(\$.075/1000 gal)*(39761.59 lb/hr)

Incremental Cooling Water = \$8.94636/hr

Pumps

Modeled as Centrifugal Pumps (Seider 506-514)

$C_p = (566/394)*(C_{pump} + C_{motor})$

$S=Q\ (H)^{0.5}$

Where S = Size Factor

Q = flow rate through the pump (GPM)

H = Pump head (ft)

Pump head calculated from

H=pressure rise/liquid density

Where $\Delta P= (\rho *g/g_c* h)+ 172{,}500$ Pa (corresponds to 25 psi drop across piping)

For pumps with unknown ending fluid heights a pressure change corresponding to 50 psi was used. The pressure rise of the fluid entering the sterilizer heat exchanger network is 45 psi. All other pumps were put in place to continue fluid flow opposing frictional pipe wall forces rather than increasing fluid pressure for processing.

Pump Cost, C_{pump}

$C_{pump} =F_T\ F_M C_B$

F_M =1 for carbon steel

F_T = 1 for 50-900 gpm, 50-400 ft Pump Head

Or F_T =2 for 250-5000 gpm , 50-500 ft Pump Head

$C_B= \exp\{ 9.2951-0.06019*\ln(S) + 0.0519*\ln(S)^2\}$

Motor Cost, C_{motor}

$C_{motor} = F_T\ C_B$

F_T = 1.8, for explosion –proof enclosure 3600 rpm, 1-250 Hp

$C_B = \exp\{ 5.4866 + 0.13141*\ln(P_c) + 0.053255*\ln(P_c)^2 + 0.028628*\ln(P_c)^3 -0.0035549* \ln(P_c)^4\}$

$P_{c,}$ Power Consumption(Hp)=$(QH\ \rho)/(33{,}000\eta_p\eta_M)$

η_p, Fractional efficiency of pump=$-0.316+0.24015*(\ln Q)-0.01199*(\ln Q)^2$

$\eta_{M,}$, Fractional Efficiency of motor=$0.8+0.0319*\ln P_B -0.00182*\ln (P_B)^2$

$P_B=(QH\ \rho)/(3300*\ \eta_p)$

Pumps for Feed Preparation Section						
Pump	P-FP-01	P-FP-02	P-FP-03	P-FP-04	P-FP-05	P-FP-06
Flow rate(L/hr)	35,169.79	151,104.80	927.42	32,356.21	4,832.32	185,192.86
density of stream(kg/L)	1.23	1.00	1.00	1.23	1.36	1.04
Height of column entering(m)		2.06	2.06	2.06	2.74	6.51
density of stream(kg/m^3)	1233.16	1000.00	1000.00	1233.16	1359.00	1036.39
Pressure(Pa) (not incl. 25 psi drop)	0.00	20201.73	20201.73	24912.03	36491.78	66221.38
Head (Pa)	28.55	37.23	19.64	16.32	15.68	40.45
Head (ft)	93.64	122.11	64.43	53.53	51.42	132.66
Flow rate(gallons per min)	154.85	665.31	4.08	142.46	21.28	815.40
S=Q(H^0.5)	1498.45	7351.84	32.78	1042.28	152.57	9391.84
Cp PUMP (carbon steel, CE =394)	$2,140.70	$3,133.98	$2,506.60	$2,035.90	$1,960.30	$3,401.86
Q (gpm)	154.85	665.31	4.08	142.46	21.28	815.40
ηP	0.59	0.74	0.60	0.58	0.31	0.76
density of stream (lb/gal)	10.29	8.35	8.35	10.29	11.34	8.65
PB (Hp)	7.66	27.82	0.11	4.10	1.23	37.55
ηB	0.82	0.83	0.76	0.82	0.80	0.83
PC (Hp)	9.34	33.68	0.15	5.02	1.53	45.43
Cb motor	$531.95	$1,493.51	$177.28	$377.58	$258.31	$1,999.77
Cp motor (CE = 394)	$957.51	$2,688.32	$319.11	$679.65	$464.96	$3,599.59
Cp total (motor + pump) (2009, For Guthrie)	$4,500	$8,400	$4,100	$3,900	$3,500	$10,100

Pumps for Plant Seed Fermentation Train							
Pump	P-101	P-102	P-103	P-104	P-105	P-106	P-107
Flow rate(L/hr)	2600.02	51950.00	62325.00	96683.00	2628.57	53349.40	63293.21
density of stream(kg/L)	1.03	1.04	1.04	1.04	0.96	0.96	0.96
Height of column entering(m)	1.01	2.84	7.56	14.90	2.84	7.56	14.90
density of stream(kg/m^3)	1031.56	1036.39	1036.39	1036.39	964.53	963.45	964.52
Pressure(Pa) (not incl. 25 psi drop)	10182.64	28879.87	76911.28	151526.37	26877.22	71497.87	141018.61
Head=Total P /(density(m)*g)	18.05	19.81	24.53	31.87	21.07	25.82	33.13
Head(ft)	59.21	64.97	80.46	104.53	69.11	84.68	108.68
Flow rate(gallons per min)	11.45	228.74	274.42	425.70	11.57	234.90	278.68
S=Q(H^0.5)	88.09	1843.67	2461.55	4352.40	96.22	2161.52	2905.25
Cp PUMP (CE=394, carbon steel)	$2080.71	$2216.51	$2344.10	$2684.95	$2056.53	$2283.39	$2430.02
Q (gpm)	11.45	228.74	274.42	425.70	11.57	234.90	278.68
ηP	0.20	0.63	0.65	0.70	0.20	0.64	0.66
density of stream (lb/gal)	8.61	8.65	8.65	8.65	8.05	8.04	8.05
PB (Hp)	0.89	6.14	8.84	16.70	0.97	7.60	11.26
ηB	0.80	0.82	0.82	0.82	0.80	0.82	0.82
PC (Hp)	1.12	7.49	10.76	20.25	1.22	9.26	13.68
Cb motor	$245.16	$465.16	$584.22	$945.74	$248.37	$529.16	$692.98
Cp motor (CE = 394)	$441.29	$837.29	$1,051.60	$1,702.34	$447.07	$952.49	$1,247.36
C_{PB} total (motor + pump) (2009)	$3,700	$4,400	$4,900	$6,400	$3,600	$4,700	$5,300

Pumps for Main Fermentation Section					
Pump	P-FA	P-FB	P-FC	P-FD	P-FE
Flow rate(L/hr)	300,300.00	2,820.06	1,525,403.90	178,734.19	25,423.40
density of stream(kg/L)	1.04	0.96	0.96	0.96	0.96
Height of column entering(m)	21.68	21.68	7.81	--	21.68
density of stream(kg/m^3)	1,036.39	964.62	964.55	964.55	964.55
Pressure(Pa) (not incl. 25 psi drop)	220,390.93	205,127.74	73,899.70	172,500.00	205112.2995
Head (Pa)	38.64	39.91	26.04	36.46	18.23045187
Head(ft)	126.75	130.89	85.41	119.59	59.79588214
Flow rate (gpm)	1,322.22	12.42	1,343.27	786.97	111.94
S=Q(H^0.5)	14,886.07	142.06	12,414.37	8,606.11	865.601352
Cp PUMP (CE = 394, carbon steel)	$8,074.50	$1,972.05	$7,527.03	$3,301.40	$3,989.62
Q (gpm)	1,322.22	12.42	1,343.27	786.97	111.94
ηP	0.79	0.21	0.79	0.75	0.55
density of stream (lb/gal)	8.65	8.05	8.05	8.05	8.05
PB (Hp)	55.56	1.86	35.35	30.52	3.58
ηB	0.83	0.81	0.83	0.83	0.81
PC (Hp)	67.22	2.31	42.77	36.94	4.39
Cb motor	$2,984.15	$283.85	$1,883.37	$1,631.59	$329.71
Cp motor (CE = 394)	$5,371.47	$510.93	$3,390.07	$2,936.87	$593.49
Cp total (motor + pump) (2009 For Guthrie)	$19,400	$3,600	$15,700	$9,000	$6,600

Pumps for Separation Section

Pump	P-S-101	P-S-102	P-S-104	P-S-105	P-S-106	P-S-107	P-S-108
Flow rate(L/hr)	174,995.04	180,599	42,441.20	29,396.57	205,879.00	223,070.46	27,022.50
density of stream(kg/L)	0.98	1.00	1.12	0.96	0.80	1.00	1.00
Height of column entering(m)	49.37			49.37	49.38		15.25
density of stream(kg/m^3)	979	1005	1,118	958	803	1,004	1000
Pressure(Pa) (not incl. 25 psi drop)	474,503			464,435	388,922		149602
Head (Pa)	67.33	35.01	31.05	67.78	71.35	35.02	32.87
Head(ft)	220.83	114.85	103.22	222.34	234.03	114.88	107.81
Flow rate(gpm)	770.50	795.00	178.88	129.43	906.49	1,02465	118.98
S=Q(H^0.5)	11,450.12	8,519.70	1,819.64	1,929.98	13,867.49	3,596.49	1,235.36
Cp PUMP (CE =394) Carbon Steel	$3,651.88	$3,290.16	$2,211.35	$2,234.96	$3,926.21	$7,192.98	$2,080.77
Q (gpm)	770.50	795.00	178.88	129.43	906.49	1,024.65	118.98
ηP	0.75	0.75	0.61	0.57	0.70	0.77	0.56
density of stream (lb/gal)	8.17	8.39	9.31	8.00	6.70	8.38	8.35
PB (Hp)	56.16	30.83	8.60	12.28	56.43	38.69	5.81
ηB	0.83	0.83	0.82	0.82	0.83	0.83	0.82
PC (Hp)	67.95	37.31	10.47	14.91	68.28	46.81	7.10
Cb motor	$3,018.12	$1,647.57	$573.60	$739.38	$3,033.11	$2,060.47	$451.25
Cp motor (CE = 394)	$5,432.61	$2,965.63	$1,032.48	$1,330.88	$5,459.60	$3,708.85	$812.24
Cp total (motor + pump) (2009, for Guthrie)	$13,100	$9,000	$4,700	$5,200	$13,500	$15,700	$7,200

Reflux Accumulator:

Reflux accumulators should be designed with mean residence times of 5 min at half full (Seider) so:
Volumetric flow rate =165,300 L/hr

Volume of Reflux Accumulator= (165,300 L/hr)*(1 hr/60 min)*(5 min)*(2)*(0.0353146667 ft^3/L)
V= 606 ft^3
Furthermore, it is typical to design reflux accumulators as horizontal vessels with an aspect ratio of 2, so:
D=2L, or L = D/2.

$$V = \pi\left(\frac{D}{2}\right)^2\left(\frac{D}{2}\right)$$

D = 11.6 ft
L = 5.8 ft
t_s = 0.5 in

The weight follows the vessel costing of the distillation column (see section for D-1)
W = 2,596 lbs

Cost for Horizontal vessel (Seider 527), F_M = 1 for Carbon Steel

$$C_V = \exp\left[8.717 - 0.2330\ln(W) + 0.04333(\ln(W))\right]$$

$$C_{PL} = 1580(D_i)^{0.20294}$$

$$C_P = \left(\frac{566}{394}\right)[F_M C_V + C_{PL}]$$

C_{PB} (2009) = $47,000

Rotary Drum Vacuum Filter:

Mass flow rate of solids in (S-S-109) = 296 kg/hr biomass + (0.5)(927.39 kg/hr CSL)
(CSL is 50% solids)
= 0.082244 kg/s biomass + 0.1288 kg/s CSL solids
= 0.21105 kg/s (mass flow rate solids only)
Total mass flow rate = 47.88 kg/s (total solution)
(0.44 wt % solids)

Area of Rotary Drum Vacuum Filter (Ulrich 222 Table 4-23) based on mass flow rate of solids in kg/s:

$$A\ (m^2) = \frac{\dot{m}}{0.02}$$

A = 10.55 m^2 = 113.58 ft^2

Power consumption range based on area (Ulrich):

$$P\ (kW) = A^{0.75}\ to\ 2A^{0.75}$$

P = 5.85 kW to 11.71 kW.
Average = 8.78 kW = 11.777 HP

Cost of Rotary Drum Vacuum Filter (Seader 555) based on A, the filtration area in ft^2.

$$C_P = \left(\frac{566}{394}\right)\exp\left[11.432 - 0.1905\ln(A) + 0.0554(\ln(A))^2\right]$$

C_P(2009) = $ 184,400

Cake leaving is typically 70% solids. 90% of solids from stream are removed. (Ulrich) These assumptions used to determine the mass flow rates of the cake and filtrate leaving the filter.

Diatomaceous Earth Filter Pre-coat Considerations (Schweitzer 4-13, 4-48):

Recommendation of Filter Pre-coat material Diatomaceous Earth (DE)
Pre-coat lasts 2-4 days = 72 hours average
Plant operational for 330 days/yr* 24 hours/ day = 7920 hr/yr
Pre-coat thickness = 3 – 5 inches = 4 inches average
DE requirement = 2 lb/ ft^2-in
Cost of DE = $ 0.15 / lb

$$\frac{lb\ DE}{yr} = \left(\frac{2\ lb}{ft^2\ in}\right)(4\ in)(113.6\ ft^2)\left(\frac{1}{72\ hr}\right)\left(\frac{7920\ hr}{1\ yr}\right) = 99{,}968\ lb/yr$$

99,968 lb DE/yr * $0.15 /lb = $15,000 / yr for Diatomaceous Earth pre-coat.

Screw Conveyor:

After drying, the stream of succinic acid crystals (463.39 kg/hr) must be transported into the holding tank at a height of 12 feet at a 30 degree angle, yielding a 24 foot long conveyor. Cost equation: (Seider 554)

$$C_P = \left(\frac{566}{394}\right) \$55.6(D)(L)^{0.59}$$

Where D is in inches and L is in feet.
The smallest Diameter system is 6 inches, which can handle up to 75 ft^3/hr, is sufficient for this.

C_P (2009) = $ 12,500.60

For the drive and power requirements (Seider 548):

$$P = 0.0146(\dot{m})^{0.85} + 0.00182(\dot{m})(h)$$

Where is in lb/s and h is in ft.

$\dot{m}$ = (463.39 kg/hr)*(2.2 lb/kg)/(3600 s/hr)
= 0.283183 lb/s
P= 0.126085 Hp, rounded up to a 1 Hp motor (Seider 510)

$$C_B = \exp\left[5.4866 + 0.1314\ln(P) + 0.053255(\ln(P))^2 + 0.028628((\ln(P))^3 - 0.0035549((\ln(P))^4\right]$$

C_B=$ 241.43
C_P=F_T*C_B
F_t=1.3 (from Table 16.22 Seider for 1800 rpm totally enclosed fan cooled motors between 1 & 250Hp)
C_P=$ 313.86
C_P(2009) = $ 313.86/394*566
C_P(2009) = $ 450.88
C_{PB}(2009) Total (Motor + conveyor) = $ 13,000

Spray Nozzles for Clean-In-Place System

As per recommendations by industrial consultant Mr. Bruce Vrana, spray nozzles will be purchased to supply caustic to the large fermenter tanks for the Clean-In-Place system. Mr. Vrana recommends purchasing spray nozzles from supplier Gammajet, at $10,000 per nozzle. His recommendation is 4 nozzles per 2,000,000 L tank, for a total of 48 nozzles in the main fermentation section. Additionally, the largest seed fermenters Seed Ferm 7A/B will use 3 nozzles per tank, for a total of 6 spray nozzles.

Storage, Mixing, and Holding Tanks

All Storage Tanks: Height: Diameter Aspect Ratio = 1:3.
T-110 has Height: Diameter Aspect Ratio of 2:1 (Solids contained)

Crude Glycerol Storage Tank (T-101), Corn Steep Liquor Storage Tank (T-103), and Gasoline Storage Tank (T-109) and hold a 3 -day supply of feedstock. Brine Storage Tank (T-104) has a one day supply. Denatured Ethanol Holding Tank (T-111) holds a 3 day supply of product (Seider). Succinic Acid Holding Tank (T-110) holds a 3 day supply of product. All tanks have a working volume of 80%.

Mixing Tank (T-105) has a residence time of 10 minutes. Mixing Tank (T-108) has a residence time of 10 minutes. Mixing tanks have a working volume of 50%.

Intermediate holding tanks between the continuous and batch processes:
T-106 volume calculation:
(Amount of feed required for initializing one batch) + (Amount of feed entering tank continuously x time for charging fermenter with feed – Amount of feed leaving during charging) / 0.8 (for 80 % working volume)

Or volumes from stream tables:
[(S-S-115) + (S-FP-112 x 5 – S-S-115)]/0.8

T-107 volume calculation:
(Amount of feed from one FERM1 tank) + (Amount of feed from one FERM1 tank - Amount of feed leaving tank continuously x amount of time for draining tank) / 0.8 (for 80 % working volume)

Or volumes from stream tables:
[(S-S-137) + (S-S-137 – S-140 x 5)]/0.8

T-101, T-106, T-107, T-108, T-109, T-111 modeled as a Floating Roof Tank (Volatiles)
T-103, T-104, T-105, T-110 modeled as Cone Roof Tank (Non-volatiles)
Floating Roof Tanks (Seider 555) with V in gallons :

$$C_p = (566/394)*375*V^{0.51}$$

Cone Roof Tanks (Seider 555) with V in gallons :

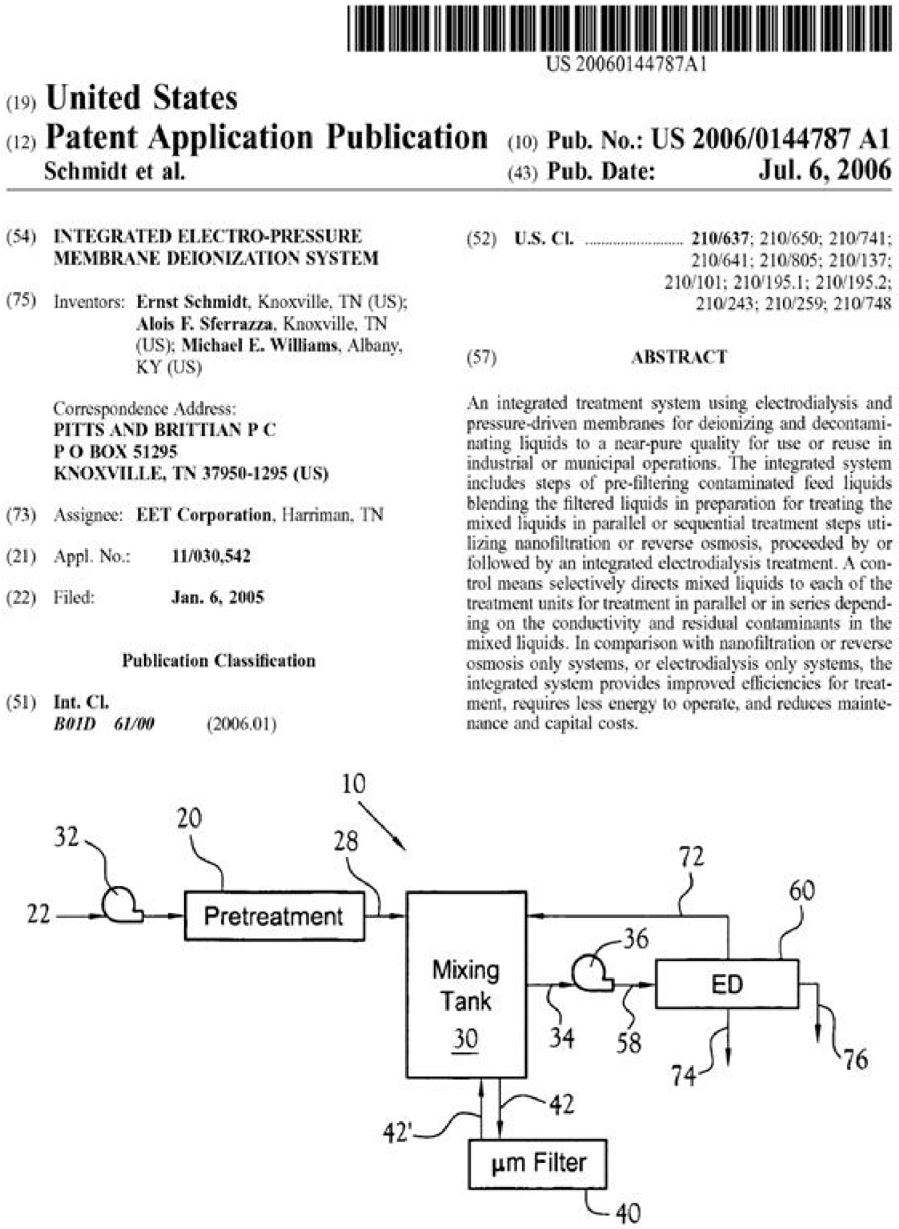
$$C_p = (566/394)*210*V^{0.51}$$

Floating Roof Storage Tanks						
	T-101	T-106	T-107	T-108	T-109	T-111
Volume(L)	3,165,281.51	1,157,455.63	3,370,526.25	7,619.58	41,145.75	2,057,287.39
Volume(gal)	836,178.75	305,700.91	890,205.14	2,012.88	10,869.55	543,477.73
Volume (m^3)	3,165.28	1,157.46	3,370.53	7.60	41.15	2,057.29
Diameter (m)	22.95	5.47	23.44	3.07	5.40	19.88
Height(m)	7.65	16.41	7.81	1.02	1.80	6.62
Cp (2009)	$564,600	$338,000	$582,900	$26,800	$101,000	$453,300

Cone Roof Storage Tanks				
	T-103	T-104	T-105	T-110
Volume(L)	83,467.68	144,969.67	61,730.95	26,477.50
Volume(gal)	22,049.82	38,296.93	16,307.59	6994.61
Volume(m^3)	83.47	144.97	61.73	26.47
Diameter(m)	6.83	8.21	6.18	19.88
Height(m)	2.28	2.74	2.06	1.04
Cp	$49,600	$65,700	$42,500	$27,600

Appendix C.

R-101 Glycerol Purification System Patent Application



US 20060144787A1

(19) **United States**
(12) **Patent Application Publication** (10) **Pub. No.: US 2006/0144787 A1**
Schmidt et al. (43) **Pub. Date: Jul. 6, 2006**

(54) **INTEGRATED ELECTRO-PRESSURE MEMBRANE DEIONIZATION SYSTEM**

(75) Inventors: **Ernst Schmidt**, Knoxville, TN (US); **Alois F. Sferrazza**, Knoxville, TN (US); **Michael E. Williams**, Albany, KY (US)

Correspondence Address:
PITTS AND BRITTIAN P C
P O BOX 51295
KNOXVILLE, TN 37950-1295 (US)

(73) Assignee: **EET Corporation**, Harriman, TN

(21) Appl. No.: **11/030,542**

(22) Filed: **Jan. 6, 2005**

Publication Classification

(51) **Int. Cl.**
B01D 61/00 (2006.01)

(52) **U.S. Cl.** **210/637**; 210/650; 210/741; 210/641; 210/805; 210/137; 210/101; 210/195.1; 210/195.2; 210/243; 210/259; 210/748

(57) **ABSTRACT**

An integrated treatment system using electrodialysis and pressure-driven membranes for deionizing and decontaminating liquids to a near-pure quality for use or reuse in industrial or municipal operations. The integrated system includes steps of pre-filtering contaminated feed liquids blending the filtered liquids in preparation for treating the mixed liquids in parallel or sequential treatment steps utilizing nanofiltration or reverse osmosis, proceeded by or followed by an integrated electrodialysis treatment. A control means selectively directs mixed liquids to each of the treatment units for treatment in parallel or in series depending on the conductivity and residual contaminants in the mixed liquids. In comparison with nanofiltration or reverse osmosis only systems, or electrodialysis only systems, the integrated system provides improved efficiencies for treatment, requires less energy to operate, and reduces maintenance and capital costs.

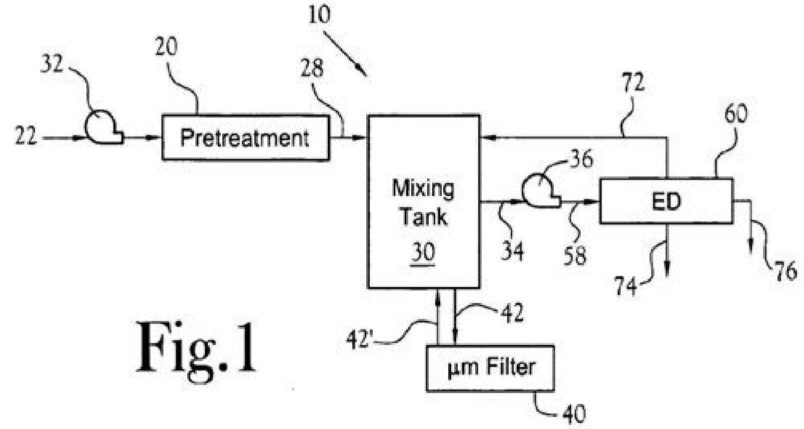


Fig.1

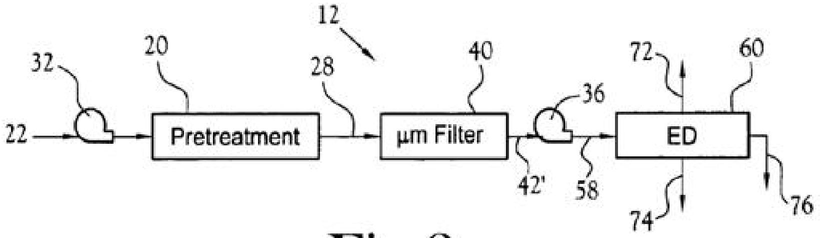


Fig.2

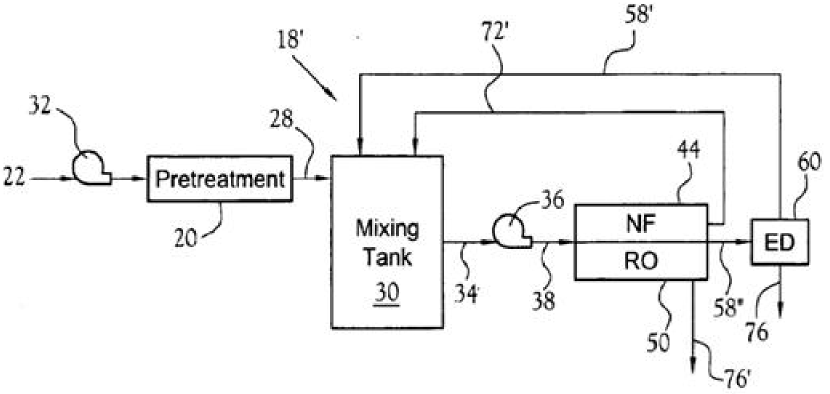


Fig.5B

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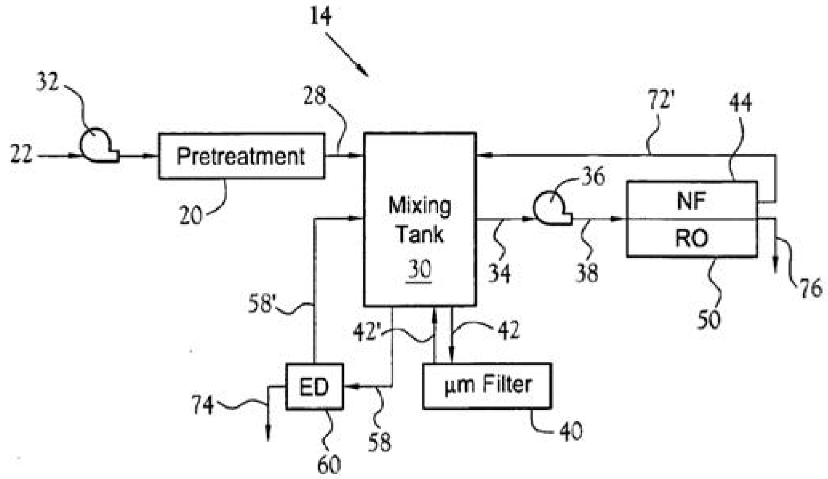

Fig.3

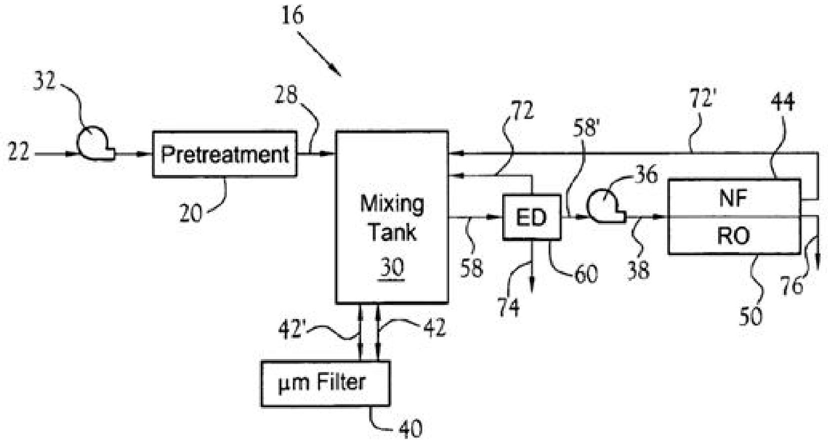

Fig.4

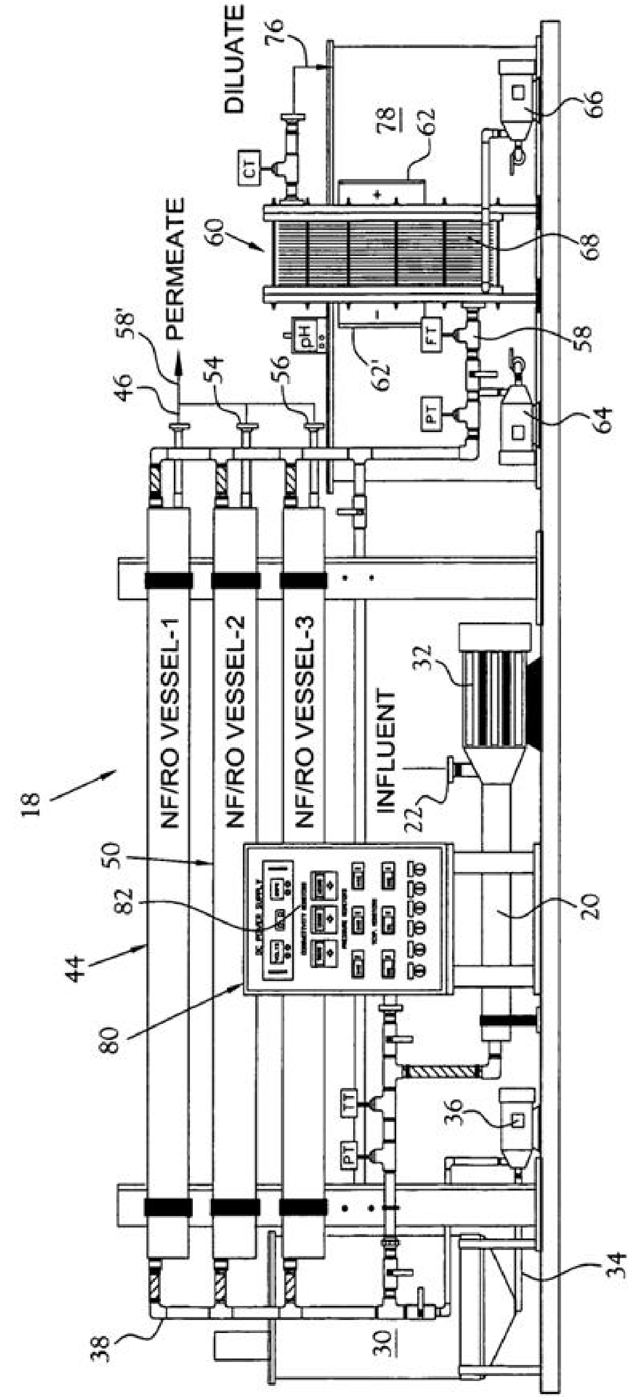
DILUATE
76
CT
78
62
+
PERMEATE
60
68
58'
46
54
56
pH
62'
-
FT
58
PT
64
66
18
NF/RO VESSEL-1
NF/RO VESSEL-2
NF/RO VESSEL-3
50
82
44
80
INFLUENT
22
32
20
TT
PT
36
34
38
30

Fig.5A

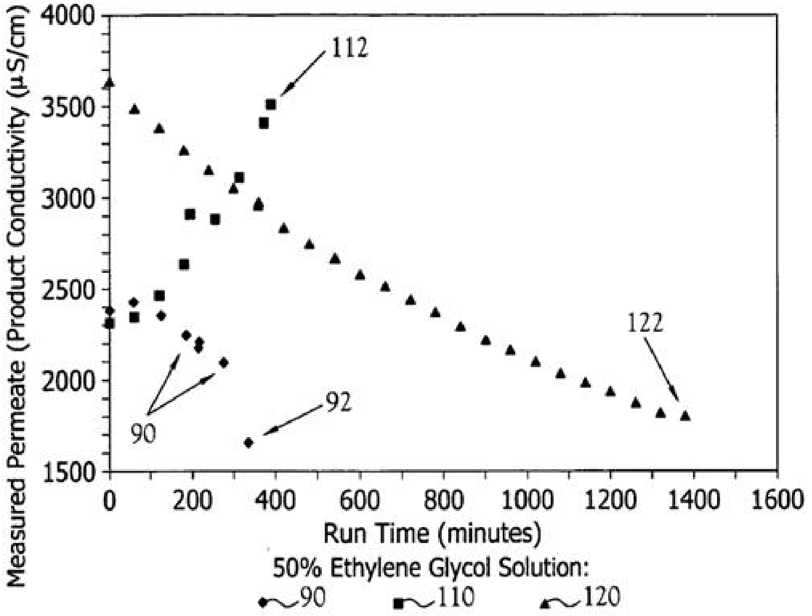
4000
3500
3000
2500
2000
1500
Measured Permeate (Product Conductivity (µS/cm)
0
200
400
600
800
1000
1200
1400
1600
Run Time (minutes)
112
122
90
92
50% Ethylene Glycol Solution:
90
110
120

Fig.6

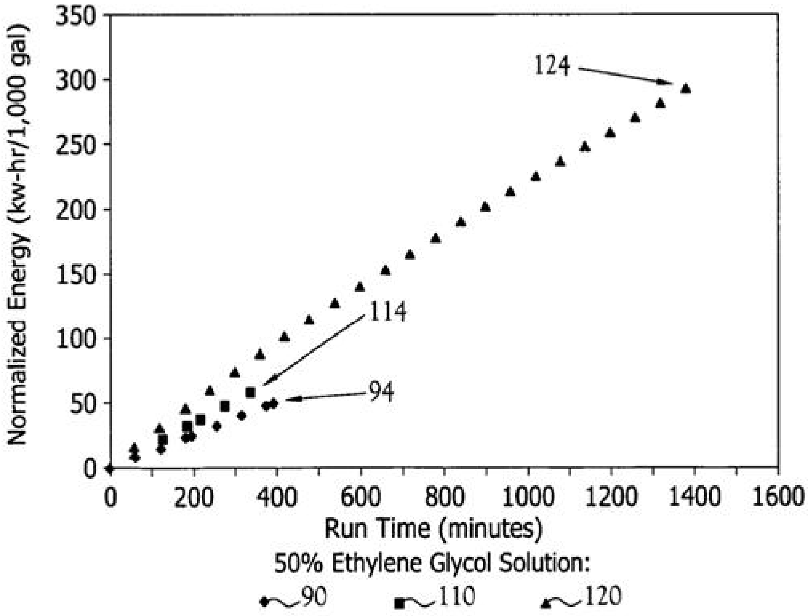
350
300
250
200
150
100
50
0
Normalized Energy (kw-hr/1,000 gal)
0
200
400
600
800
1000
1200
1400
1600
Run Time (minutes)
124
114
94
50% Ethylene Glycol Solution:
90
110
120

Fig.7

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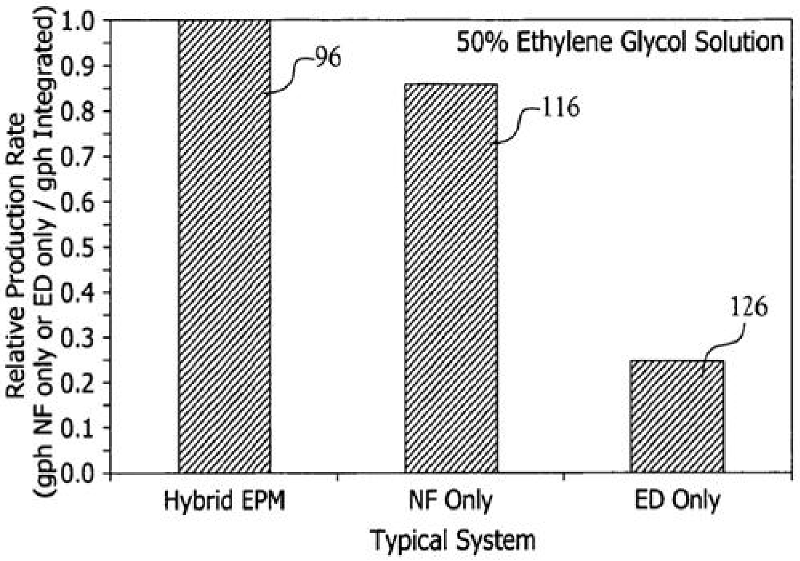

Fig.8

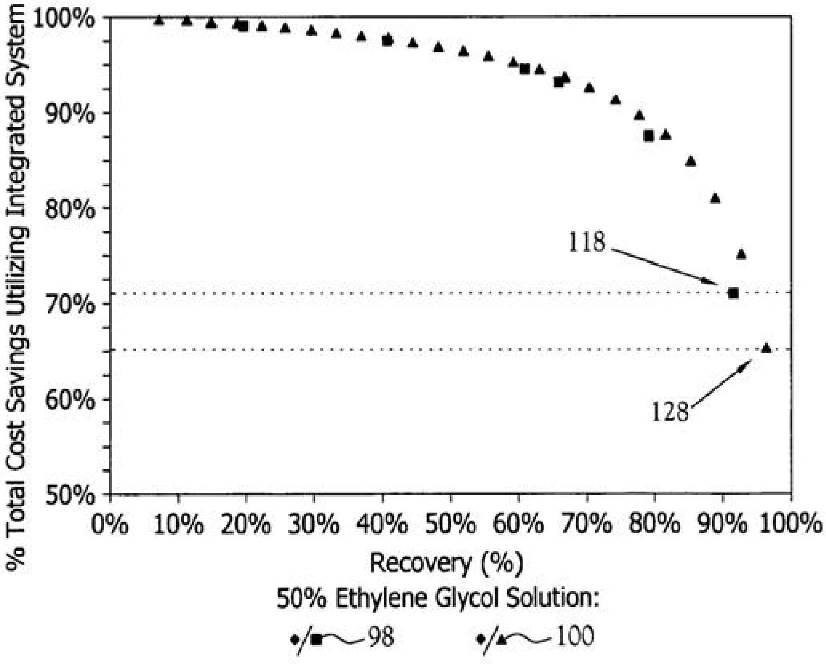

Fig.9

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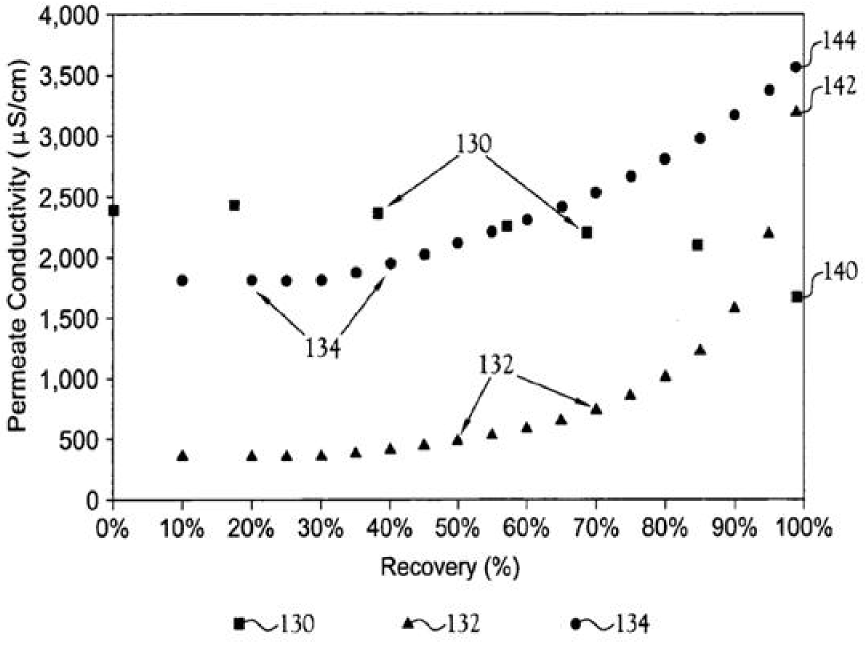


Fig.10

INTEGRATED ELECTRO-PRESSURE MEMBRANE DEIONIZATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable.

BACKGROUND OF THE INVENTION

[0003] 1. Field of Invention

[0004] The invention pertains to a system for purification of contaminated liquids. More particularly, this invention pertains to a system for treatment utilizing a plurality of electric-driven membranes and pressure-driven membranes in a plurality of integrated configurations for removal of contaminants and deionization of liquids.

[0005] 2. Description of the Related Art

[0006] In many areas of the world, treatment of saline water and industrial wastewater is necessary to obtain adequate and protect existing supplies of drinking water. In highly developed countries, recycling of waste liquids generated by industry is required by government regulations, and/or is preferred by industry to maximize recovery of useful liquids, to reduce costs of feed liquids, and to minimize waste discharge.

[0007] Currently, a number of systems are utilized for desalination and deionization applications, and for treating aqueous waste streams and aqueous/organic mixtures, including membrane-based technologies, distillation and evaporation, and ion exchange. Membrane-based desalting technologies may be categorized as pressure-driven reverse osmosis (RO) and nanofiltration (NF) and electrically-driven electrodialysis (ED). RO, NF, and ED have commonality in that these processes use semi-permeable membranes as key elements in performing the separation, resulting in significant energy savings compared to thermal processes such as distillation or evaporation, and substantial operational cost savings compared to ion exchange resin methods.

[0008] The pressure driven processes ultrafiltration (UF), RO, and NF rely on a semi-permeable membrane to separate one component of a solution from another by means of size exclusion, preferential transport, and pressure. UF typically rejects organics over 1,000 molecular weight (MW) while passing ions and small organics along with water, while RO provides separation of both ions and many small organics. NF provides separation in the range between UF and RO. NF membranes have a wide range of performance characteristics but typically reject organic solutes on the order of a nanometer or 10 angstroms in size as well as larger, highly charged multivalent ions such as sulfate and phosphate. NF will typically not efficiently retain or reject smaller species like chloride and organic acids

[0009] UF, NF, and RO systems provide varying filtration and separation efficiencies but many times may lack the ability to economically produce a deionized product liquid of sufficient quality or quantity for reuse in industry, discharge, or municipal use; additional treatment may also be required as some components of the liquid may fall outside the operating ranges where separations are the most efficient and economically feasible for these membrane processes

[0010] NF and RO processes have been widely utilized for a range of desalination and deionization applications, but product recovery has a major impact on the economics of pressure-driven membranes and limits process applicability. Furthermore, pressure-based membranes have several inherent technical and economical limitations to achieving high feed recoveries, the most severe of which is the osmotic pressure of the feed solution that has to be overcome by the applied hydrostatic (feed) pressure. The osmotic pressure of saline solutions such as brackish water and seawater can be significant. Moreover, since the osmotic pressure is determined by the salt concentration directly at the membrane surface, it can be affected by concentration polarization, which is the build-up of salt near the surface of the membrane due to incomplete mixing of the surface boundary layer fluid with the bulk solution, a phenomenon accentuated by high pressure fluid passing through the membrane material. Although concentration polarization can be minimized by design and operating parameters, it can never be completely excluded and must be overcome by increased applied hydrostatic (feed) pressure, particularly as feed recovery is increased. Overcoming high osmotic pressures and concentration polarization resulting from higher recoveries requires not only substantial energy to produce the necessary higher pressures and flow rates but also additional investment in capital cost for additional membrane area and pumping capacity. It can also result in shorter useful life of the membrane due to compaction effects and enhanced fouling that can occur at higher pressures and recoveries as a result of the concentration of scaling components near the surface of the membrane, particularly for membrane elements near the end of the process line where overall water recoveries are higher. Enhanced fouling increases the required frequency of membrane cleaning, increasing labor and chemical cost, and reducing throughput. For feeds with total dissolved solids (TDS) levels typical of seawater, recoveries approaching and beyond 50% are seldom feasible; for brackish water levels of TDS, recoveries beyond 80% are rarely economical, resulting in substantial waste of pretreated feed that must be returned to the source or alternately disposed.

[0011] Furthermore, membrane process equipment size is determined according to feed or concentrate flow requirements and decreases with increased recovery rate and lower feed concentration; conversely, pressure based membranes perform optimally, producing the best product quality and highest permeate flux rates, with low recoveries and low concentration feeds. Energy requirements are also directly related to feed pressures and feed water flow rates necessary to achieve a particular recovery. The design permeate flux rate predicted at a particular recovery likewise affects the number of pressure vessels, manifold connections, and size of membrane skid, as well as the size of the feed water supply systems and pretreatment equipment that are necessary.

[0012] Consequently, it is clear that a critical parameter that has the largest effect on investment and operating cost for pressure-driven membrane methods in most applications is the recovery rate ratio of permeate to feed. The feed flow is inversely proportional to the design recovery rate; therefore, the recovery rate directly affects the size and cost of all process equipment and power consumption. Higher recovery rate also contributes to reduced pretreatment capital cost and chemicals used. However, higher recoveries can increase membrane replacement cost as a result of fouling and compaction. Furthermore, pressure based membrane systems inherently perform better at lower feed concentrations and lower recoveries in which the osmotic pressure of the feed and its fouling and scaling potential are minimized.

[0013] In an electrodialysis (ED) process, separation, removal, or concentration of ionic species is accomplished by the selective transport of the ions through ion exchange membranes under the influence of an electrical field. Flowing through the series of anion and cation exchange membranes arranged in an alternating pattern between the electrodes having an electrical potential difference, the water diluate (D) feed stream (e.g., seawater for desalination), concentrate (C) stream, and electrode (E) stream are allowed to circulate in the appropriate cell compartments. Under the influence of the electrical potential difference, the negatively charged chlorides, sulfates, and other anions in the diluate (D) stream migrate toward the anode. These ions pass through the positively charged anion exchange membrane, but are rejected by the negatively charged cation exchange membrane and therefore stay in the C stream, which becomes concentrated with the ionic contaminants. The positively charged species such as sodium and other metals in the D stream migrate toward the cathode and pass through the negatively charged cation exchange membrane. These ions also stay in the C stream, being rejected by the anion exchange membrane. The E stream is the electrode stream (e.g., a sodium sulfate solution), which does not become contaminated with any ionic species from the diluate or concentrate streams, although small amounts of hydrogen are generated at the cathode and oxygen at the anode which are subsequently dissipated as the E streams are combined to maintain a neutral pH in the E stream holding tank. The overall result of the ED processing is an ion concentration increase in the concentrate stream with a depletion of ions in the diluted feed stream.

[0014] Multi-cell electrodialysis (ED) process stacks are generally built of membrane sheets separated from each other by suitably configured gaskets. For efficient separations, the distance (gap) between the sheets is as small as possible. In most designs, a spacer is introduced between the individual membrane sheets, both to assist in supporting the membrane and to help control the liquid flow distribution. The ED process stacks are typically assembled in the same fashion as a plate-and-frame filter press, the gaskets corresponding to the frames and the membrane sheets corresponding to the plates. The ED process stack configurations include flow channels for distribution of liquids to be treated to each of various layered compartments which are formed by ingenious patterns of mating holes and slots through the gaskets and the membranes prior to assembly of the ED process stack (see U.S. Pat. No. 6,537,436, Schmidt et al.).

[0015] In typical ED process stacks, the flow pattern within each compartment (i.e., between any two successive membranes) is determined by the configuration of the gasket and spacer elements used between the membranes. Two distinctively different flow arrangements are typically used. One is known as a tortuous-path design which can incorporate pressure differentials of up to about 125 pounds per square inch between inflow/outflow portions of the ED unit, while the other flow arrangement makes use of a sheet-flow principle which can incorporate pressure differentials up to about 50 pounds per square inch between inflow/outflow portions of the ED unit. ED process stacks include limitations to constant operation at high efficiencies. One design problem for both flow arrangements for multi-membrane and multi-cell stacks is that of assuring uniform fluid flow to the various compartments and effective transport of the separated ionic constituents to the membrane surfaces for removal from the ED process stack. These difficulties are obstacles to economical demineralization.

[0016] ED also has inherent limitations, working best at removing low molecular weight ionic components from a feed stream. Non-charged, higher molecular weight, and less mobile ionic species will not typically be significantly removed. This can be a disadvantage when potable water is produced from feed water sources having high suspended solids content or which are contaminated by microorganisms, which would require additional pre-treatment processes for removal prior to ED processing.

[0017] Furthermore, the concentration that can be achieved in the ED brine stream (concentrate or "C" stream) is limited by the membrane selectivity loss due to the Donnan exclusion mechanism and water transport from the dilute to the brine caused by osmosis; in particular, at very high concentrations, diffusion of ions from the concentrate stream back into the diluate stream and transport of water across the membranes can offset separation resulting from the applied electric potential, resulting in a poor (i.e., higher ion concentration than desired) product. However, in general, significantly higher brine concentration can be achieved by ED than by RO and the problem of scaling (i.e., precipitation of insoluble di- or multi-valent salts such as calcium sulfate) is less severe in ED than in RO since mono-valent ions are in general transported through the ion exchange membranes faster than multi-valent ions, resulting in a brine less concentrated in the multi-valent ions and so having less scaling potential. In contrast to RO, ED becomes less economical when extremely low salt concentrations in the product are required, as the current density becomes limited and current utilization efficiency decreases as the feed salt concentration becomes lower: with fewer ions in solution to carry current, both ion transport and energy efficiently greatly declines. Consequently, comparatively large membrane areas are required to satisfy capacity requirements for low concentration (and sparingly conductive) feed solutions.

[0018] Furthermore, at low feed concentrations, the reduction of ionic concentration polarization becomes an important design issue for ED membranes. Ionic concentration polarization is the reduction of ion concentrations near the membrane surface compared to those in the bulk solution flowing through the membrane compartment. With substantial ionic concentration polarization, electrolytic water splitting occurs due to the deficiency of solute ions adjacent to the membranes that carry the requisite electric current needed for ED membrane operation. The electrolytic water splitting is detrimental to ED process stack efficiency because of the tendency of ionic concentration polarization to occur at the membrane surface due to the hydrodynamic characteristic of channel flow providing thin viscous boundary layers adjacent to confining surfaces (i.e. adjacent membranes). The thin viscous boundary layers impose a resistance to passage of ions much greater than that of a layer of like thickness in a turbulent area of channel flow, and hence increase the likelihood of ionic concentration polarization at the membrane surfaces. Ionic concentration polarization is objectionable due to an inefficient increase in energy consumption without increasing removal of ionic constituents, requiring increased membrane area, along with pH changes in the feed and concentrate streams due to water splitting causing scale deposition in ED stacks.

[0019] In general, additional membrane area can be included in an ED process stack to counteract low separation efficiencies. However, the number of cells in an ED stack is limited by practical considerations of assembly and maintenance requirements. Since the failure of a single electrodialysis (ED) membrane can seriously impair stack performance, the necessity to be able to disassemble and reassemble a stack to replace membranes, and the necessity to be able to perform this quickly and easily, effectively limits the number of membranes that can be practically utilized in a stack. As a result, it is often desirable to use several smaller modular-size ED stacks rather than one large ED stack by using several small subassemblies having about 50 to 100 cell pairs (CP), and arranging as many as 10 of these subassemblies in series in a single clamping press. However, such a configuration increases capital costs and makes the process less economically feasible.

[0020] An alternative to utilizing modular-size ED stacks or NF or RO alone for separations is to use ED, UF, microfiltration (MF), RO, NF, distillation, evaporation, and other processes in combination with or as a pretreatment in various configurations. However, each process has drawbacks as discussed hereinabove, and prior utilized hybrid systems (e.g., RO coupled with distillation) for increased recovery have been treated as individual unit operations arranged in series sequence, with no interdependence (e.g., RO concentrate only affects operation of the distillation unit, with no reciprocal impact), with each individual process retaining its individual drawback (e.g., low recovery of RO, high operating cost of distillation.

[0021] Due to the inadequacies of each of the separate NF, RO and ED treatment systems for deionization, there exists a need for an integrated approach to deionization systems utilizing multiple types of highly efficient liquid treatment subunits including electrodialysis (ED) membrane units operated in integrated configurations with nanofiltration (NF) and/or reverse osmosis (RO) units as determined by an operator, with the feed liquids for each subunit being channeled through at least one mixing unit in order to blend numerous liquid streams into feed liquid streams having constituents optimized for removal of both TDS solids and ionized constituents by the integrated deionization system. The current invention is not a traditional hybrid process, but instead is an integral process, overcoming limitations inherent to both single processes by integrating the two individual unit processes into a single interdependent system. This integrated, interdependent system allows both the pressure-based membranes and ED membranes to operate at the optimum efficiency point of each, with both systems' operation configured to be optimally affected and enhanced by the presence of the other system.

BRIEF SUMMARY OF THE INVENTION

[0022] In accordance with the present invention, an integrated electro-pressure membrane (EPM) system is provided for treating contaminated feed liquids in order to generate decontaminated and deionized product liquids for use or for reuse in place of "virgin" liquids. The EPM system includes a pre-filtering step for the contaminated feed liquids, followed by blending the filtered liquids in a mixing unit, followed by any one of a plurality of treatment steps utilizing a NF treatment unit or a RO treatment unit operated in conjunction with an ED unit and the mixing unit.

[0023] Each disclosed embodiment of the integrated EPM system includes a central control means for an operator to control the fluid flow through respective filtering and treatment units in a parallel fluid flow configuration utilizing NF or RO units, with recirculation of reject liquid streams to at least one ED subunit. The EPM system is also readily operated in a sequential fluid flow configuration providing continuous flow through a pretreatment filtration unit, at least one ED unit, and a NF or RO unit. When operated in the sequential mode, the control means is adjustable to vary the voltage intensity supplied to the electric-driven membranes of the ED unit when a high purity decontaminated and deionized product liquid is desired.

[0024] The plurality of treatment units are maintained in fluidic interconnection and include a pretreatment unit, at least one mixing tank unit, at least one pretreatment filter unit, and one or more combinations of (a) a nanofiltration unit, or (b) a reverse osmosis unit, in combination with an electrodialysis unit disposed in fluid communication in series or parallel orientation. An operator provides input signals by control means for routing fluid flow through any one or more of the subunits (a) NF, (b) RO and/or (c) ED for generation of a product which is approximately 99% recovered relative to the input waste stream, a substantial improvement over the 70 to 96% recovery possible with conventional systems.

[0025] One embodiment of a membrane-based system for treating contaminated feed liquids includes an initial step of providing a pretreatment filtration unit through which contaminated feed liquids are filtered with a selected volume of pretreated filtrate liquid being channeled to a mixing unit for mixing with additional pretreated and recycled filtrate liquids. A step of transferring includes transferring through appropriately sized fluid conduits a selected volume of the mixed pretreated filtrate liquids to a second treatment unit consisting of an ED unit, a nanofiltration unit, or a reverse osmosis unit. If the second treatment unit is an ED unit, the pretreated filtrate liquids are electrically activated and are directed along a tortuous fluid path between a plurality of ED membranes, spacers, and gaskets whereby an ionic concentrate liquid is separated and removed from the filtrate liquids forming a decontaminated product liquid; channeling the ionic concentrate liquid for mixing with a diluate liquid stream and directing the liquid mixture through a pressure driven membrane unit providing pressure induced liquid transfer across permeable membranes while excluding passage of a specified size or ionic charge of contaminants by the pressure driven membrane unit to generate a decontaminated liquid for storage, and a concentrated reject liquid redirected to the mixing unit for blending and additional treatment in the NF or RO units, or in the ED unit, depending on constituents remaining in the blended concentrated reject liquid.

[0026] Feed rate to the surge tank and permeate flow rate out of the system can be constant, thus making it a continuous process, or feed to the tank can be batch-wise added, making the system a semi-continuous process. Feed and product salinity may be controlled as desired by adjusting ion-exchange membrane and pressure membrane areas of the ED unit and the NF or RO unit, respectively, to continuously remove and concentrate the desired mass of salt necessary to optimize performance of the EPM system. Furthermore, in addition to optimizing the respective ED and NF or RO membrane areas, the selection of membrane types for the ED, NF, or RO best suited for the particular desalting application's performance specifications, and offering the operational synergy between the ED and NF or RO units, provides the basis for optimizing the EPM system to provide the least cost and/or highest performance, integral desalting system. Consequently, this integrated apparatus and method may be used to retrofit and optimize performance of existing NF and RO treatment systems.

[0027] Furthermore, the proposed current EPM process also eliminates the need for additional staging of both NF or RO as well as the ED component, which differs from other desalting processes in the degree of desalting achieved in a single stage. NF or RO or ion exchange desalination may require more than one pass to achieve desired product quality. In ED the degree of desalting will usually be limited to 50% per pass, and some type of staging is needed for further desalting. This is normally achieved by passage through additional stacks or internal electric and/or hydraulic stages in one stack assembly. Batch recirculation is simplistic and the least capital cost intensive arrangement. Batch recirculation with ED alone however is less effective because of the lack of steady state, the high power requirements, and variable current density necessary. Variable current density leads to current efficiencies outside of the optimal range in stand alone ED processes. The novel integrated EPM process overcomes this limitation where a constant state of high current utilization efficiency may be maintained.

[0028] Another advantage of the proposed invention is that a more optimum feed concentration is maintained for both units, ED and NF or RO of the process. In the traditional continuous NF or RO system, as permeate is recovered, increased salt concentration is fed to the next membrane element in the system, resulting in decreased flux and lower product quality from that element. In a batch system in which concentrate from the NF or RO elements is returned to the feed tank, the concentration in the feed tank also increases over time, resulting in decreased water permeate flux and product quality for all membrane elements in the system. In the current invention, both in continuous and batch operation, the coupled ED unit works to decrease the concentration in the feed tank, resulting in a feed to the NF or RO unit with lower salt concentration, thus allowing higher permeate flux and product quality. In addition, as concentrate from the NF or RO unit is returned to the surge tank, it helps to maintain a constant salt concentration in the tank, allowing feed concentration to the ED unit to be maintained at a level sufficient to provide good current efficiencies for transport of ions. Consequently, both systems operate in the more optimum and energy efficient range for maximizing production and product quality.

[0029] A further benefit of the EPM process is that scaling components and subsequent NF or RO scaling is minimized. The ED unit actively transports multi-valent ions such as calcium and sulfate across the ED membranes, maintaining these at a constant or lower level than would be observed if NF or RO alone with multiple stages or concentrate recycle were employed. As a result, reduced concentrations of multi-valent ions such as calcium and sulfate which tend to scale and foul NF or RO membranes are reduced, leading to improved production rate and permeate characteristics, increasing the time required between cleaning operations, and providing longer NF or RO membrane life.

[0030] Another benefit of the current invention is that improved recoveries are possible compared to NF or RO only systems. Recoveries as high as 99+% are possible using EPM since the feed concentration is maintained at relatively constant level due to the combined separation actions of each sub-system. Since feed concentration is relatively constant, the osmotic pressure, and so productivity, of the NF or RO membranes remain constant over the entire processing time (for batch) or recovery range (for continuous systems), allowing almost complete reclamation of the feed. The resulting enhanced recovery can greatly improve the economic feasibility and cost effectiveness of a variety of desalination operations. Cost components of interest affected by improved recovery include pretreatment costs, value of recovered product, cost of disposal of concentrate, capital cost, and energy cost required to perform the additional recovery.

[0031] Another advantage of the current invention is improved product quality compared to NF or RO or ED only systems. Since the feed concentration is relatively constant over the whole range of recoveries, the rejection of the salts and productivity of the NF or RO remains constant, resulting in improved permeate product compared to NF or RO only systems in which the permeate product quality would decrease as a function of recovery.

[0032] Another advantage is lower energy requirements compared to ED only systems. While ED only systems are capable of 99+% recovery, treatment to achieve low concentrations or treatment of dilute or sparingly conductive solutions results in low energy efficiencies and the need for decreased production rate or increased membrane area and capital costs. The EPM integrated system ensures that each sub-system operates in the feed concentration range where it is most energy efficient and removal effectiveness for each subsystem is optimal, resulting in lower energy operating costs.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0033] The above-mentioned features of the invention will become more clearly understood from the following detailed description of the invention read together with the drawings in which:

[0034] **FIG. 1** is a flow diagram of one embodiment of a typical ED only system for comparison with the present invention, illustrating pretreatment and recycling operations with an ED unit coupled with microfiltration;

[0035] **FIG. 2** is a flow diagram of another embodiment of a typical ED only system of **FIG. 1**, including flow through pretreatment filtration and pressurized filter treatment in conjunction with an ED unit;

[0036] **FIG. 3** is a flow diagram of the current invention EPM system, including parallel operation of an ED unit, a filtration unit, and a NF or RO unit with a single mixing tank serving as feed to both units;

[0037] **FIG. 4** is a flow diagram of an additional embodiment of the EPM system of **FIG. 3** including sequential liquid flow through an ED unit and a NF or RO unit with a single mixing tank serving as feed to both units;

[0038] **FIG. 5A** is a schematic view of one embodiment of an EPM system illustrating a plurality of liquid treatment units including a NF/RO unit and an ED unit controlled by a central control means;

[0039] **FIG. 5B** is a flow diagram of the embodiment of **FIG. 5A**, including sequential liquid flow through a NF or RO unit and an ED unit controlled by a central control means;

[0040] **FIG. 6** is a graphical representation of reduction in product conductivity of permeate by an integrated EPM system compared to a NF only system or an ED only system;

[0041] **FIG. 7** is a graphical representation of energy use by an integrated EPM system during generation of permeate compared to a NF only system or an ED only system;

[0042] **FIG. 8** is a graphical representation of relative production rate for an integrated EPM system treating feed liquids of about 50% ethylene glycol compared to a NF only system or a ED only system;

[0043] **FIG. 9** is a graphical representation of total cost savings for an integrated EPM system compared to a NF only system or an ED only system; and

[0044] **FIG. 10** is a graphical representation of permeate conductivity verse recovery for an integrated EPM system compared to a NF only system or an ED only system.

DETAILED DESCRIPTION OF THE INVENTION

[0045] In the embodiments illustrated in **FIGS. 3, 4, 5A**, and **5B** of the integrated electro-pressure membrane (EPM) systems **14, 16, 18**, and **18'**, provide treatment of contaminated feed liquids **22** such as glycol based thermal transfer liquids in which ionized constituents are present along with metals and other insoluble contaminants and soluble or colloidal contaminants. Typical candidates for treatment by an EPM system includes feed liquids such as industrial wastewaters, industrial-grade spent ethylene glycol, other glycol/water mixtures used in vehicular engine coolant systems, out-of-specification liquids from pharmaceutical production, and/or waste organic chemicals from petrochemical industries including certain solvent liquids deemed valuable if recovery and recycling of the solute and solvent are not cost-prohibitive. Desalination of brackish water and seawater is also a possible application. Furthermore, the EPM process should not be limited to use of ED as minor modifications through the use of bi-polar membranes to recover acids and bases from corresponding salts is possible. Similarly, the EPM process may employ non-conventional electro-deionization methods, for instance continuous deionization (CDI), in conjunction with NF or RO as well.

[0046] Membrane-based deionizing technologies may be categorized as pressure-driven membrane units, UF, NF and/or RO, and as electrical-driven ED units. Operation of a pressure-driven process utilizes a plurality of semi-permeable membranes to separate one constituent of a solution from another by means of constituent size exclusion and pressure. A filtration unit **20** having at least one filtration membrane, and/or filtration media such as layers of screens or porous material, is typically utilized with sufficient pore diameters to deny passage of insoluble particles, oils and/or organics over 1,000 molecular weight (MW), and optimally operates for selective separation of constituents in a range between about 30 Angstroms (Å) to about 1000 Å, while passing smaller ions along with water. A RO unit **50** is typically utilized for separation of constituents in the range between about 1 Å to about 20 Å. A RO unit **50** is typically operated at pressures of about 200 to about 1000 pounds per square inch maintained between inflow/outflow portions of the RO unit **50**. A NF unit **44** is typically utilized to provide separation of ions and selected organic compounds from water in a size range between UF and RO treatment. NF membranes have a wide range of performance characteristics and typically provide removal of constituents in a range between about 8 Å to about 200 Å, depending on the selectivity of the NF membranes. A pressure-driven NF unit **44** is typically operated to maintain fluid pressures between about 50 pounds per square inch to about 1,000 pounds per square inch maintained between inflow/outflow portions of the NF unit **44**. One preferred EPM system includes a NF unit **44** or a RO unit **50** capable of operations to maintain fluid pressures between about 50 pounds per square inch to about 400 pounds per square inch for low pressure fluid treatment applications. Another preferred EPM system includes a NF unit **44** or a RO unit **50** capable of operations to maintain fluid pressures between about 400 pounds per square inch to about 1,000 pounds per square inch for high pressure fluid treatment applications.

[0047] An ED system can be operated for removing low molecular weight ionic constituents of between about 1 Å to about 10 Å from a feed stream. As a contaminated and pressurized liquid is pumped through an ED membrane cell stack **68** having a plurality of interleaved with spacer layers, gaskets, and at least one anion plate and at least one cation plate, the ionic constituents are transported toward the respective anion plate and cation plate under the influence of an electric field for removal of the ionic constituents from the liquid to form a diluate liquid referred to as a decontaminated product liquid **76**. A disadvantage of an ED operation is that non-charged constituents and higher molecular weight contaminants are not typically efficiently removed by an ED unit. Conversely, NF and/or RO subunits will operate optimally to remove highly charged and some non-charged constituents and higher molecular weight contaminants, but will not typically be as efficient at removing smaller molecular weight and mono-valence charged constituents from a feed stream. The commonality of combining NF or RO subunits in series or in parallel with an ED unit, and providing for pretreatment and blending in a central mixing tank allows for optimal separation of contaminants and ionized constituents by each subunit, resulting in significant energy savings compared to thermal separation processes such as distillation or evaporation, and substantial operational cost savings compared to ion-exchange resin process units. The integrated EPM system provides a plurality of treatment units including a multi-cell electrodialysis unit **60** which removes ionic constituents and provides treatment of the NF or RO reject liquids **72'** after blending in a mixing unit **30** thereby allowing multiple treatment options and providing maximum recovery efficiency.

[0048] For each of the ED membrane units **60** utilized in treatment systems **10**, **12**, **14**, **16**, **18** and **18'**, an ED membrane cell stack **68** typically includes a plurality of stacked membrane layers having interdisposed spacers, gaskets and turbulence layers. Each ED membrane stack **68** (see **FIG. 5A**) includes at least one inlet and at least one fluid outlet for rapid liquid flow therethrough while an electric potential is maintained across the stacked layers by at least one positive electrode or plate **62** and at least one negative electrode or plate **62'**. Pumps associated with each ED membrane cell stack **68** include a concentrate liquid pump **64** and an electrolytic liquid pump **66** (see **FIG. 5A**). Each ED unit **60** is capable of operating with constant flow or batch fluid flow during treatment in sequence (see **FIGS. 2, 4** and 5B), or during treatment in parallel (see **FIGS. 1 and 3**). A plurality of arrangements of ED membranes interleaved with spacers, gaskets and turbulence inducement layers are combined in stacked configuration **68** depending upon the amount of membrane surface area desired for each ED unit. In one embodiment of the integrated EPM system, ED membranes are separated by spacers composed of ethylene propylene diene terpolymer (EPDM). Those skilled in the art will recognize that a variety of materials are readily available for ED membranes and gaskets utilized in an ED stack **68**. Clamping of the ED membranes and gaskets together in an ED stack is accomplished by perimeter oriented connectors, or centrally oriented connectors extended through the ED membranes and gaskets, in order to improve the uniformity of the clamping force distribution on the ED gasket area. Threaded connector members are preferably utilized as connectors to reduce assembly labor time for each ED stack **68** used, and to facilitate change-out of ED membranes when the membranes are spent.

[0049] One embodiment of the integrated electro-pressure membrane (EPM) system **14** includes parallel treatment of contaminated feed liquids **22** utilizing pressure-driven membrane units **44**, **50** having a plurality of pressure-driven membranes through which liquids from the mixing tank **30** are channeled, and at least one electrodialysis membrane unit **60** (see **FIG. 3**). A volume of contaminated feed liquids **22** is pumped **32** through a pretreatment filtration unit **20**, for removal of micron-sized particles before transfer from at least one effluent channel of the filtrate **28** to the mixing tank **30**. Either within the mixing tank **30** or partially external of the mixing tank, a means for mixing is provided in order to rapidly mix the filtrate **28** and additional fluids returned to the mixing tank **42'**, **58'**, **72**, **72'** (discussed further herein). The means for mixing can include a mechanical mixing device having an interior rotating or pivoting member, an interior vibrating member, an interior fluid channel outlet from recirculating pumps, or a similar mixing device as known by those skilled in the art. The integrated EPM system **14** includes an operator adjusted control means **80** providing liquid transfer **58** from mixing tank **30** into an ED unit **60** for electric-driven liquid treatment. A deionized liquid **58'** is generated and returned to the mixing tank **30** in order to reduce the concentration of ionic constituents in feed liquids in the mixing tank **30** before mixed liquids are transferred **38** and pressurized by the second pump means **36** to the NF unit **44**, or to a RO unit **50**, for pressure-driven removal of contaminants. A polishing step is provided for liquids transferred through a micron filter unit **40** concurrent with operation of the ED unit **60**, in which an operator selects transfer **42** of mixed liquids through micron filter unit **40** or a UF unit before a filtrate **42'** is transferred back to a mixing tank **30** for subsequent transfer **34**, pressurization by the second pump means **36**, and transfer **38** for pressure-driven treatment in NF unit **44**, or RO unit **50**, if utilized. The maximum practical efficiency of a typical nonintegrated ED unit is typically about 90% to about 96% removal of ionic constituents. Testing results **90**, **92** have provided efficiency values for the diluate forming the decontaminated product liquid **76** recovered from integrated EPM embodiments **14**, **16**, **18**, and **18'** (see **FIGS. 3**, **4**, 5A, and 5B), including treatment in a NF **44** or a RO unit **50**, and an ED unit **60**, of about 98+% efficiency **92** over a significantly short run time (see **FIG. 6**).

[0050] Additional configurations for combining the two sub-systems include providing sequential treatment of liquids (see **FIGS. 4 and** 5B), or parallel treatment of liquids (see **FIG. 3**), in numerous combinations of an ED unit **60** and a NF unit **44**, or a RO unit **50** if utilized, and a liquid mixing tank **30**. For each integrated EPM system disclosed herein, when the feed rate **28** to the mixing tank and the effluent flow rate for decontaminated product liquid **76** are generally constant, the treatment system is identified as a continuous process. When the feed rate **28** to the mixing tank **30** includes sequential batch volumes, the system is classified as a semi-continuous process. For each integrated EPM system, the volume and conductivity is monitored by sampling devices such as conductivity sensors reporting to control means **80** for specific liquid transfers within the system, such as mixed liquids transfer **38** to the NF or RO units, and liquids transfer **58** to the ED unit **60**. In addition, monitoring of the filtration pressures for the NF or RO units, and the strength of electrical field(s) for each ED unit **60** are monitored and controlled by the control means **80** which includes computer circuitry for multiple analyses of liquids during transfers, of liquids blended in mixing unit **30**, and of liquids after each treatment unit. The control means **80** and includes visual readouts of the liquid conductivity and pressure parameters for each subunit, and adjustable controls **82** for operating each unit of the integrated EPM system. The visual readouts and controls **82** allow an operator to monitor performance of each unit during operation and provide a control means for an operator to increase or decrease the operating parameters of mixing tank **30**, the NF unit **44**, the RO unit **50** if utilized, and the ED unit **60**.

[0051] Each integrated EPM system utilizes a common mixing tank **30** from which feed liquids are transferred **34**, **58** to each of a plurality of treatment units **40**, **44**, **50** and **60**. Control of the liquids added to the common mixing tank **30** by an operator's adjustments of control means **80**, provides for optimized parameters of low concentrations of non-ionic contaminants and control of mixed liquids conductivity when liquids are transferred to each treatment unit **40**, **44**, **50**, **60**, thereby providing improved overall system efficiency as measured by a decrease in decontaminated product liquid **76** conductivity (i.e. removal of ionic constituents). Actual performance parameters of the integrated EPM system **90**, **92** have been tested to maintain about 98+%

recovery efficiency during integrated system operations, as compared to a NF only system **110**, **112** (about 90%), or an ED only system **120**, **122** (about 90% to about 96%) over similar run times (**FIG. 6**). Use of a common mixing tank **30**, as opposed to two or more separate filtrate and permeate storage tanks, provides a central control of feed liquid flow, and allows for rapid adjustments to the system run time for optimizing reduction in permeate conductivity during run time to maintain performance at 98+% while minimizing energy usage for the integrated EPM system **90**, **94**, compared to a NF only system **110**, **114**, or an ED only system **120**, **124** over similar run times (see **FIG. 7**).

[0052] The integrated system illustrated in **FIG. 4** is a sequential process having a filtration unit **40** operating in parallel with operation in series for the ED unit **60** and NF unit **44**, or a RO unit **50**. Contaminated feed liquids **22** having ionic constituents and non-ionic constituents are pumped **32** through a pretreatment filtration unit **20**, for removal of micron-sized particles and delivery of the filtrate **28** to the mixing tank **30**. The integrated EPM system **14** includes an operator adjusted control means **80** providing control of the mixed liquid transfer **58** into the ED unit **60** for electric-driven liquid treatment. Treatment in the ED unit **60** provides for generation of a deionized product liquid **76** which is released for reuse in commerce, and concentrated brine **74** which is removed for discard. Additional effluents from the ED unit **60** can include a non-specification liquid portion **72** (see **FIGS. 1 and 2**) which is transferred by a recycle channel to the mixing tank **30**, or discarded. Alternative pathways for partially deionized fluids **58'** are illustrated in **FIGS. 3, 4** and 5B, with the effluent **58'** from the ED unit **60** being transferred to pressure-driven filtration units **44** or **50** (see **FIG. 4**), or the partially deionized fluids **58'** being transferred by recycle channels for mixing in the mixing tank **30** (see **FIG. 5B**), The deionized diluate liquid **58'** is transferred and pressurized by the second pump means **36** for pressure-driven treatment in the NF unit **44**, and/or in a RO unit **50** if utilized, to generate a pressure-driven membrane separation of non-ionized constituents to generate a permeate liquid identified as the decontaminated product liquid **76**. A second non-specification liquid portion **72'** is generated and transferred after NF or RO treatment to the mixing tank **30** for blending with pretreated liquid **28** and filtrate liquid **42'** in order to reduce the concentration of ionic constituents in feed liquids in the mixing tank **30** before mixed liquids are transferred **38** and pressurized by second pump means **36** to the NF unit **44**, or to a RO unit **50**, for pressure-driven removal of non-ionized contaminants. A deionized and decontaminated product liquid **76** is generated by the integrated system **16** which is reduced in conductivity at an overall efficiency of about 98+%, when compared to a NF only system **110** (approximately 90% efficient **112**), or an ED only system **120** (approximately 96% efficient **122**) over similar run times (see **FIG. 6**).

[0053] In **FIG. 5A**, an equipment configuration **18** is illustrated for equipment typically utilized for each of the treatment units of the integrated EPM system **16**. All of the treatment units of **FIG. 5A** are not required for operation of integrated EPM systems. The control means **80** provides a means for an operator's control and shut-down of treatment units not needed for treating feed liquids **22** lacking certain contaminants. The integrated system optimizes treatment options while delivering energy cost savings by selectively channeling filtered and mixed liquids **42'**, **58** by activation of appropriately positioned valves and pumps to allow liquid flow to appropriate system units as selected by an operator having knowledge of the composition of the mixed liquids **42'**, **58** in conjunction with knowledge of the current operational performance parameters of each system unit. The specific treatment units of **FIG. 5A** are discussed further herein for the embodiments illustrated in **FIGS. 3**, **4**, and **5B**.

[0054] An additional embodiment for an integrated system **18'** is illustrated in **FIG. 5B**, which utilizes the equipment and control means **80** illustrated in **FIG. 5A**. The integrated system **18'** is a sequential process providing liquid treatment in a NF unit **44** or a RO unit **50**, followed in series by liquid treatment in an ED unit **60**. Contaminated feed liquids **22** having ionic constituents and non-ionic constituents are pumped **32** through a pretreatment filtration unit **20**, for removal of micron-sized particles and delivery of the filtrate **28** to the mixing tank **30** for blending of a variety of concentrated liquids. The goal is to manage separate concentrated liquid streams **58'**, **72'** in order to reduce the average concentration of ionic constituents and dissolved solids in mixed liquids transferred **34** to additional treatment units **44**, **50**, **60**. The integrated system **18'** provides for blending in the mixing tank **30** of two or more liquids including the pretreated feed liquids **28**, deionized product liquids **58'** from an ED unit, and non-specification liquids **72'** from treatment in a NF or RO unit, in order to reduce the average concentration of ionic constituents and dissolved solids in permeate liquids in the mixing tank **30** before treatment. The mixed liquids are transferred **34** and pressurized by the second pump means **36** for transfer **38** to a NF unit **44**, or to a RO unit **50**, for pressure-driven removal of constituents such as inorganic compounds and soluble contaminants such as synthetic dyes and organic compounds. If a decontaminated product liquid **76'** is needed which is not deionized, then an effluent product liquid **76'** is separated from the NF/RO unit for use in commerce. If additional deionization treatment is preferred, the pressure treated liquid **58"** is transferred to an ED unit **60** for deionization and separation as decontaminated and deionized product liquid **76**. The integrated EPM system **18'** includes an operator adjusted control means **80** providing transfer of the reject liquid **72'** from the NF/RO unit to the mixing tank **30**, and transfer of a partially deionized fluid **58'** from the ED unit **60** to the mixing tank **30** for further mixing and additional treatment. The final product can be either the NF or RO treatment unit effluent separated as a product liquid **76'**, or the decontaminated and deionized product liquid **76** from the ED unit **60**. Either product liquid **76**, **76'** is decontaminated at efficiencies of at least 98%, for production of reclaimed liquids having sufficient purity to meet "virgin" liquid specifications.

[0055] Benefits of the integrated EPM systems described herein include high production rates for decontaminating ethylene glycol with recovery rates in excess of 98%, with high gallons per hour (gph) throughput as illustrated for an integrated EPM system **96**, compared to NF only 116, or ED only 126 systems (see **FIG. 8**). Additional benefits for the integrated EPM systems include relatively low capital expenditures and operating costs, leading to significant total cost savings of about 75% for integrated EPM systems **98** having recovery efficiencies of 98+%, compared to the costs to obtain a maximum practical NF only recovery efficiency of about 90% for NF only systems **118** (see **FIG. 9**). Alternately, significant total cost savings of about 65% for integrated EPM systems **100** having recovery efficiencies of 98+% for integrated EPM systems **98**, compared to the costs to obtain a maximum practical recovery efficiency of about 96% for ED only systems **128** (see **FIG. 9**). The integrated EPM systems typically do not generate hazardous by-products, are easy to operate, control and automate, and easy to maintain. Also, studies indicate that the invention is capable of producing a product with extremely low conductivity levels (down to as low as 2.6 μMho/cm). Those skilled in the art will recognize that this represents a substantial improvement compared to traditional ED designs, which are typically limited to product with conductivities >30 μMho/cm. As a result, the invention would represent a new pretreatment option for production of ultra-pure water. The results of a plurality of production runs of varying lengths and with different configurations of treatment units are illustrated in **FIGS. 6-10**. Production runs have indicated that the embodiments of the integrated EPM system are a substantial improvement over traditional designs. As illustrated in **FIG. 10**, comparisons of permeate conductivity as a function of recovery for feed liquids of 50% ethylene glycol solution, indicate that the integrated EPM systems **130** readily perform at 98+% efficiency **140**, compared to RO only systems **132** providing about 96-97% efficiency **142**, or NF only systems **134** providing about 90-97% efficiency **144**. Those skilled in the art will recognize that the improved design of the integrated EPM systems result in each ED membrane cell stack requiring significantly less ED membrane area while being more energy efficient.

[0056] In addition to the described use of the method and apparatus to decontaminate and deionize used antifreeze, the system may be used to decontaminate and deionize wash water (vehicular, laundry, mop water, trailer/tank washout, textile rinses, metal, aqueous parts cleaners), oil and gas field fluids (glycol base natural gas dehydration fluids, glycol/water heat transfer fluids, amines from treatment of natural gas, produced water), other thermal transfer fluids (secondary coolants from HVAC systems and coolants from ice-skating rinks), cooling water reuse, nuclear wastewater, mixed wastewater having nuclear/radioactive and hazardous/chemical contaminates, hazardous wastewater, desalination of sea or brackish water, and drinking water production and/or provide pretreatment for ultra-pure water production.

[0057] While the present invention has been illustrated by description and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicant's general inventive concept.

Having thus described the aforementioned invention, we claim:

1. A membrane-based system for treating contaminated feed liquids, comprising the steps of:

providing contaminated feed liquids having a plurality of insoluble and soluble contaminants and ionic constituents therein;

removing insoluble particles from said contaminated feed liquids in a pretreatment filtration unit for removal of particles thereby generating a pretreated filtrate liquid;

channeling said pretreated filtrate liquid to a mixing unit for blending thereby forming a blended filtrate liquid;

filtering insoluble contaminants from said blended filtrate liquid in a microfiltration unit in fluidic connection with said mixing unit;

transferring a selected flow rate of said blended filtrate liquid to an electric-driven membrane unit;

separating ionic constituents in said blended filtrate liquid during passage through said electric-driven membrane unit having a plurality of electrically charged membranes interspaced with gaskets and having channels therebetween, said separating step providing electric-driven membrane removal of ionic constituents thereby forming a deionized product liquid and a separated ionic diluate liquid;

redirecting said separated ionic diluate liquid to said mixing unit for additional blending and further treatment by said step of separating ionic constituents; and

removing said deionized product liquid from said membrane-based system for reuse.

2. The system of claim 1 further comprising the step of:

controlling flow of pretreated filtrate liquid transferring to said electric-driven membrane unit, wherein said step of separating ionic constituents is continuously occurring in parallel with said step of filtering soluble contaminants from said blended filtrate liquid before transfer through said electric-driven membrane unit.

3. The system of claim 2 wherein said step of separating ionic constituents includes:

providing an electrodialysis unit having at least one each of anode and cathode energized membranes; and

securing a plurality of membranes having liquid flow channels therein interspaced with a plurality of spacers and interleaved with said energized membranes to define said electrodialysis unit through which said blended filtrate liquid is transferred therethrough by said step of transferring, whereby said ionic constituents are separated and diverted for removal from said electrodialysis unit by induced transport across said anode and cathode energized membranes thereby said deionized product liquid is separated from said separated ionic diluate liquid and redirected to said mixing unit for additional blending and further treatment by said step of separating.

4. The system of claim 2 further comprising the step of:

pressurizing said deionized product liquid during passage through a pressure-driven membrane unit having a plurality of permeable membranes responsive to pressure-driven flow differences of said deionized product liquid for separation of soluble contaminants from said deionized product liquid thereby generating a decontaminated product liquid.

5. The system of claim 4 wherein said step of pressurizing including pressurizing said deionized product liquid during passage through said pressure-driven membrane unit to pressures between about 50 pounds per square inch to about 400 pounds per square inch maintained on opposed inflow and outflow portions of said pressure-driven membrane unit including a plurality of nanofiltration membranes for removal of soluble contaminants from said deionized product liquid for generating said decontaminated product liquid.

6. The system of claim **4** wherein said step of pressurizing including pressurizing said deionized product liquid during passage through said pressure-driven membrane unit to pressures between about 200 pounds per square inch to about 1,000 pounds per square inch maintained on opposed inflow and outflow portions of said pressure-driven membrane unit including a plurality of reverse osmosis membranes for removal of soluble contaminants from said deionized product liquid for generating said decontaminated product liquid.

7. A membrane-based system for treating contaminated feed liquids, comprising the steps of:

providing contaminated feed liquids having a plurality of insoluble and soluble contaminants, and ionic constituents therein;

filtering said contaminated feed liquids in a pretreatment filtration unit for removal of particles thereby generating a pretreated filtrate liquid;

channeling said pretreated filtrate liquid to a mixing unit for blending thereby forming a blended liquid;

separating ionic constituents from said blended liquid during passage through an electric-driven membrane unit having a plurality of electrically charged membranes interspaced with gaskets and having channels therebetween, said separating step providing electric-driven membrane removal of ionic constituents thereby forming a deionized product liquid and a separated ionic diluate liquid; returning said deionized product liquid to said mixing tank for blending with said blended liquid;

transferring a selected flow rate of said blended filtrate liquid to a pressurization unit;

discarding said ionic diluate liquid from said electric-driven membrane unit;

pressurizing said deionized product liquid during passage through a pressure-driven membrane unit having a plurality of permeable membranes responsive to pressure-driven flow of said deionized product liquid for separation of soluble contaminants from said deionized product liquid thereby generating a decontaminated product liquid separated from a deionized concentrated liquid; and

removing said decontaminated product liquid from said pressure-driven membrane unit for reuse.

8. The system of claim 7 further comprising the step of:

controlling flow of pretreated filtrate liquid transferring to said electric-driven membrane unit, wherein said step of separating ionic constituents is continuously occurring in parallel with said step of pressurizing said deionized product liquid thereby generating said decontaminated product liquid separated from said deionized concentrated liquid.

9. The system of claim 7 further comprising the step of:

controlling the flow of pretreated blended filtrate liquid transferring to said step of separating ionic constituents whereby said steps of separating and pressurizing are occurring in series thereby generating said decontaminated product liquid separated from said deionized concentrated liquid.

10. The system of claim 7 wherein said step of separating ionic constituents includes:

providing an electrodialysis unit having at least one each of anode and cathode energized membranes; and

securing a plurality of spacers interleaved with said energized membranes to define said electrodialysis unit through which said blended filtrate liquid is transferred by application of continuous liquid flow therethrough whereby said ionic constituents are separated and diverted for removal across said anode and cathode energized membranes thereby said deionized liquids are separated for removal from said electrodialysis unit.

11. The system of claim 7 wherein said step of pressurizing includes:

providing said plurality of membranes for separation of contaminants from said deionized product liquid, said plurality of permeable membranes being configured as an ultrafiltration unit, a nanofiltration unit, or a reverse osmosis unit through which said ionic diluate liquid is pressure driven across a plurality of semi-permeable membranes whereby said semi-permeable membranes selectively separate said ionic diluate liquid into said decontaminated product liquid separate from said deionized concentrated liquid.

12. An apparatus for electrodialysis treatment of contaminated feed liquids, comprising:

a pretreatment filtration unit having at least one filtration membrane through which contaminated feed liquids are directed, said at least one filtration membrane having sufficient pore diameters to deny passage of insoluble particles and to allow passage of filtrate liquids, said pretreatment filtration unit having at least one effluent channel for passage of said filtrate liquids;

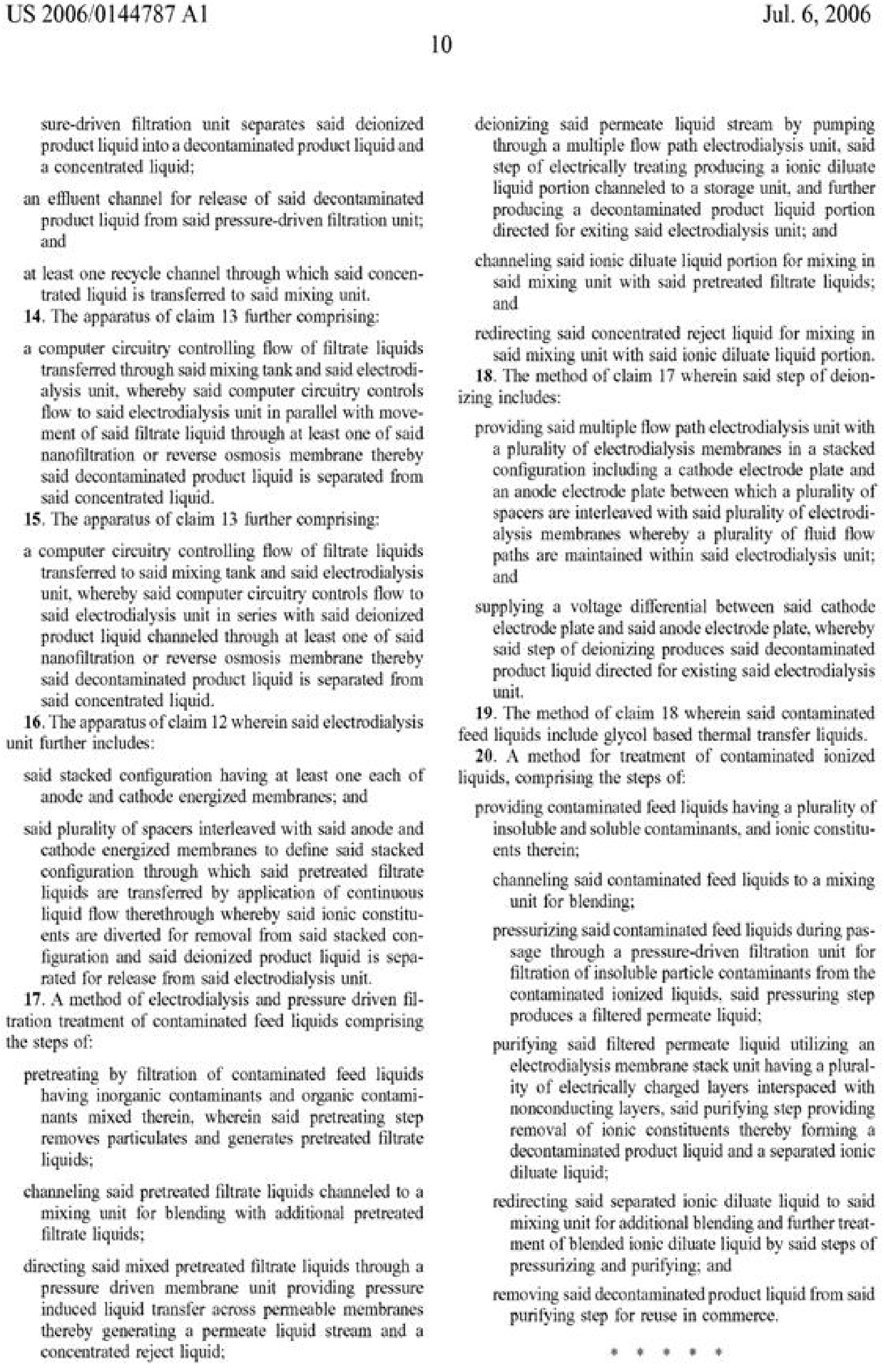
a mixing unit in hydraulic connection with said at least one effluent channel of said pretreatment filtration unit, said mixing unit including means for mixing fluids transferred to said mixing unit; and

an electrodialysis unit in hydraulic connection with said mixing unit, said electrodialysis unit including a stacked configuration of a plurality of interdisposed anion cell membranes and cation cell membranes interleaved with a plurality of spacers, said electrodialysis unit providing at least one fluid path therethrough for movement of said filtrate liquids whereby a deionized product liquid and partially deionized fluids are separated from said filtrate liquids by said at least one fluid path through said stacked configuration of said electrodialysis unit with said deionized product liquid channeled for release from said electrodialysis unit; and

a recycle conduit through which partially deionized fluids are transferred to said mixing unit.

13. The apparatus of claim 12 further comprising:

a pressure-driven filtration unit including at least one of a nanofiltration or reverse osmosis membrane through which said deionized product liquid is channeled for separation of ionic and nonionic contaminants from said deionized product liquid, at least one of said nanofiltration or reverse osmosis membrane having a plurality of fluid paths through which said deionized product liquid is pressure driven whereby said pres-



sure-driven filtration unit separates said deionized product liquid into a decontaminated product liquid and a concentrated liquid;

an effluent channel for release of said decontaminated product liquid from said pressure-driven filtration unit; and

at least one recycle channel through which said concentrated liquid is transferred to said mixing unit.

14. The apparatus of claim 13 further comprising:

a computer circuitry controlling flow of filtrate liquids transferred through said mixing tank and said electrodialysis unit, whereby said computer circuitry controls flow to said electrodialysis unit in parallel with movement of said filtrate liquid through at least one of said nanofiltration or reverse osmosis membrane thereby said decontaminated product liquid is separated from said concentrated liquid.

15. The apparatus of claim 13 further comprising:

a computer circuitry controlling flow of filtrate liquids transferred to said mixing tank and said electrodialysis unit, whereby said computer circuitry controls flow to said electrodialysis unit in series with said deionized product liquid channeled through at least one of said nanofiltration or reverse osmosis membrane thereby said decontaminated product liquid is separated from said concentrated liquid.

16. The apparatus of claim 12 wherein said electrodialysis unit further includes:

said stacked configuration having at least one each of anode and cathode energized membranes; and

said plurality of spacers interleaved with said anode and cathode energized membranes to define said stacked configuration through which said pretreated filtrate liquids are transferred by application of continuous liquid flow therethrough whereby said ionic constituents are diverted for removal from said stacked configuration and said deionized product liquid is separated for release from said electrodialysis unit.

17. A method of electrodialysis and pressure driven filtration treatment of contaminated feed liquids comprising the steps of:

pretreating by filtration of contaminated feed liquids having inorganic contaminants and organic contaminants mixed therein, wherein said pretreating step removes particulates and generates pretreated filtrate liquids;

channeling said pretreated filtrate liquids channeled to a mixing unit for blending with additional pretreated filtrate liquids;

directing said mixed pretreated filtrate liquids through a pressure driven membrane unit providing pressure induced liquid transfer across permeable membranes thereby generating a permeate liquid stream and a concentrated reject liquid;

deionizing said permeate liquid stream by pumping through a multiple flow path electrodialysis unit, said step of electrically treating producing a ionic diluate liquid portion channeled to a storage unit, and further producing a decontaminated product liquid portion directed for exiting said electrodialysis unit; and

channeling said ionic diluate liquid portion for mixing in said mixing unit with said pretreated filtrate liquids; and

redirecting said concentrated reject liquid for mixing in said mixing unit with said ionic diluate liquid portion.

18. The method of claim 17 wherein said step of deionizing includes:

providing said multiple flow path electrodialysis unit with a plurality of electrodialysis membranes in a stacked configuration including a cathode electrode plate and an anode electrode plate between which a plurality of spacers are interleaved with said plurality of electrodialysis membranes whereby a plurality of fluid flow paths are maintained within said electrodialysis unit; and

supplying a voltage differential between said cathode electrode plate and said anode electrode plate, whereby said step of deionizing produces said decontaminated product liquid directed for existing said electrodialysis unit.

19. The method of claim 18 wherein said contaminated feed liquids include glycol based thermal transfer liquids.

20. A method for treatment of contaminated ionized liquids, comprising the steps of:

providing contaminated feed liquids having a plurality of insoluble and soluble contaminants, and ionic constituents therein;

channeling said contaminated feed liquids to a mixing unit for blending;

pressurizing said contaminated feed liquids during passage through a pressure-driven filtration unit for filtration of insoluble particle contaminants from the contaminated ionized liquids, said pressuring step produces a filtered permeate liquid;

purifying said filtered permeate liquid utilizing an electrodialysis membrane stack unit having a plurality of electrically charged layers interspaced with nonconducting layers, said purifying step providing removal of ionic constituents thereby forming a decontaminated product liquid and a separated ionic diluate liquid;

redirecting said separated ionic diluate liquid to said mixing unit for additional blending and further treatment of blended ionic diluate liquid by said steps of pressurizing and purifying; and

removing said decontaminated product liquid from said purifying step for reuse in commerce.

* * * * *

Appendix D.

Glycerol Purification System Supplier Information

Appendix D. Glycerol Purification System Supplier Information, from website for EET Corporation

EET's glycerol purification process, based on its patented and patents pending HEED® processes and equipment, is the economical solution for the purification of glycerol streams derived from the biodiesel industry (read more about biodiesel production) and from soap production by saponification. With EET technology, biodiesel-derived and saponification -produced glycerol can be refined up to quality requirements of USP grade* 99.7. Alternately, lower cost, intermediate purity grades can be produced for direct use, subsequent chemical conversion into other compounds such as propylene glycol, or further purification with evaporation or distillation. The EET membrane-based technology avoids many of the issues associated with standalone evaporation and distillation such as foaming, carryover of contaminants, corrosion, limited recovery, and high capital, energy, maintenance and operating costs.

The robustness of the process allows the EET technology to be applied prior to or after methanol removal for biodiesel-produced crude, over a range of feed compositions. In particular, it can purify:

- Neutralized glycerol streams containing methanol (before methanol stripping)
- Neutralized glycerol streams from which methanol has been stripped
- Refined glycerol streams which have been distilled or evaporated but still contain residual salts and organics and require further treatment

EET's glycerin purification process begins with pretreatment of the glycerol to remove any solids and fouling organics and partially remove color-causing organics. The HEED® or HEEPM™ system configuration is used, with customized automated controls and control logic, providing optimal desalting of the preatreated crude glycerol. The result is a colorless liquid with low salt content.

Specifications

- Available for licensing in capacities from 1,000 to 200,000 gallons glycerol feed per day (3.8 to 760 cubic meters per day; 3 million to 730 million pounds per year)
- USP 99.7 production rates from 850 to 170,000 gallons per day (3.2 to 644 cubic meters per day; 3 million to 620 million pounds per year)
- Feed TDS up to 12 wt%
- Feed temperatures to 35°C (95°F) using standard system components
- Feed pH 3 to 7
- Up to 99+% glycerol recovery, depending on feed composition and end product characteristics

HEED® Model 400-B-75.2
Glycerol Desalting System

Key Features

- Proven technology with full-scale installations currently in operation
- High recoveries with much lower capital and operating costs compared to other technologies
- Salt removal to specified levels, including to USP glycerol, with the system able to adapt to changing feed supply contaminant types and concentrations
- Robust unit operation(s) for removal of Free Fatty Acids (FFAs), Matter Organic Not Glycerol (MONG), organic acids, color and odor
- Modular systems, easily scaleable to increase capacity
- Semi-automated system easy to use and control
- Minimum downtime required (typically 23+ operating hours per day)
- Nonhazardous side streams consisting of dry filter cake and aqueous brine solution for easy disposal

Space, Utility, and Tank Requirements

- The space/footprint needed will depend on the overall production capacity, feed chemistry, and product characteristics. In general, the process equipment requires only a fraction of the space of storage tanks for feed and product. For example, processing equipment with work tanks for a 10 million pound/year (~2,500 gpd) plant producing USP 99.7 grade glycerol using typical chloride containing crude feed will occupy about 7,000 square feet, while the actual process equipment will occupy only about 1,000 square feet (see EET facility photos)
- Three-phase 480V electrical utility preferred; three-phase 230V or single-phase 110V acceptable for some size units
- Process air
- Softened, de-chlorinated make-up water (or tap water with <3 ppm free chlorine)
- Appropriate feed, product, and brine concentrate tanks and lines to and from these to the working tanks of the EET-supplied systems

Maintenance

Maintenance requirements for the EET glycerol purification system are minimal. Depending on feed characteristics, periodic cleaning, typically <1 hour per day, is required. Although each installation and application will vary, installed units have been in operation for over 5 years with no change in HEED® membrane stack and no major component (e.g., pumps, rectifier, controls) replacement.

By-products of Glycerol Purification

- Concentrated brine stream, typically dischargeable as sanitary wastes (check with your local regulators)
- A dry solid waste (nonhazardous) passing the paint filter test (no free liquids). The amount of solid waste will depend on the amount of MONG and FFAs in the biodiesel-derived glycerol
- Small amounts of hydrogen and oxygen gas, which are typically vented to atmosphere

Appendix E.

Carbon Dioxide Cap and Trade Legislation

Appendix E. Carbon Dioxide Cap and Trade Legislation

Cap and Trade Pending Legislation

The idea behind Cap and Trade programs is that each company, power plant, or other large-scale carbon emitter will be able to reduce carbon emissions at different rates. Each will be given a capped amount of carbon it can emit. Over time, the caps get stricter and stricter until the ultimate emissions goals are reached. Since some carbon emitters will be able to reduce emissions more easily and cheaply than others, those that can reduce to levels below their specified caps can sell on the open market, carbon allowances to emitters that cannot meet their specified levels. This is trade part of the system.

The 110th US Congress, which was in session in 2007 and 2008, introduced a flurry of proposals to address climate change, 235 pieces in total. By the end of January 2008, seven main congressional bills addressed carbon and other greenhouse gas emissions through a variety of methods. All set goals for at least slowing the rate of emissions to the atmosphere. The Pew Center on Global Climate Change summed up each of these bills and created a chart of what effects on emissions these bills would have if each of their goals were met (Pew), which is Fig CT-1 below.

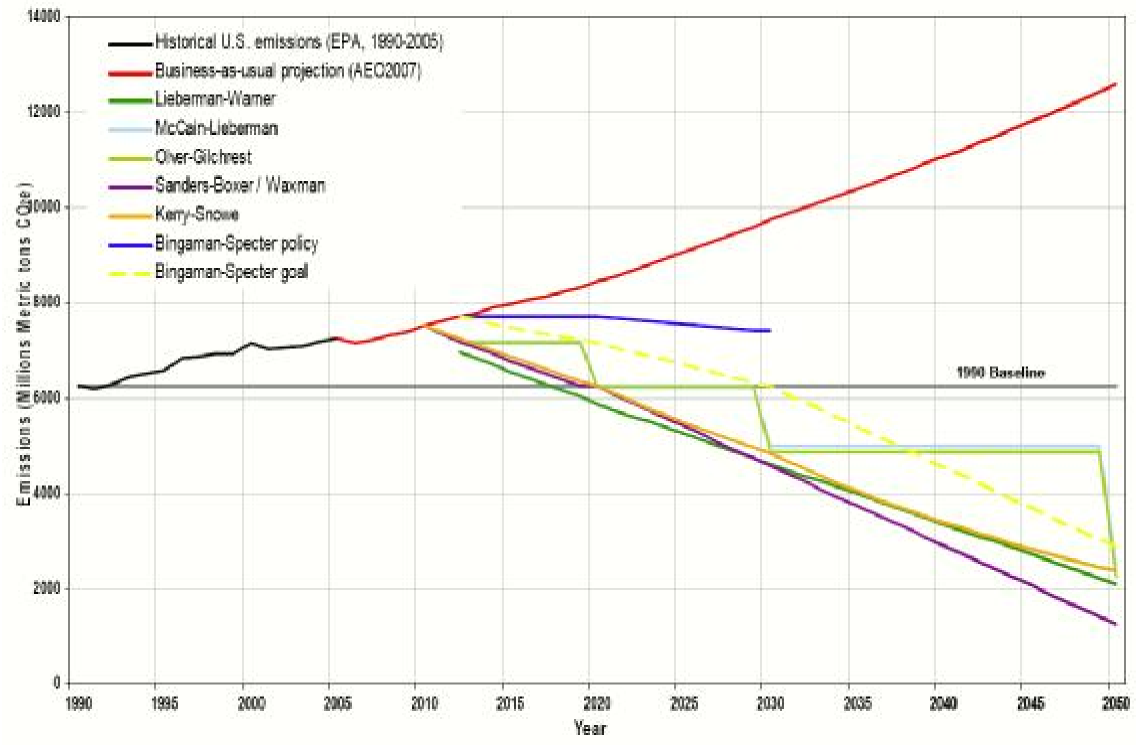


Figure CT-2. The Pew Center on Global Climate Change summary of congressional bills. Graph shows what effects on Carbon Dioxide emissions these bills would have if each of their goals were met

The most radical of these plans is the Sanders-Boxer/ Waxman proposal (s.309), an amendment to the Clean Air Act, which calls for a steady 2% reduction in emissions year-on-year, so that by 2050 total emissions will be reduced 80% from their 1990 value. This plan does not require Cap and Trade, but allows for systems of cap and trade to exist to assist in meeting the goals. The amendment also did not specify which sectors the caps would be placed on, instead just listing total national goals. This amendment never came up for a vote, and expired when the 110th Congress did last year (Gov Track).

Many of the other plans drafted called for slightly less reduction. The Lieberman-Warner (s.2191) bill, called for caps to be auctioned off on the open market and gave incentives for carbon sequestering, and the Olver-Gilchrest (H.R. 620) bill would have provided for a step-down approach to limiting emissions(Gov Track). The bills set target years for emissions to be reduced to certain levels, and had no specifications on reduction in between these target years. The Lieberman-Warner bill reached the committee phase, but no further action was taken; the Olver-Gilchrest bill did not even make it to committee(Gov Track).

The one proposed bill that took on the issue slightly differently was Spector-Bingham (s.1766) The bill calls for a reduction back to 1990 emissions levels by 2030, primarily through Cap and Trade. The bill has many incentives for research, including special carbon capture allocations and funding for green research. The bill also gives the President the power to set the goals to a more aggressive level, up to 60% below 1990 levels by 2050, in the event that international regulations or actions change over this time period. The bill did not make it past introduction.

In short, it seems to be a few years before the Cap and Trade system will be applied within the United States.

Appendix F.

Problem Statement

Glycerol to Ethanol

(recommended by Bruce Vrana, DuPont)

Glycerol is a byproduct of biodiesel manufacture, with relatively few industrial uses. As the production of biodiesel increases, particularly in Europe due to government regulations but also in the U.S. due to public demand for renewable fuels, the price of glycerol is expected to continue to decrease.

Your research organization has recently isolated a naturally occurring *E. coli*, code-named Penn09, that will ferment glycerol to ethanol and a small amount of succinic acid. Ethanol is in high demand for transportation fuel, and succinic acid is a high-value specialty chemical.

You have been asked to determine whether this technology could be commercially successful, using the following assumptions, determined by your research director. You need to design a plant that will make 50MM gallons per year of fuel ethanol using this technology and estimate the economics.

Crude glycerol is a good substrate for this strain of *E. coli*. The salts in the glycerol contain all the nutrients that the organism needs to survive and reproduce. The fermentation is anaerobic, and the overall reactions can be written as:

$$CH_2OH\text{-}CHOH\text{-}CH_2OH \ \textbf{à}\ CH_3\text{-}CH_2OH + CO_2 + H_2 \qquad (1)$$

Glycerol Ethanol

$$CH_2OH\text{-}CHOH\text{-}CH_2OH + CO_2 \ \textbf{à}\ HOOC\text{-}CH_2\text{-}CH_2\text{-}COOH + H_20 \qquad (2)$$

Glycerol Succinic acid

Assume that 98% of the glycerol is converted in reaction 1, 1% of the glycerol is converted in reaction 2, and 1% is converted to biomass. The overall reaction rate is 1.6 g EtOH formed/L of reaction volume/hour. Feed only enough glycerol to the batch fermenter to reach a final ethanol titer of 100 g/L.

Sterility in the fermentation area is a significant concern. Suitable measures must be taken to ensure that no adventitious organisms enter the process, eating feedstock and generating undesired products. Everything entering the fermenter must be sterile, except of course for the innoculum.

The organism is a naturally occurring strain that poses no known hazards to humans and thus is less stringently regulated than if it were genetically modified. Nonetheless, it would be prudent to design facilities to physically contain the live organism. Prior to removal from containment, the organism must be deactivated or killed and then disposed of properly. Landfill is adequate for final disposal. Likewise, operating vents and spills that could contain the live organism are to be contained and treated. The operating vent could be treated with a scrubber using a low concentration of bleach. Spills could be sent to a tank and heated to sterilization temperature prior to discharge.

Also fed to the fermenters is your *E. coli* inoculum, which you produce in a separate seed fermentation train. The biochemistry of the organism is outside the scope of this project. Fortunately, your research organization has developed a simple scenario for your use. The organism will come from 1 ml vials stored in a freezer on site. It will be grown in successive stages each 20 times the size of the prior stage, each stage taking 24 hours.* After 24 hours, it is put in the next larger vessel along with water and a sugar source. If you use less than a 20 X factor for any stage of fermentation, you must still allow 24 hours for that stage of fermentation to take place. 10 liters is the largest stage that can be grown in the lab before transferring to the first seed fermenter in the plant. Lab scale fermentations will use clean glycerol and other nutrients, the cost of which can be ignored for this evaluation, along with the cost of the initial vial of organism. (Note, however, that the vials do have a cost, so you may only use one vial per production fermenter batch.) Once the laboratory-produced seed is taken to the plant seed fermentation train, each stage of seed fermentation will be fed with plant water and enough glycerol to produce the maximum titer of 100 g/L ethanol before transfer to the next larger seed fermenter, or ultimately the production fermenter(s). Your material and energy balance should include the amount of water and glycerol fed to the plant seed train.

Fermentation is the only batch step in the process. Your design must consider how to best match up fermentation with the continuous back end of the plant. A Gantt chart may be helpful to illustrate the filling, fermentation, emptying and cleaning process for however many production and seed fermenters your design employs.

Fermentation off-gas will, unlike in ethanol plants, contain a significant amount of hydrogen, as shown in the stoichiometry above. Your design needs to handle this stream in a safe, environmentally acceptable and economical manner before discharge to the atmosphere. You may assume a slight positive pressure in the fermenters, say 5 inches of water gauge, which will help keep the fermentation anaerobic.

*This 24 hour time period was found to be in disagreement with the calculated 60 hr period using the given growth rate and end ethanol concentration, so this 24-hour time period was ignored at the later suggestion of Mr. Vrana.

Downstream of fermentation, it is expected that this process will have many similarities to the fuel ethanol process used in the U.S. and Brazil. Should you wish to use the fuel ethanol industry process standard for drying ethanol from near the azeotrope to 99.5% purity, molecular sieves, you need to know that regeneration of the molecular sieves requires recycling 20% of the dry ethanol product back to the sieves. This regeneration stream, which on average contains 37% water after leaving the molecular sieves, must then be recycled back to your separation process. The composition of the regeneration stream varies with time, so your design should take that into consideration. A brief, but informative, discussion of the ethanol molecular sieve process is contained in Aden et al. (2002).

A packaged unit for drying ethanol with molecular sieves costs $2.5 million to process 34,000 lb/hr on a pure ethanol basis. The feed is saturated vapor at 1 atm, 92% ethanol, 8% water by weight. The products are saturated liquid at 1 atm. Scale the cost with a 0.6 exponent. Electrical usage is 0.002 kWhr/lb of product. Steam usage is 0.04 lb/lb of product for additional heating. Cooling water usage is 3 gal/lb of product. Since this is a packaged unit, it includes local piping, instrumentation, etc. and thus should have different installation factors than most other purchased equipment.

Ethanol must be denatured on site with 2-5% by volume of unleaded gasoline, to conform to the Bureau of Alcohol, Tobacco and Firearms regulations (preventing human consumption of untaxed alcohol). Prior to denaturing, it must be 99.5% pure ethanol.

Corrosion and cleanliness dictate that most process equipment be fabricated from 304 stainless steel. This holds for any equipment that contains water. Exceptions include corn silos, product storage tanks, and any distillation or other separation systems that contain less than 1% water, which may use carbon steel.

Since your product is intended for transportation fuel use, it is imperative that the process be as energy efficient as possible. The current benchmark for energy use in a fuel ethanol plant is about 35,000 BTU/gallon of product. (This is calculated as the amount of heat and electricity needed by the process, not the amount of fuel consumed in the boiler.) You should certainly be able to surpass that benchmark, due to differences in the process.

The plant design should be as environmentally friendly as possible. Recover and recycle process materials to the maximum economic extent. Also, energy consumption should be minimized, to the extent economically justified. The plant design must also be controllable and safe to operate. Remember that you will be there for the start-up and will have to live with whatever design decisions you have made.

Your purchasing organization believes that the equilibrium price for byproduct glycerol is $0.15/lb, delivered to your U. S. Gulf Coast plant. Your marketing organization believes they can sell denatured ethanol for $2.50/gal. Succinic acid can be sold for $2.00/lb provided it meets normal purity specs. Unleaded regular gasoline used for denaturing costs $2.50/gallon wholesale. All prices referenced here are in 2009 dollars. Obviously, you will want to test the sensitivity of your economics to these price forecasts.

Undoubtedly, you will need additional data beyond that given here. Cite any literature data used. If need be, make reasonable assumptions, state them, and whether your design or economics are sensitive to the assumptions you have made.

References

The Renewable Fuels Association web site has a good description of the fuel ethanol process and industry. http://www.ethanolrfa.org

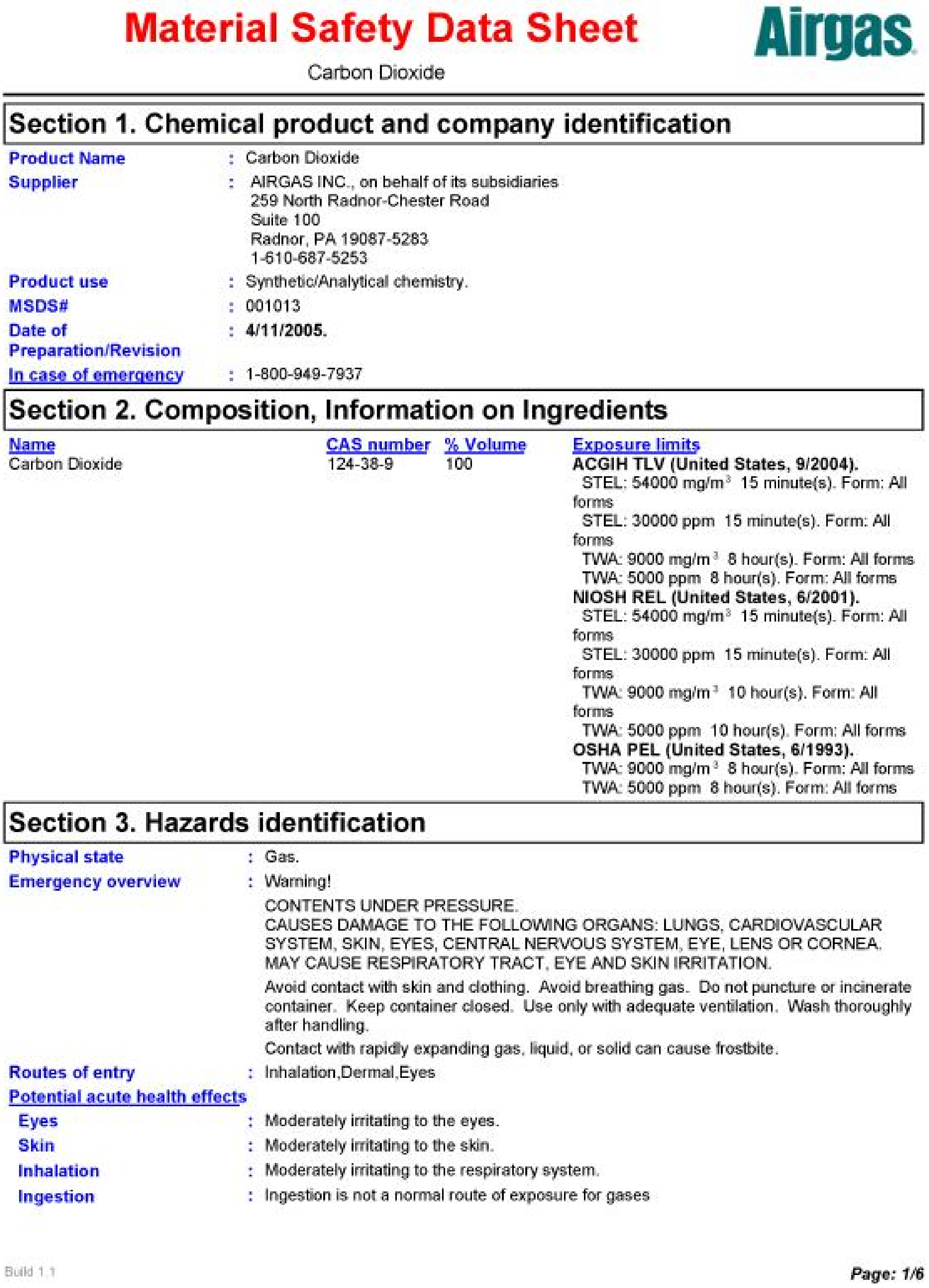
A good model for much of the dry grind ethanol process is discussed on http://www.intelligen.com/literature.shtml which links to a paper by Kwiatkowski et al. This includes a SUPERPRO DESIGNER model that works with their evaluation version of the software. Note, however, that SUPERPRO DESIGNER does not handle VLE rigorously and thus is not suitable for designing this process.

Dharmadi, Y., A. Murarka, and R. Gonzalez, "Anaerobic Fermentation of Glycerol by *Escherichia coli*: A New Platform for Metabolic Engineering", Wiley InterScience, 5/20/2006 contains a description of the biochemistry in a similar organism.

Aden, A., et al., "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover", NREL/TP-510-32438 (2002).

Appendix G.

Relevant MSDS



Material Safety Data Sheet

Carbon Dioxide

Section 1. Chemical product and company identification

Product Name : Carbon Dioxide

Supplier : AIRGAS INC., on behalf of its subsidiaries
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

Product use : Synthetic/Analytical chemistry.

MSDS# : 001013

Date of Preparation/Revision : **4/11/2005.**

In case of emergency : 1-800-949-7937

Section 2. Composition, Information on Ingredients

Name	CAS number	% Volume	Exposure limits
Carbon Dioxide	124-38-9	100	**ACGIH TLV (United States, 9/2004).** STEL: 54000 mg/m^3 15 minute(s). Form: All forms STEL: 30000 ppm 15 minute(s). Form: All forms TWA: 9000 mg/m^3 8 hour(s). Form: All forms TWA: 5000 ppm 8 hour(s). Form: All forms **NIOSH REL (United States, 6/2001).** STEL: 54000 mg/m^3 15 minute(s). Form: All forms STEL: 30000 ppm 15 minute(s). Form: All forms TWA: 9000 mg/m^3 10 hour(s). Form: All forms TWA: 5000 ppm 10 hour(s). Form: All forms **OSHA PEL (United States, 6/1993).** TWA: 9000 mg/m^3 8 hour(s). Form: All forms TWA: 5000 ppm 8 hour(s). Form: All forms

Section 3. Hazards identification

Physical state : Gas.

Emergency overview : Warning!

CONTENTS UNDER PRESSURE.
CAUSES DAMAGE TO THE FOLLOWING ORGANS: LUNGS, CARDIOVASCULAR SYSTEM, SKIN, EYES, CENTRAL NERVOUS SYSTEM, EYE, LENS OR CORNEA.
MAY CAUSE RESPIRATORY TRACT, EYE AND SKIN IRRITATION.

Avoid contact with skin and clothing. Avoid breathing gas. Do not puncture or incinerate container. Keep container closed. Use only with adequate ventilation. Wash thoroughly after handling.

Contact with rapidly expanding gas, liquid, or solid can cause frostbite.

Routes of entry : Inhalation,Dermal,Eyes

Potential acute health effects

Eyes : Moderately irritating to the eyes.

Skin : Moderately irritating to the skin.

Inhalation : Moderately irritating to the respiratory system.

Ingestion : Ingestion is not a normal route of exposure for gases

Potential chronic health effects	**CARCINOGENIC EFFECTS:** Not available. **MUTAGENIC EFFECTS:** Not available. **TERATOGENIC EFFECTS:** Not available.
Medical conditions aggravated by overexposure	Acute or chronic respiratory conditions may be aggravated by overexposure to this gas.

See toxicological Information (section 11)

Section 4. First aid measures

No action shall be taken involving any personal risk or without suitable training.If fumes are still suspected to be present, the rescuer should wear an appropriate mask or a self-contained breathing apparatus.It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

Eye contact	In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical attention immediately.
Skin contact	In case of contact, immediately flush skin with plenty of water. Remove contaminated clothing and shoes. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention.
Frostbite	Try to warm up the frozen tissues and seek medical attention.
Inhalation	If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention.
Ingestion	Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical attention if symptoms appear.

Section 5. Fire fighting measures

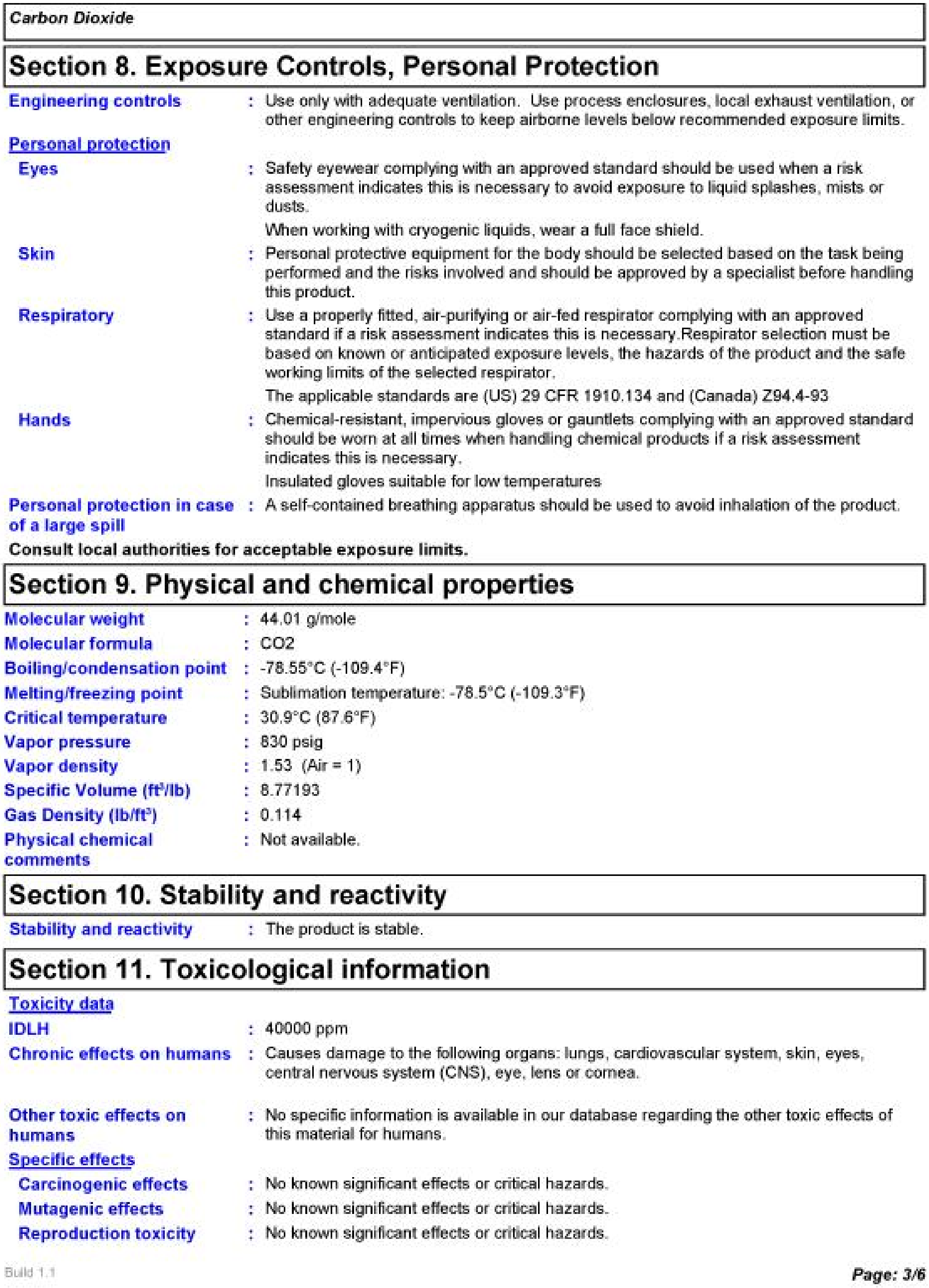
Flammability of the product	Non-flammable.
Fire fighting media and instructions	Use an extinguishing agent suitable for surrounding fires. If involved in fire, shut off flow immediately if it can be done without risk. Apply water from a safe distance to cool container and protect surrounding area. No specific hazard.
Special protective equipment for fire-fighters	Fire fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full facepiece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions	Immediately contact emergency personnel. Keep unnecessary personnel away. Use suitable protective equipment (Section 8). Shut off gas supply if this can be done safely. Isolate area until gas has dispersed.
Environmental precautions	Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers.

Section 7. Handling and storage

Handling	Avoid contact with eyes, skin and clothing. Keep container closed. Use only with adequate ventilation. Do not puncture or incinerate container. Wash thoroughly after handling. High pressure gas. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement. Never allow any unprotected part of the body to touch uninsulated pipes or vessels that contain cryogenic liquids. Prevent entrapment of liquid in closed systems or piping without pressure relief devices. Some materials may become brittle at low temperatures and will easily fracture.
Storage	Keep container tightly closed. Keep container in a cool, well-ventilated area. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).



Carbon Dioxide

Section 8. Exposure Controls, Personal Protection

Engineering controls : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits.

Personal protection

Eyes : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists or dusts.

When working with cryogenic liquids, wear a full face shield.

Skin : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory : Use a properly fitted, air-purifying or air-fed respirator complying with an approved standard if a risk assessment indicates this is necessary.Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

The applicable standards are (US) 29 CFR 1910.134 and (Canada) Z94.4-93

Hands : Chemical-resistant, impervious gloves or gauntlets complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary.

Insulated gloves suitable for low temperatures

Personal protection in case of a large spill : A self-contained breathing apparatus should be used to avoid inhalation of the product.

Consult local authorities for acceptable exposure limits.

Section 9. Physical and chemical properties

Molecular weight : 44.01 g/mole

Molecular formula : CO2

Boiling/condensation point : -78.55°C (-109.4°F)

Melting/freezing point : Sublimation temperature: -78.5°C (-109.3°F)

Critical temperature : 30.9°C (87.6°F)

Vapor pressure : 830 psig

Vapor density : 1.53 (Air = 1)

Specific Volume (ft^3/lb) : 8.77193

Gas Density (lb/ft^3) : 0.114

Physical chemical comments : Not available.

Section 10. Stability and reactivity

Stability and reactivity : The product is stable.

Section 11. Toxicological information

Toxicity data

IDLH : 40000 ppm

Chronic effects on humans : Causes damage to the following organs: lungs, cardiovascular system, skin, eyes, central nervous system (CNS), eye, lens or cornea.

Other toxic effects on humans : No specific information is available in our database regarding the other toxic effects of this material for humans.

Specific effects

Carcinogenic effects : No known significant effects or critical hazards.

Mutagenic effects : No known significant effects or critical hazards.

Reproduction toxicity : No known significant effects or critical hazards.

Build 1.1

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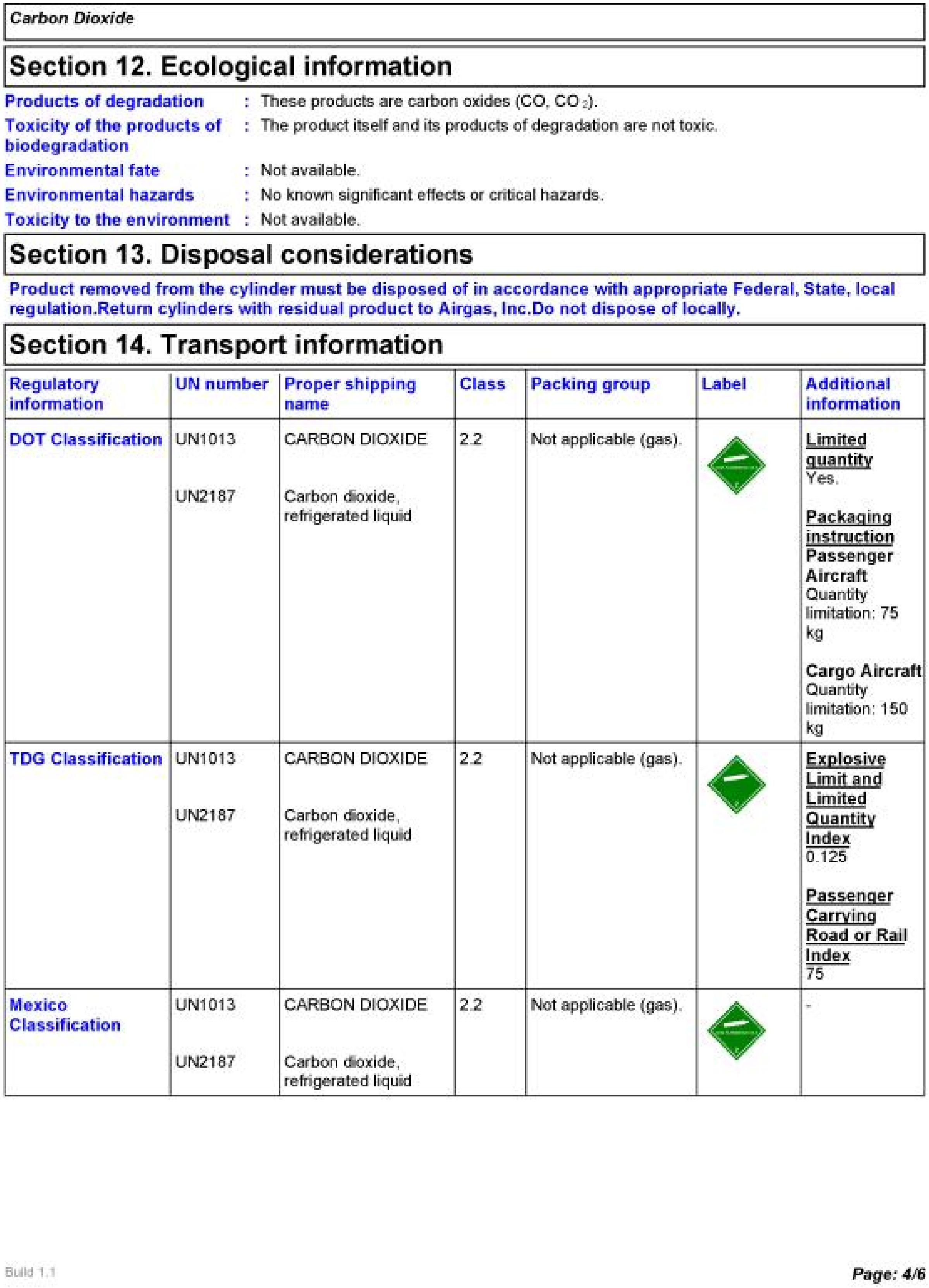

Section 12. Ecological information

Products of degradation	: These products are carbon oxides (CO, CO_2).
Toxicity of the products of biodegradation	: The product itself and its products of degradation are not toxic.
Environmental fate	: Not available.
Environmental hazards	: No known significant effects or critical hazards.
Toxicity to the environment	: Not available.

Section 13. Disposal considerations

Product removed from the cylinder must be disposed of in accordance with appropriate Federal, State, local regulation.Return cylinders with residual product to Airgas, Inc.Do not dispose of locally.

Section 14. Transport information

Regulatory information	UN number	Proper shipping name	Class	Packing group	Label	Additional information
DOT Classification	UN1013 UN2187	CARBON DIOXIDE Carbon dioxide, refrigerated liquid	2.2	Not applicable (gas).	◆	**Limited quantity** Yes. **Packaging instruction** **Passenger Aircraft** Quantity limitation: 75 kg **Cargo Aircraft** Quantity limitation: 150 kg
TDG Classification	UN1013 UN2187	CARBON DIOXIDE Carbon dioxide, refrigerated liquid	2.2	Not applicable (gas).	◆	**Explosive Limit and Limited Quantity Index** 0.125 **Passenger Carrying Road or Rail Index** 75
Mexico Classification	UN1013 UN2187	CARBON DIOXIDE Carbon dioxide, refrigerated liquid	2.2	Not applicable (gas).	◆	-

Section 15. Regulatory information

United States

U.S. Federal regulations : TSCA 8(b) inventory: Carbon Dioxide

SARA 302/304/311/312 extremely hazardous substances: No products were found.
SARA 302/304 emergency planning and notification: No products were found.
SARA 302/304/311/312 hazardous chemicals: Carbon Dioxide
SARA 311/312 MSDS distribution - chemical inventory - hazard identification: Carbon Dioxide: Sudden Release of Pressure, Immediate (Acute) Health Hazard, Delayed (Chronic) Health Hazard

Clean Water Act (CWA) 307: No products were found.

Clean Water Act (CWA) 311: No products were found.

Clean air act (CAA) 112 accidental release prevention: No products were found.

Clean air act (CAA) 112 regulated flammable substances: No products were found.

Clean air act (CAA) 112 regulated toxic substances: No products were found.

State regulations : Pennsylvania RTK: Carbon Dioxide: (generic environmental hazard)
Massachusetts RTK: Carbon Dioxide
New Jersey: Carbon Dioxide

Canada

WHMIS (Canada) : Class A: Compressed gas.

CEPA DSL: Carbon Dioxide

Section 16. Other information

United States

Label Requirements : CONTENTS UNDER PRESSURE.
CAUSES DAMAGE TO THE FOLLOWING ORGANS: LUNGS, CARDIOVASCULAR SYSTEM, SKIN, EYES, CENTRAL NERVOUS SYSTEM, EYE, LENS OR CORNEA.
MAY CAUSE RESPIRATORY TRACT, EYE AND SKIN IRRITATION.

Canada

Label Requirements : Class A: Compressed gas.

Hazardous Material Information System (U.S.A.) :

Health	*	1
Fire hazard		0
Reactivity		0
Personal protection		C

liquid:

Health		3
Fire hazard		0
Reactivity		0
Personal protection		

National Fire Protection Association (U.S.A.) :

liquid:

Carbon Dioxide

Health 3
Flammability 0
Instability 0
Special

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above named supplier nor any of its subsidiaries assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

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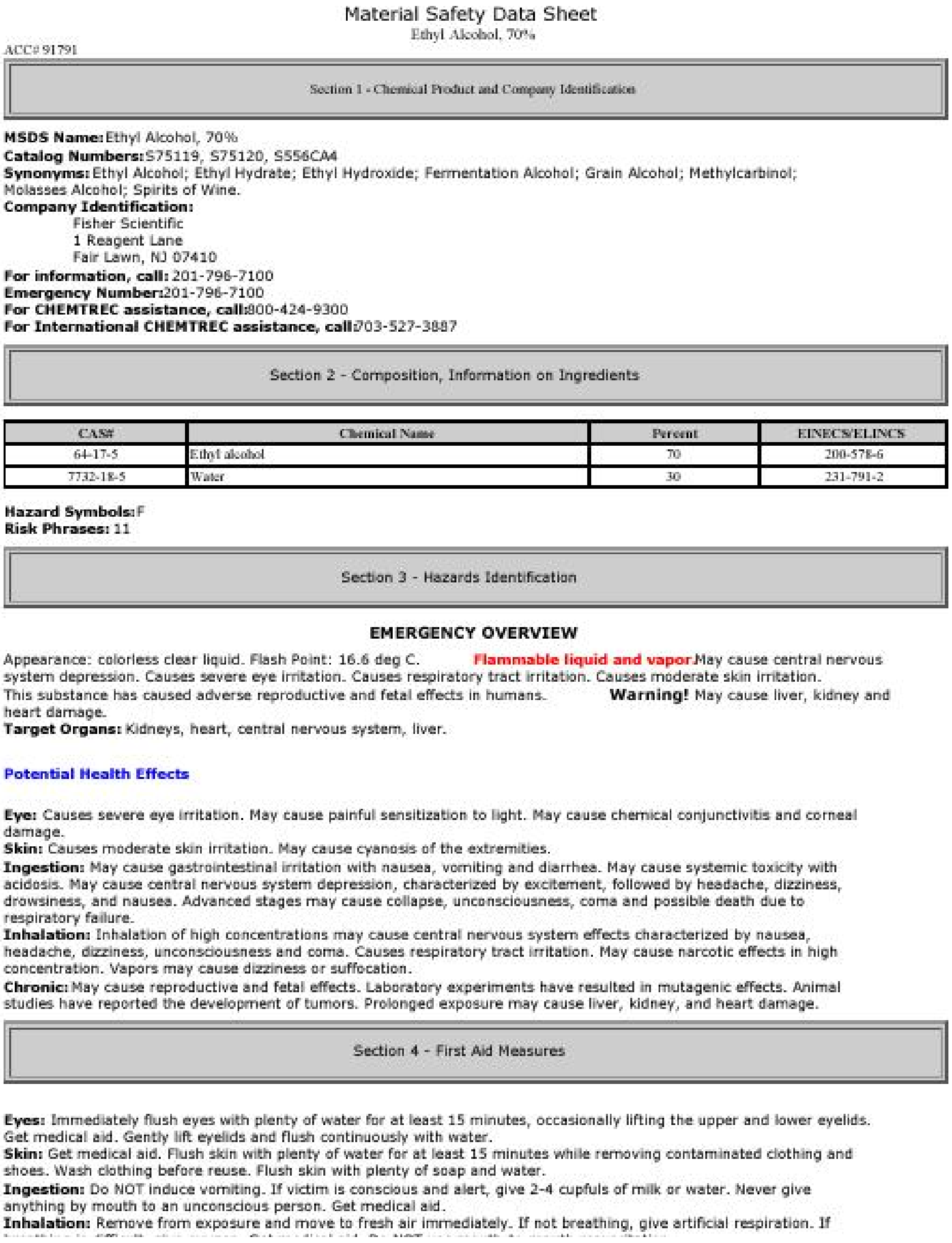


Material Safety Data Sheet

Ethyl Alcohol, 70%

ACC# 91791

Section 1 - Chemical Product and Company Identification

MSDS Name: Ethyl Alcohol, 70%

Catalog Numbers: S75119, S75120, S556CA4

Synonyms: Ethyl Alcohol; Ethyl Hydrate; Ethyl Hydroxide; Fermentation Alcohol; Grain Alcohol; Methylcarbinol; Molasses Alcohol; Spirits of Wine.

Company Identification:

Fisher Scientific
1 Reagent Lane
Fair Lawn, NJ 07410

For information, call: 201-796-7100
Emergency Number: 201-796-7100
For CHEMTREC assistance, call: 800-424-9300
For International CHEMTREC assistance, call: 703-527-3887

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
64-17-5	Ethyl alcohol	70	200-578-6
7732-18-5	Water	30	231-791-2

Hazard Symbols: F
Risk Phrases: 11

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: colorless clear liquid. Flash Point: 16.6 deg C. **Flammable liquid and vapor.** May cause central nervous system depression. Causes severe eye irritation. Causes respiratory tract irritation. Causes moderate skin irritation.
This substance has caused adverse reproductive and fetal effects in humans. **Warning!** May cause liver, kidney and heart damage.

Target Organs: Kidneys, heart, central nervous system, liver.

Potential Health Effects

Eye: Causes severe eye irritation. May cause painful sensitization to light. May cause chemical conjunctivitis and corneal damage.

Skin: Causes moderate skin irritation. May cause cyanosis of the extremities.

Ingestion: May cause gastrointestinal irritation with nausea, vomiting and diarrhea. May cause systemic toxicity with acidosis. May cause central nervous system depression, characterized by excitement, followed by headache, dizziness, drowsiness, and nausea. Advanced stages may cause collapse, unconsciousness, coma and possible death due to respiratory failure.

Inhalation: Inhalation of high concentrations may cause central nervous system effects characterized by nausea, headache, dizziness, unconsciousness and coma. Causes respiratory tract irritation. May cause narcotic effects in high concentration. Vapors may cause dizziness or suffocation.

Chronic: May cause reproductive and fetal effects. Laboratory experiments have resulted in mutagenic effects. Animal studies have reported the development of tumors. Prolonged exposure may cause liver, kidney, and heart damage.

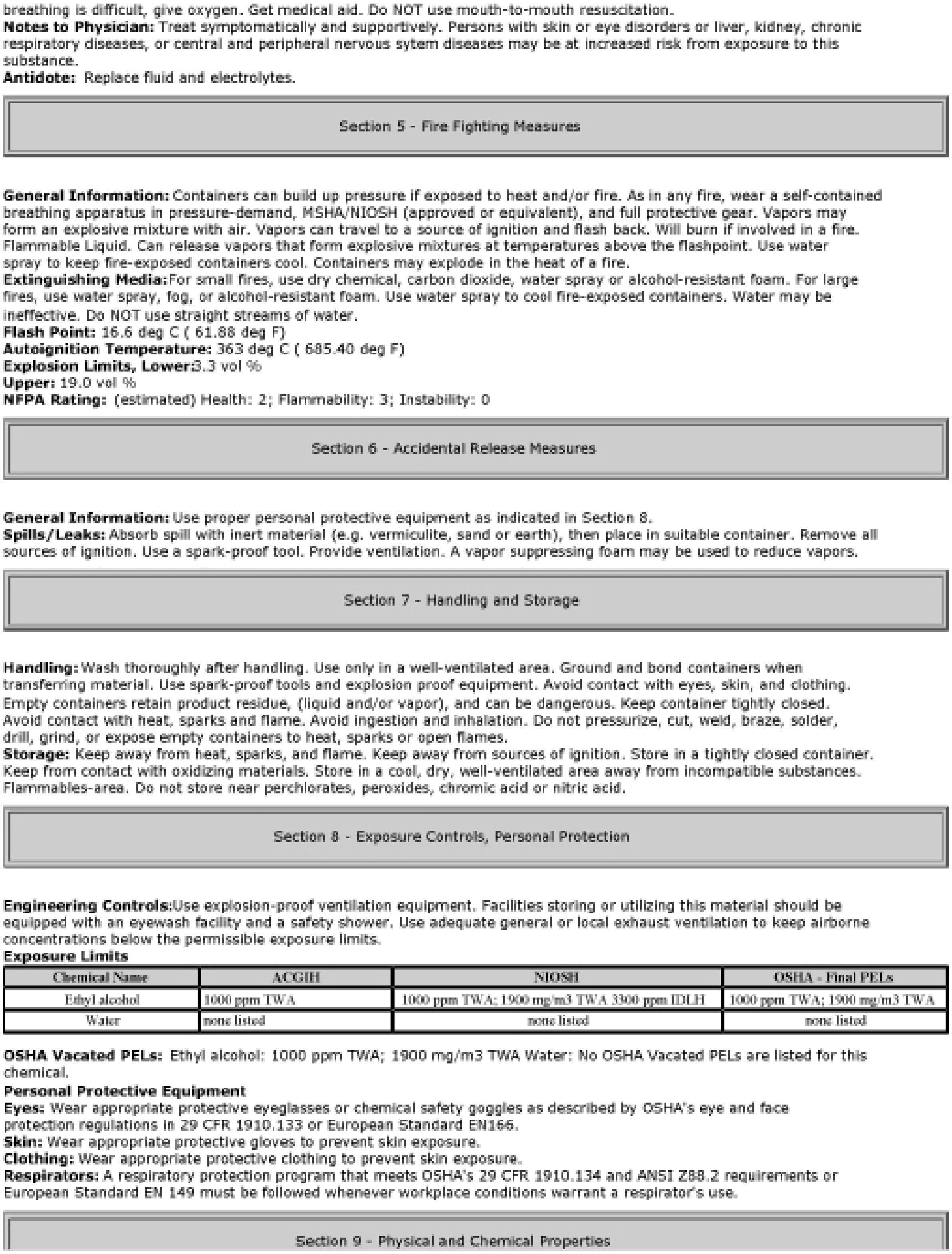
Section 4 - First Aid Measures

Eyes: Immediately flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid. Gently lift eyelids and flush continuously with water.

Skin: Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. Flush skin with plenty of soap and water.

Ingestion: Do NOT induce vomiting. If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid.

Inhalation: Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If



breathing is difficult, give oxygen. Get medical aid. Do NOT use mouth-to-mouth resuscitation.
Notes to Physician: Treat symptomatically and supportively. Persons with skin or eye disorders or liver, kidney, chronic respiratory diseases, or central and peripheral nervous sytem diseases may be at increased risk from exposure to this substance.
Antidote: Replace fluid and electrolytes.

Section 5 - Fire Fighting Measures

General Information: Containers can build up pressure if exposed to heat and/or fire. As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Vapors may form an explosive mixture with air. Vapors can travel to a source of ignition and flash back. Will burn if involved in a fire. Flammable Liquid. Can release vapors that form explosive mixtures at temperatures above the flashpoint. Use water spray to keep fire-exposed containers cool. Containers may explode in the heat of a fire.
Extinguishing Media: For small fires, use dry chemical, carbon dioxide, water spray or alcohol-resistant foam. For large fires, use water spray, fog, or alcohol-resistant foam. Use water spray to cool fire-exposed containers. Water may be ineffective. Do NOT use straight streams of water.
Flash Point: 16.6 deg C (61.88 deg F)
Autoignition Temperature: 363 deg C (685.40 deg F)
Explosion Limits, Lower: 3.3 vol %
Upper: 19.0 vol %
NFPA Rating: (estimated) Health: 2; Flammability: 3; Instability: 0

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Remove all sources of ignition. Use a spark-proof tool. Provide ventilation. A vapor suppressing foam may be used to reduce vapors.

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Use only in a well-ventilated area. Ground and bond containers when transferring material. Use spark-proof tools and explosion proof equipment. Avoid contact with eyes, skin, and clothing. Empty containers retain product residue, (liquid and/or vapor), and can be dangerous. Keep container tightly closed. Avoid contact with heat, sparks and flame. Avoid ingestion and inhalation. Do not pressurize, cut, weld, braze, solder, drill, grind, or expose empty containers to heat, sparks or open flames.
Storage: Keep away from heat, sparks, and flame. Keep away from sources of ignition. Store in a tightly closed container. Keep from contact with oxidizing materials. Store in a cool, dry, well-ventilated area away from incompatible substances. Flammables-area. Do not store near perchlorates, peroxides, chromic acid or nitric acid.

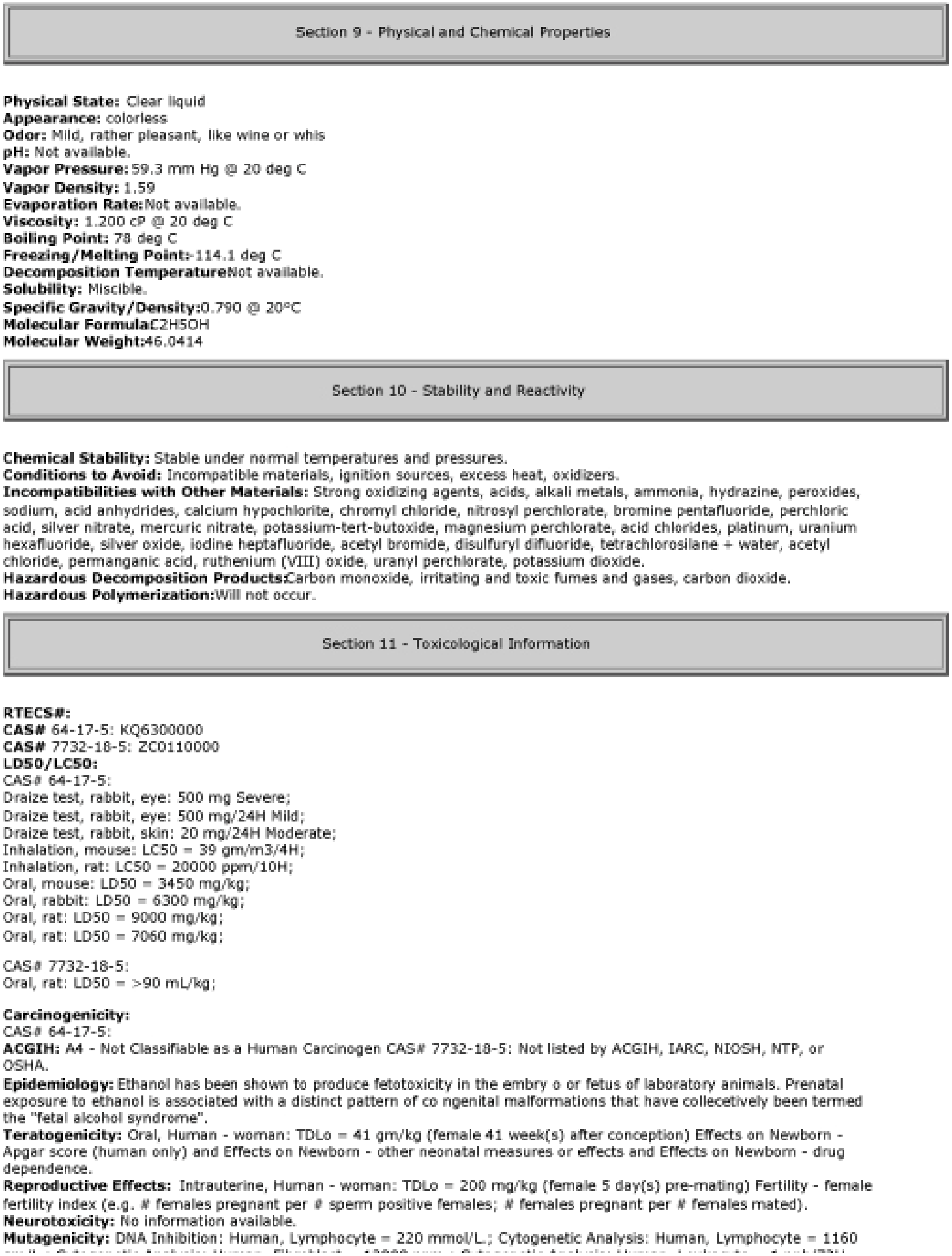
Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Use explosion-proof ventilation equipment. Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.
Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Ethyl alcohol	1000 ppm TWA	1000 ppm TWA; 1900 mg/m3 TWA 3300 ppm IDLH	1000 ppm TWA; 1900 mg/m3 TWA
Water	none listed	none listed	none listed

OSHA Vacated PELs: Ethyl alcohol: 1000 ppm TWA; 1900 mg/m3 TWA Water: No OSHA Vacated PELs are listed for this chemical.
Personal Protective Equipment
Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin: Wear appropriate protective gloves to prevent skin exposure.
Clothing: Wear appropriate protective clothing to prevent skin exposure.
Respirators: A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant a respirator's use.

Section 9 - Physical and Chemical Properties



Section 9 - Physical and Chemical Properties

Physical State: Clear liquid
Appearance: colorless
Odor: Mild, rather pleasant, like wine or whis
pH: Not available.
Vapor Pressure: 59.3 mm Hg @ 20 deg C
Vapor Density: 1.59
Evaporation Rate: Not available.
Viscosity: 1.200 cP @ 20 deg C
Boiling Point: 78 deg C
Freezing/Melting Point:-114.1 deg C
Decomposition Temperature Not available.
Solubility: Miscible.
Specific Gravity/Density:0.790 @ 20°C
Molecular Formula:C2H5OH
Molecular Weight:46.0414

Section 10 - Stability and Reactivity

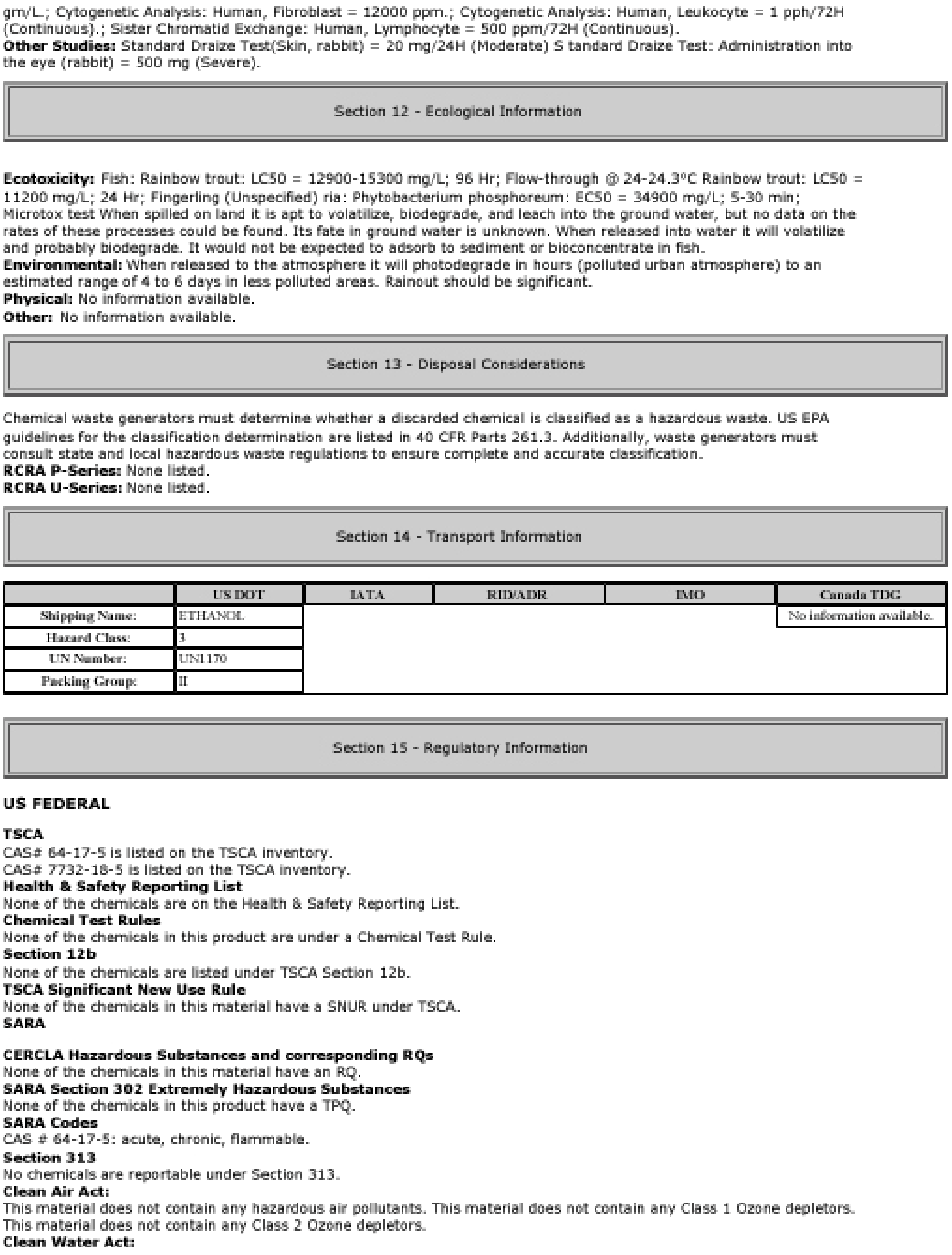
Chemical Stability: Stable under normal temperatures and pressures.
Conditions to Avoid: Incompatible materials, ignition sources, excess heat, oxidizers.
Incompatibilities with Other Materials: Strong oxidizing agents, acids, alkali metals, ammonia, hydrazine, peroxides, sodium, acid anhydrides, calcium hypochlorite, chromyl chloride, nitrosyl perchlorate, bromine pentafluoride, perchloric acid, silver nitrate, mercuric nitrate, potassium-tert-butoxide, magnesium perchlorate, acid chlorides, platinum, uranium hexafluoride, silver oxide, iodine heptafluoride, acetyl bromide, disulfuryl difluoride, tetrachlorosilane + water, acetyl chloride, permanganic acid, ruthenium (VIII) oxide, uranyl perchlorate, potassium dioxide.
Hazardous Decomposition Products: Carbon monoxide, irritating and toxic fumes and gases, carbon dioxide.
Hazardous Polymerization: Will not occur.

Section 11 - Toxicological Information

RTECS#:
CAS# 64-17-5: KQ6300000
CAS# 7732-18-5: ZC0110000
LD50/LC50:
CAS# 64-17-5:
Draize test, rabbit, eye: 500 mg Severe;
Draize test, rabbit, eye: 500 mg/24H Mild;
Draize test, rabbit, skin: 20 mg/24H Moderate;
Inhalation, mouse: LC50 = 39 gm/m3/4H;
Inhalation, rat: LC50 = 20000 ppm/10H;
Oral, mouse: LD50 = 3450 mg/kg;
Oral, rabbit: LD50 = 6300 mg/kg;
Oral, rat: LD50 = 9000 mg/kg;
Oral, rat: LD50 = 7060 mg/kg;

CAS# 7732-18-5:
Oral, rat: LD50 = >90 mL/kg;

Carcinogenicity:
CAS# 64-17-5:
ACGIH: A4 - Not Classifiable as a Human Carcinogen CAS# 7732-18-5: Not listed by ACGIH, IARC, NIOSH, NTP, or OSHA.
Epidemiology: Ethanol has been shown to produce fetotoxicity in the embry o or fetus of laboratory animals. Prenatal exposure to ethanol is associated with a distinct pattern of co ngenital malformations that have collecetively been termed the "fetal alcohol syndrome".
Teratogenicity: Oral, Human - woman: TDLo = 41 gm/kg (female 41 week(s) after conception) Effects on Newborn - Apgar score (human only) and Effects on Newborn - other neonatal measures or effects and Effects on Newborn - drug dependence.
Reproductive Effects: Intrauterine, Human - woman: TDLo = 200 mg/kg (female 5 day(s) pre-mating) Fertility - female fertility index (e.g. # females pregnant per # sperm positive females; # females pregnant per # females mated).
Neurotoxicity: No information available.
Mutagenicity: DNA Inhibition: Human, Lymphocyte = 220 mmol/L.; Cytogenetic Analysis: Human, Lymphocyte = 1160



gm/L.; Cytogenetic Analysis: Human, Fibroblast = 12000 ppm.; Cytogenetic Analysis: Human, Leukocyte = 1 pph/72H (Continuous).; Sister Chromatid Exchange: Human, Lymphocyte = 500 ppm/72H (Continuous).
Other Studies: Standard Draize Test(Skin, rabbit) = 20 mg/24H (Moderate) S tandard Draize Test: Administration into the eye (rabbit) = 500 mg (Severe).

Section 12 - Ecological Information

Ecotoxicity: Fish: Rainbow trout: LC50 = 12900-15300 mg/L; 96 Hr; Flow-through @ 24-24.3°C Rainbow trout: LC50 = 11200 mg/L; 24 Hr; Fingerling (Unspecified) ria: Phytobacterium phosphoreum: EC50 = 34900 mg/L; 5-30 min; Microtox test When spilled on land it is apt to volatilize, biodegrade, and leach into the ground water, but no data on the rates of these processes could be found. Its fate in ground water is unknown. When released into water it will volatilize and probably biodegrade. It would not be expected to adsorb to sediment or bioconcentrate in fish.
Environmental: When released to the atmosphere it will photodegrade in hours (polluted urban atmosphere) to an estimated range of 4 to 6 days in less polluted areas. Rainout should be significant.
Physical: No information available.
Other: No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: None listed.

Section 14 - Transport Information

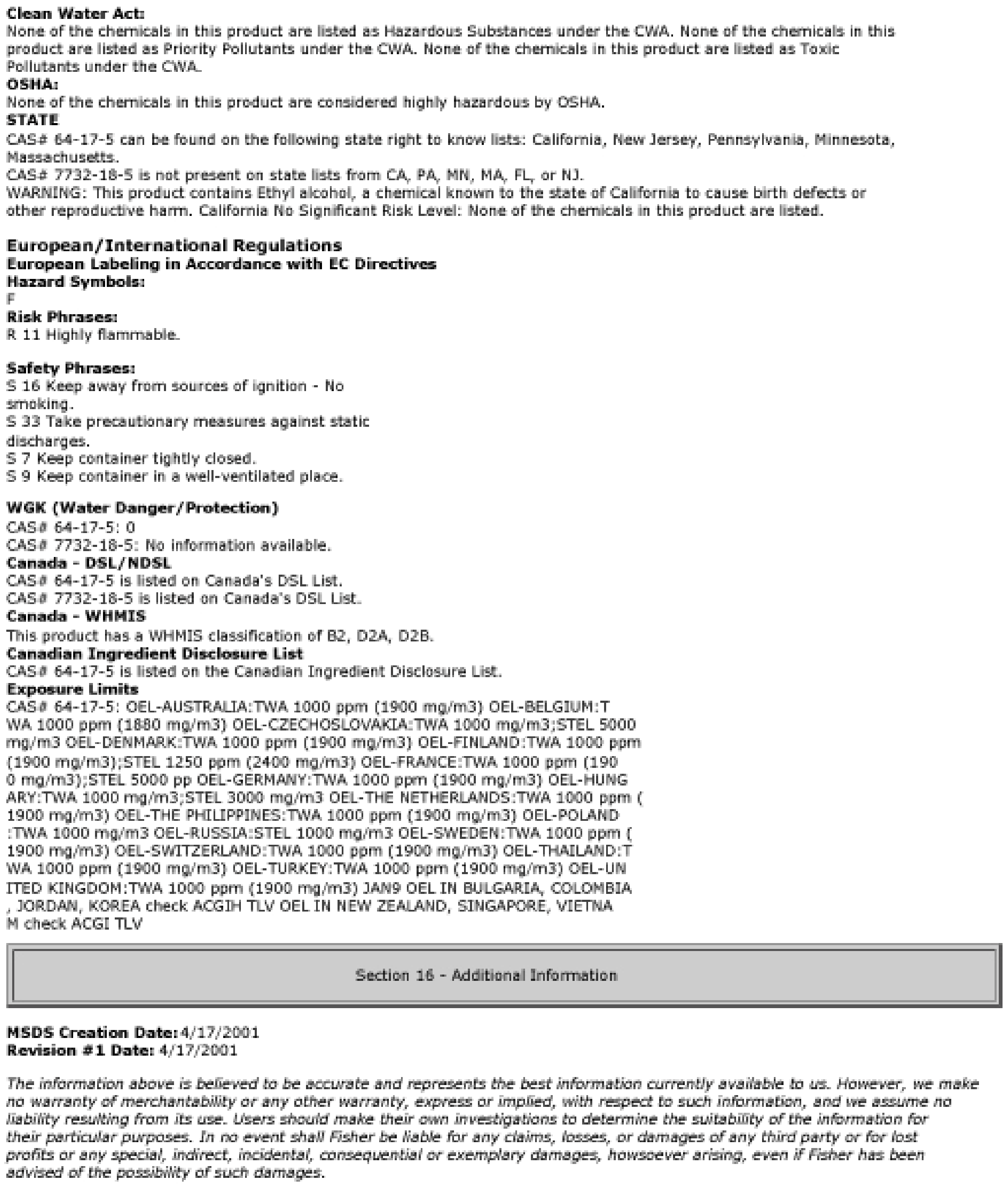
	US DOT	IATA	RID/ADR	IMO	Canada TDG
Shipping Name:	ETHANOL				No information available.
Hazard Class:	3				
UN Number:	UN1170				
Packing Group:	II				

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 64-17-5 is listed on the TSCA inventory.
CAS# 7732-18-5 is listed on the TSCA inventory.
Health & Safety Reporting List
None of the chemicals are on the Health & Safety Reporting List.
Chemical Test Rules
None of the chemicals in this product are under a Chemical Test Rule.
Section 12b
None of the chemicals are listed under TSCA Section 12b.
TSCA Significant New Use Rule
None of the chemicals in this material have a SNUR under TSCA.
SARA

CERCLA Hazardous Substances and corresponding RQs
None of the chemicals in this material have an RQ.
SARA Section 302 Extremely Hazardous Substances
None of the chemicals in this product have a TPQ.
SARA Codes
CAS # 64-17-5: acute, chronic, flammable.
Section 313
No chemicals are reportable under Section 313.
Clean Air Act:
This material does not contain any hazardous air pollutants. This material does not contain any Class 1 Ozone depletors. This material does not contain any Class 2 Ozone depletors.
Clean Water Act:



Clean Water Act:
None of the chemicals in this product are listed as Hazardous Substances under the CWA. None of the chemicals in this product are listed as Priority Pollutants under the CWA. None of the chemicals in this product are listed as Toxic Pollutants under the CWA.
OSHA:
None of the chemicals in this product are considered highly hazardous by OSHA.
STATE
CAS# 64-17-5 can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Minnesota, Massachusetts.
CAS# 7732-18-5 is not present on state lists from CA, PA, MN, MA, FL, or NJ.
WARNING: This product contains Ethyl alcohol, a chemical known to the state of California to cause birth defects or other reproductive harm. California No Significant Risk Level: None of the chemicals in this product are listed.

European/International Regulations
European Labeling in Accordance with EC Directives
Hazard Symbols:
F
Risk Phrases:
R 11 Highly flammable.

Safety Phrases:
S 16 Keep away from sources of ignition - No smoking.
S 33 Take precautionary measures against static discharges.
S 7 Keep container tightly closed.
S 9 Keep container in a well-ventilated place.

WGK (Water Danger/Protection)
CAS# 64-17-5: 0
CAS# 7732-18-5: No information available.
Canada - DSL/NDSL
CAS# 64-17-5 is listed on Canada's DSL List.
CAS# 7732-18-5 is listed on Canada's DSL List.
Canada - WHMIS
This product has a WHMIS classification of B2, D2A, D2B.
Canadian Ingredient Disclosure List
CAS# 64-17-5 is listed on the Canadian Ingredient Disclosure List.
Exposure Limits
CAS# 64-17-5: OEL-AUSTRALIA:TWA 1000 ppm (1900 mg/m3) OEL-BELGIUM:TWA 1000 ppm (1880 mg/m3) OEL-CZECHOSLOVAKIA:TWA 1000 mg/m3;STEL 5000 mg/m3 OEL-DENMARK:TWA 1000 ppm (1900 mg/m3) OEL-FINLAND:TWA 1000 ppm (1900 mg/m3);STEL 1250 ppm (2400 mg/m3) OEL-FRANCE:TWA 1000 ppm (1900 mg/m3);STEL 5000 pp OEL-GERMANY:TWA 1000 ppm (1900 mg/m3) OEL-HUNGARY:TWA 1000 mg/m3;STEL 3000 mg/m3 OEL-THE NETHERLANDS:TWA 1000 ppm (1900 mg/m3) OEL-THE PHILIPPINES:TWA 1000 ppm (1900 mg/m3) OEL-POLAND:TWA 1000 mg/m3 OEL-RUSSIA:STEL 1000 mg/m3 OEL-SWEDEN:TWA 1000 ppm (1900 mg/m3) OEL-SWITZERLAND:TWA 1000 ppm (1900 mg/m3) OEL-THAILAND:TWA 1000 ppm (1900 mg/m3) OEL-TURKEY:TWA 1000 ppm (1900 mg/m3) OEL-UNITED KINGDOM:TWA 1000 ppm (1900 mg/m3) JAN9 OEL IN BULGARIA, COLOMBIA, JORDAN, KOREA check ACGIH TLV OEL IN NEW ZEALAND, SINGAPORE, VIETNAM check ACGI TLV

Section 16 - Additional Information

MSDS Creation Date: 4/17/2001
Revision #1 Date: 4/17/2001

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Fisher be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if Fisher has been advised of the possibility of such damages.

MATERIAL SAFETY DATA SHEET

Gasoline, All Grades **MSDS No. 9950**

EMERGENCY OVERVIEW
DANGER!
EXTREMELY FLAMMABLE - EYE AND MUCOUS MEMBRANE IRRITANT - EFFECTS CENTRAL NERVOUS SYSTEM - HARMFUL OR FATAL IF SWALLOWED - ASPIRATION HAZARD

NFPA 704 (Section 16)

High fire hazard. Keep away from heat, spark, open flame, and other ignition sources.

If ingested, do NOT induce vomiting, as this may cause chemical pneumonia (fluid in the lungs). Contact may cause eye, skin and mucous membrane irritation. Harmful if absorbed through the skin. Avoid prolonged breathing of vapors or mists. Inhalation may cause irritation, anesthetic effects (dizziness, nausea, headache, intoxication), and respiratory system effects.

Long-term exposure may cause effects to specific organs, such as to the liver, kidneys, blood, nervous system, and skin. Contains benzene, which can cause blood disease, including anemia and leukemia.

1. CHEMICAL PRODUCT and COMPANY INFORMATION

Hess Corporation
1 Hess Plaza
Woodbridge, NJ 07095-0961

EMERGENCY TELEPHONE NUMBER (24 hrs):	**CHEMTREC (800)424-9300**
COMPANY CONTACT (business hours):	Corporate Safety (732)750-6000
MSDS (Environment, Health, Safety) Internet Website	www.hess.com

SYNONYMS: Hess Conventional (Oxygenated and Non-oxygenated) Gasoline; Reformulated Gasoline (RFG); Reformulated Gasoline Blendstock for Oxygenate Blending (RBOB); Unleaded Motor or Automotive Gasoline

See Section 16 for abbreviations and acronyms.

2. COMPOSITION and INFORMATION ON INGREDIENTS *

INGREDIENT NAME (CAS No.)	CONCENTRATION PERCENT BY WEIGHT
Gasoline (86290-81-5)	100
Benzene (71-43-2)	0.1 - 4.9 (0.1 - 1.3 reformulated gasoline)
n-Butane (106-97-8)	< 10
Ethyl Alcohol (Ethanol) (64-17-5)	0 - 10
Ethyl benzene (100-41-4)	< 3
n-Hexane (110-54-3)	0.5 to 4
Methyl-tertiary butyl ether (MTBE) (1634-04-4)	0 to 15.0
Tertiary-amyl methyl ether (TAME) (994-05-8)	0 to 17.2
Toluene (108-88-3)	1 - 25
1,2,4- Trimethylbenzene (95-63-6)	< 6
Xylene, mixed isomers (1330-20-7)	1 - 15

A complex blend of petroleum-derived normal and branched-chain alkane, cycloalkane, alkene, and aromatic hydrocarbons. May contain antioxidant and multifunctional additives. Non-oxygenated Conventional Gasoline and RBOB do not have oxygenates (Ethanol or MTBE and/or TAME).

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Oxygenated Conventional and Reformulated Gasoline will have oxygenates for octane enhancement or as legally required.

3. HAZARDS IDENTIFICATION

EYES
Moderate irritant. Contact with liquid or vapor may cause irritation.

SKIN
Practically non-toxic if absorbed following acute (single) exposure. May cause skin irritation with prolonged or repeated contact. Liquid may be absorbed through the skin in toxic amounts if large areas of skin are exposed repeatedly.

INGESTION
The major health threat of ingestion occurs from the danger of aspiration (breathing) of liquid drops into the lungs, particularly from vomiting. Aspiration may result in chemical pneumonia (fluid in the lungs), severe lung damage, respiratory failure and even death.

Ingestion may cause gastrointestinal disturbances, including irritation, nausea, vomiting and diarrhea, and central nervous system (brain) effects similar to alcohol intoxication. In severe cases, tremors, convulsions, loss of consciousness, coma, respiratory arrest, and death may occur.

INHALATION
Excessive exposure may cause irritations to the nose, throat, lungs and respiratory tract. Central nervous system (brain) effects may include headache, dizziness, loss of balance and coordination, unconsciousness, coma, respiratory failure, and death.

WARNING: the burning of any hydrocarbon as a fuel in an area without adequate ventilation may result in hazardous levels of combustion products, including carbon monoxide, and inadequate oxygen levels, which may cause unconsciousness, suffocation, and death.

CHRONIC EFFECTS and CARCINOGENICITY
Contains benzene, a regulated human carcinogen. Benzene has the potential to cause anemia and other blood diseases, including leukemia, after repeated and prolonged exposure. Exposure to light hydrocarbons in the same boiling range as this product has been associated in animal studies with systemic toxicity. See also Section 11 - Toxicological Information.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE
Irritation from skin exposure may aggravate existing open wounds, skin disorders, and dermatitis (rash). Chronic respiratory disease, liver or kidney dysfunction, or pre-existing central nervous system disorders may be aggravated by exposure.

4. FIRST AID MEASURES

EYES
In case of contact with eyes, immediately flush with clean, low-pressure water for at least 15 min. Hold eyelids open to ensure adequate flushing. Seek medical attention.

SKIN
Remove contaminated clothing. Wash contaminated areas thoroughly with soap and water or waterless hand cleanser. Obtain medical attention if irritation or redness develops.

INGESTION

DO NOT INDUCE VOMITING. Do not give liquids. Obtain immediate medical attention. If spontaneous vomiting occurs, lean victim forward to reduce the risk of aspiration. Small amounts of material which enter the mouth should be rinsed out until the taste is dissipated.

INHALATION
Remove person to fresh air. If person is not breathing, ensure an open airway and provide artificial respiration. If necessary, provide additional oxygen once breathing is restored if trained to do so. Seek medical attention immediately.

5. FIRE FIGHTING MEASURES

FLAMMABLE PROPERTIES:

FLASH POINT:	-45 °F (-43°C)
AUTOIGNITION TEMPERATURE:	highly variable; > 530 °F (>280 °C)
OSHA/NFPA FLAMMABILITY CLASS:	1A (flammable liquid)
LOWER EXPLOSIVE LIMIT (%):	1.4%
UPPER EXPLOSIVE LIMIT (%):	7.6%

FIRE AND EXPLOSION HAZARDS
Vapors may be ignited rapidly when exposed to heat, spark, open flame or other source of ignition. Flowing product may be ignited by self-generated static electricity. When mixed with air and exposed to an ignition source, flammable vapors can burn in the open or explode in confined spaces. Being heavier than air, vapors may travel long distances to an ignition source and flash back. Runoff to sewer may cause fire or explosion hazard.

EXTINGUISHING MEDIA
SMALL FIRES: Any extinguisher suitable for Class B fires, dry chemical, CO2, water spray, fire fighting foam, or Halon.

LARGE FIRES: Water spray, fog or fire fighting foam. Water may be ineffective for fighting the fire, but may be used to cool fire-exposed containers.

During certain times of the year and/or in certain geographical locations, gasoline may contain MTBE and/or TAME. Firefighting foam suitable for polar solvents is recommended for fuel with greater than 10% oxygenate concentration - refer to NFPA 11 "Low Expansion Foam - 1994 Edition."

FIRE FIGHTING INSTRUCTIONS
Small fires in the incipient (beginning) stage may typically be extinguished using handheld portable fire extinguishers and other fire fighting equipment.

Firefighting activities that may result in potential exposure to high heat, smoke or toxic by-products of combustion should require NIOSH/MSHA- approved pressure-demand self-contained breathing apparatus with full facepiece and full protective clothing.

Isolate area around container involved in fire. Cool tanks, shells, and containers exposed to fire and excessive heat with water. For massive fires the use of unmanned hose holders or monitor nozzles may be advantageous to further minimize personnel exposure. Major fires may require withdrawal, allowing the tank to burn. Large storage tank fires typically require specially trained personnel and equipment to extinguish the fire, often including the need for properly applied fire fighting foam.

See Section 16 for the NFPA 704 Hazard Rating.

6. ACCIDENTAL RELEASE MEASURES

ACTIVATE FACILITY SPILL CONTINGENCY or EMERGENCY PLAN.

Evacuate nonessential personnel and remove or secure all ignition sources. Consider wind direction; stay upwind and uphill, if possible. Evaluate the direction of product travel, diking, sewers, etc. to confirm spill areas. Spills may infiltrate subsurface soil and groundwater; professional assistance may be necessary to determine the extent of subsurface impact.

Carefully contain and stop the source of the spill, if safe to do so. Protect bodies of water by diking, absorbents, or absorbent boom, if possible. Do not flush down sewer or drainage systems, unless system is designed and permitted to handle such material. The use of fire fighting foam may be useful in certain situations to reduce vapors. The proper use of water spray may effectively disperse product vapors or the liquid itself, preventing contact with ignition sources or areas/equipment that require protection.

Take up with sand or other oil absorbing materials. Carefully shovel, scoop or sweep up into a waste container for reclamation or disposal - caution, flammable vapors may accumulate in closed containers. Response and clean-up crews must be properly trained and must utilize proper protective equipment (see Section 8).

7. HANDLING and STORAGE

HANDLING PRECAUTIONS

******USE ONLY AS A MOTOR FUEL******
******DO NOT SIPHON BY MOUTH******

Handle as a flammable liquid. Keep away from heat, sparks, and open flame! Electrical equipment should be approved for classified area. Bond and ground containers during product transfer to reduce the possibility of static-initiated fire or explosion.

Special slow load procedures for "switch loading" must be followed to avoid the static ignition hazard that can exist when higher flash point material (such as fuel oil) is loaded into tanks previously containing low flash point products (such as this product) - see API Publication 2003, "Protection Against Ignitions Arising Out Of Static, Lightning and Stray Currents.

STORAGE PRECAUTIONS

Keep away from flame, sparks, excessive temperatures and open flame. Use approved vented containers. Keep containers closed and clearly labeled. Empty product containers or vessels may contain explosive vapors. Do not pressurize, cut, heat, weld or expose such containers to sources of ignition.

Store in a well-ventilated area. This storage area should comply with NFPA 30 "Flammable and Combustible Liquid Code". Avoid storage near incompatible materials. The cleaning of tanks previously containing this product should follow API Recommended Practice (RP) 2013 "Cleaning Mobile Tanks In Flammable and Combustible Liquid Service" and API RP 2015 "Cleaning Petroleum Storage Tanks".

WORK/HYGIENIC PRACTICES

Emergency eye wash capability should be available in the near proximity to operations presenting a potential splash exposure. Use good personal hygiene practices. Avoid repeated and/or prolonged skin exposure. Wash hands before eating, drinking, smoking, or using toilet facilities. Do not use as a cleaning solvent on the skin. Do not use solvents or harsh abrasive skin cleaners for washing this product from exposed skin areas. Waterless hand cleaners are effective. Promptly remove contaminated clothing and launder before reuse. Use care when laundering to prevent the formation of flammable vapors which could ignite via washer or dryer. Consider the need to discard contaminated leather shoes and gloves.

8. EXPOSURE CONTROLS and PERSONAL PROTECTION

EXPOSURE LIMITS

Component (CAS No.)	Source	Exposure Limits		
		TWA (ppm)	STEL (ppm)	Note
Gasoline (86290-81-5)	ACGIH	300	500	A3
Benzene (71-43-2)	OSHA	1	5	Carcinogen
	ACGIH	0.5	2.5	A1, skin
	USCG	1	5	
n-Butane (106-97-8)	ACGIH	1000	--	Aliphatic Hydrocarbon Gases Alkane (C1-C4)
Ethyl Alcohol (ethanol) (64-17-5)	OSHA	1000	--	
	ACGIH	1000	--	A4
Ethyl benzene (100-41-4)	OSHA	100	--	
	ACGIH	100	125	A3
n-Hexane (110-54-3)	OSHA	500	--	
	ACGIH	50	--	Skin
Methyl-tertiary butyl ether [MTBE] (1634-04-4)	ACGIH	50		A3
Tertiary-amyl methyl ether [TAME] (994-05-8)				None established
Toluene (108-88-3)	OSHA	200		Ceiling: 300 ppm; Peak: 500 ppm (10 min.)
	ACGIH	20	--	A4
1,2,4- Trimethylbenzene (95-63-6)	ACGIH	25	--	
Xylene, mixed isomers (1330-20-7)	OSHA	100	--	
	ACGIH	100	150	A4

ENGINEERING CONTROLS

Use adequate ventilation to keep vapor concentrations of this product below occupational exposure and flammability limits, particularly in confined spaces.

EYE/FACE PROTECTION

Safety glasses or goggles are recommended where there is a possibility of splashing or spraying.

SKIN PROTECTION

Gloves constructed of nitrile or neoprene are recommended. Chemical protective clothing such as that made of of E.I. DuPont Tychem ®, products or equivalent is recommended based on degree of exposure.

Note: The resistance of specific material may vary from product to product as well as with degree of exposure. Consult manufacturer specifications for further information.

RESPIRATORY PROTECTION

A NIOSH-approved air-purifying respirator with organic vapor cartridges or canister may be permissible under certain circumstances where airborne concentrations are or may be expected to exceed exposure limits or for odor or irritation. Protection provided by air-purifying respirators is limited. Refer to OSHA 29 CFR 1910.134, NIOSH Respirator Decision Logic, and the manufacturer for additional guidance on respiratory protection selection and limitations.

Use a positive pressure, air-supplied respirator if there is a potential for uncontrolled release, exposure levels are not known, in oxygen-deficient atmospheres, or any other circumstance where an air-purifying respirator may not provide adequate protection.

9. PHYSICAL and CHEMICAL PROPERTIES

APPEARANCE

A translucent, straw-colored or light yellow liquid

ODOR

A strong, characteristic aromatic hydrocarbon odor. Oxygenated gasoline with MTBE and/or TAME may have a sweet, ether-like odor and is detectable at a lower concentration than non-oxygenated gasoline.

ODOR THRESHOLD

	Odor Detection	Odor Recognition
Non-oxygenated gasoline:	0.5 - 0.6 ppm	0.8 - 1.1 ppm
Gasoline with 15% MTBE:	0.2 - 0.3 ppm	0.4 - 0.7 ppm
Gasoline with 15% TAME:	0.1 ppm	0.2 ppm

BASIC PHYSICAL PROPERTIES

BOILING RANGE:	85 to 437 °F (39 to 200 °C)
VAPOR PRESSURE:	6.4 - 15 RVP @ 100 °F (38 °C) (275-475 mm Hg @ 68 °F (20 °C)
VAPOR DENSITY (air = 1):	AP 3 to 4
SPECIFIC GRAVITY (H_2O = 1):	0.70 – 0.78
EVAPORATION RATE:	10-11 (n-butyl acetate = 1)
PERCENT VOLATILES:	100 %
SOLUBILITY (H_2O):	Non-oxygenated gasoline - negligible (< 0.1% @ 77 °F). Gasoline with 15% MTBE - slight (0.1 - 3% @ 77 °F); ethanol is readily soluble in water

10. STABILITY and REACTIVITY)

STABILITY: Stable. Hazardous polymerization will not occur.

CONDITIONS TO AVOID

Avoid high temperatures, open flames, sparks, welding, smoking and other ignition sources

INCOMPATIBLE MATERIALS

Keep away from strong oxidizers.

HAZARDOUS DECOMPOSITION PRODUCTS

Carbon monoxide, carbon dioxide and non-combusted hydrocarbons (smoke). Contact with nitric and sulfuric acids will form nitrocresols that can decompose violently.

11. TOXICOLOGICAL PROPERTIES

ACUTE TOXICITY

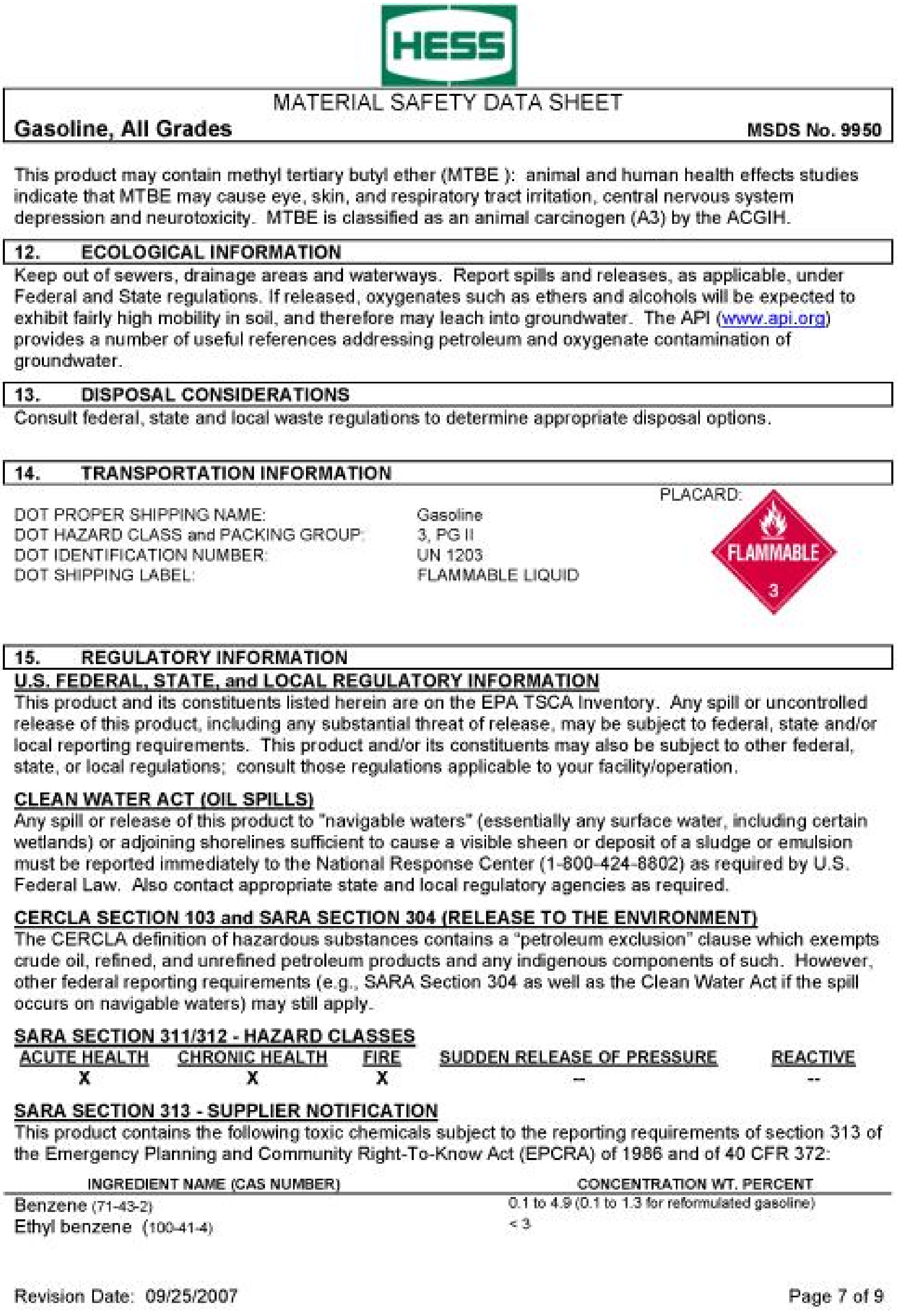
Acute Dermal LD50 (rabbits): > 5 ml/kg
Primary dermal irritation (rabbits): slightly irritating
Guinea pig sensitization: negative
Acute Oral LD50 (rat): 18.75 ml/kg
Draize eye irritation (rabbits): non-irritating

CHRONIC EFFECTS AND CARCINOGENICITY

Carcinogenicity:OSHA: NO IARC: YES - 2B NTP: NO ACGIH: YES (A3)

IARC has determined that gasoline and gasoline exhaust are possibly carcinogenic in humans. Inhalation exposure to completely vaporized unleaded gasoline caused kidney cancers in male rats and liver tumors in female mice. The U.S. EPA has determined that the male kidney tumors are species-specific and are irrelevant for human health risk assessment. The significance of the tumors seen in female mice is not known. Exposure to light hydrocarbons in the same boiling range as this product has been associated in animal studies with effects to the central and peripheral nervous systems, liver, and kidneys. The significance of these animal models to predict similar human response to gasoline is uncertain.

This product contains benzene. Human health studies indicate that prolonged and/or repeated overexposure to benzene may cause damage to the blood-forming system (particularly bone marrow), and serious blood disorders such as aplastic anemia and leukemia. Benzene is listed as a human carcinogen by the NTP, IARC, OSHA and ACGIH.



This product may contain methyl tertiary butyl ether (MTBE): animal and human health effects studies indicate that MTBE may cause eye, skin, and respiratory tract irritation, central nervous system depression and neurotoxicity. MTBE is classified as an animal carcinogen (A3) by the ACGIH.

12. ECOLOGICAL INFORMATION

Keep out of sewers, drainage areas and waterways. Report spills and releases, as applicable, under Federal and State regulations. If released, oxygenates such as ethers and alcohols will be expected to exhibit fairly high mobility in soil, and therefore may leach into groundwater. The API (www.api.org) provides a number of useful references addressing petroleum and oxygenate contamination of groundwater.

13. DISPOSAL CONSIDERATIONS

Consult federal, state and local waste regulations to determine appropriate disposal options.

14. TRANSPORTATION INFORMATION

DOT PROPER SHIPPING NAME:	Gasoline
DOT HAZARD CLASS and PACKING GROUP:	3, PG II
DOT IDENTIFICATION NUMBER:	UN 1203
DOT SHIPPING LABEL:	FLAMMABLE LIQUID

PLACARD:

FLAMMABLE
3

15. REGULATORY INFORMATION

U.S. FEDERAL, STATE, and LOCAL REGULATORY INFORMATION

This product and its constituents listed herein are on the EPA TSCA Inventory. Any spill or uncontrolled release of this product, including any substantial threat of release, may be subject to federal, state and/or local reporting requirements. This product and/or its constituents may also be subject to other federal, state, or local regulations; consult those regulations applicable to your facility/operation.

CLEAN WATER ACT (OIL SPILLS)

Any spill or release of this product to "navigable waters" (essentially any surface water, including certain wetlands) or adjoining shorelines sufficient to cause a visible sheen or deposit of a sludge or emulsion must be reported immediately to the National Response Center (1-800-424-8802) as required by U.S. Federal Law. Also contact appropriate state and local regulatory agencies as required.

CERCLA SECTION 103 and SARA SECTION 304 (RELEASE TO THE ENVIRONMENT)

The CERCLA definition of hazardous substances contains a "petroleum exclusion" clause which exempts crude oil, refined, and unrefined petroleum products and any indigenous components of such. However, other federal reporting requirements (e.g., SARA Section 304 as well as the Clean Water Act if the spill occurs on navigable waters) may still apply.

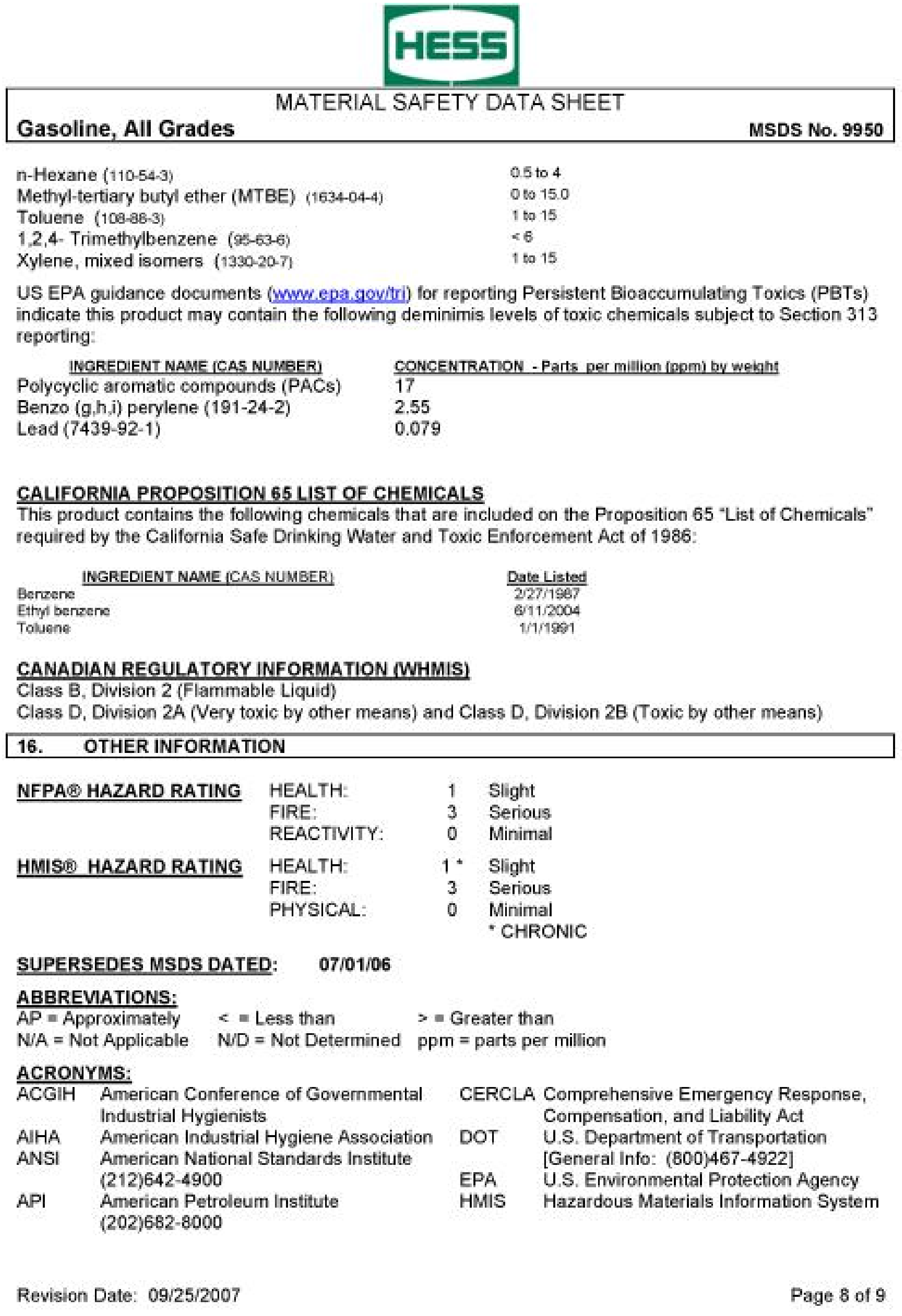
SARA SECTION 311/312 - HAZARD CLASSES

ACUTE HEALTH	CHRONIC HEALTH	FIRE	SUDDEN RELEASE OF PRESSURE	REACTIVE
X	X	X	--	--

SARA SECTION 313 - SUPPLIER NOTIFICATION

This product contains the following toxic chemicals subject to the reporting requirements of section 313 of the Emergency Planning and Community Right-To-Know Act (EPCRA) of 1986 and of 40 CFR 372:

INGREDIENT NAME (CAS NUMBER)	CONCENTRATION WT. PERCENT
Benzene (71-43-2)	0.1 to 4.9 (0.1 to 1.3 for reformulated gasoline)
Ethyl benzene (100-41-4)	< 3



n-Hexane (110-54-3)	0.5 to 4
Methyl-tertiary butyl ether (MTBE) (1634-04-4)	0 to 15.0
Toluene (108-88-3)	1 to 15
1,2,4- Trimethylbenzene (95-63-6)	< 6
Xylene, mixed isomers (1330-20-7)	1 to 15

US EPA guidance documents (www.epa.gov/tri) for reporting Persistent Bioaccumulating Toxics (PBTs) indicate this product may contain the following deminimis levels of toxic chemicals subject to Section 313 reporting:

INGREDIENT NAME (CAS NUMBER)	CONCENTRATION - Parts per million (ppm) by weight
Polycyclic aromatic compounds (PACs)	17
Benzo (g,h,i) perylene (191-24-2)	2.55
Lead (7439-92-1)	0.079

CALIFORNIA PROPOSITION 65 LIST OF CHEMICALS

This product contains the following chemicals that are included on the Proposition 65 "List of Chemicals" required by the California Safe Drinking Water and Toxic Enforcement Act of 1986:

INGREDIENT NAME (CAS NUMBER)	Date Listed
Benzene	2/27/1987
Ethyl benzene	6/11/2004
Toluene	1/1/1991

CANADIAN REGULATORY INFORMATION (WHMIS)

Class B, Division 2 (Flammable Liquid)
Class D, Division 2A (Very toxic by other means) and Class D, Division 2B (Toxic by other means)

16. OTHER INFORMATION

NFPA® HAZARD RATING	HEALTH:	1	Slight
	FIRE:	3	Serious
	REACTIVITY:	0	Minimal
HMIS® HAZARD RATING	HEALTH:	1 *	Slight
	FIRE:	3	Serious
	PHYSICAL:	0	Minimal
			* CHRONIC

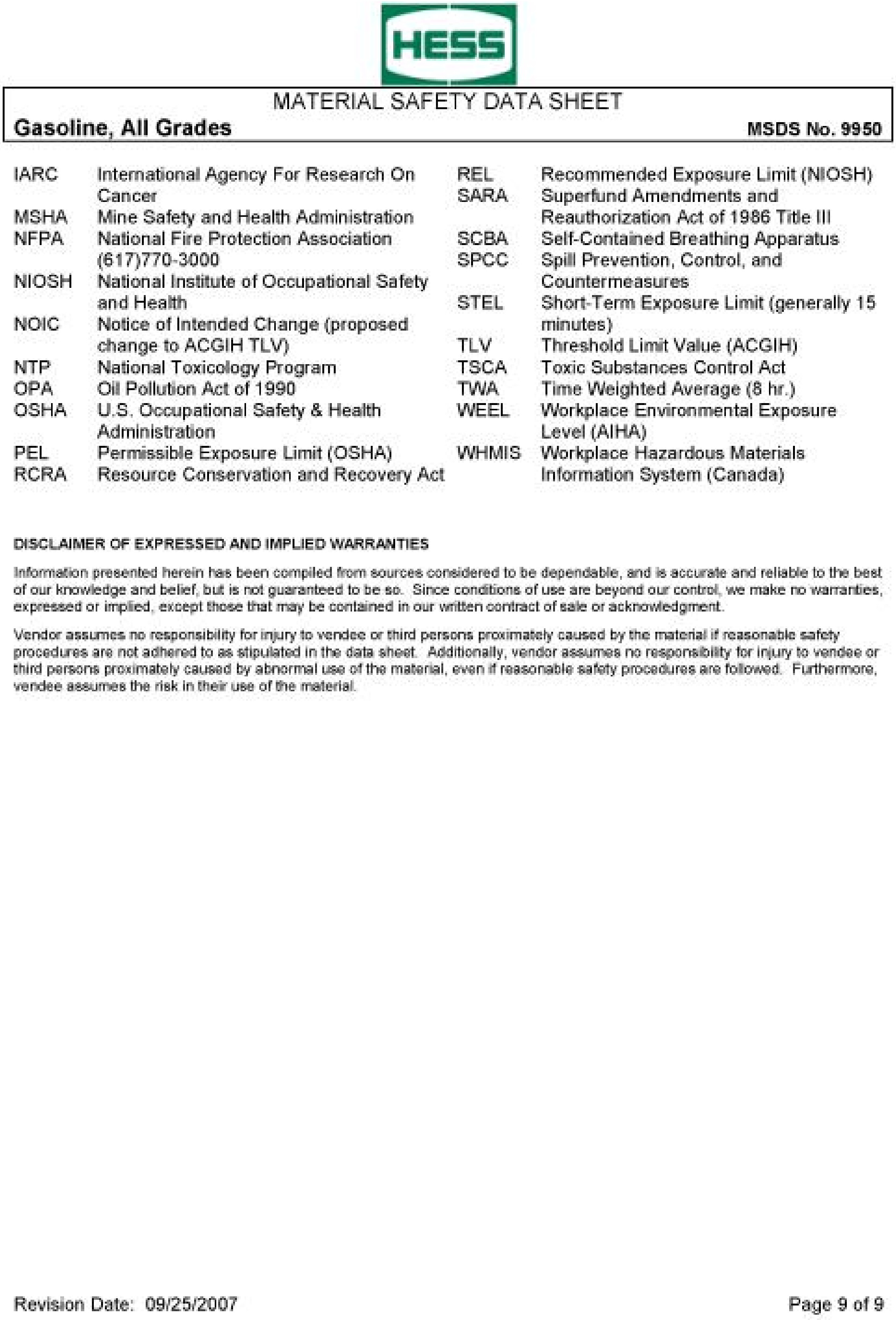
SUPERSEDES MSDS DATED: **07/01/06**

ABBREVIATIONS:

AP = Approximately
< = Less than
> = Greater than
N/A = Not Applicable
N/D = Not Determined
ppm = parts per million

ACRONYMS:

ACGIH	American Conference of Governmental Industrial Hygienists	CERCLA	Comprehensive Emergency Response, Compensation, and Liability Act
AIHA	American Industrial Hygiene Association	DOT	U.S. Department of Transportation [General Info: (800)467-4922]
ANSI	American National Standards Institute (212)642-4900	EPA	U.S. Environmental Protection Agency
API	American Petroleum Institute (202)682-8000	HMIS	Hazardous Materials Information System



MATERIAL SAFETY DATA SHEET

Gasoline, All Grades **MSDS No. 9950**

IARC	International Agency For Research On Cancer
MSHA	Mine Safety and Health Administration
NFPA	National Fire Protection Association (617)770-3000
NIOSH	National Institute of Occupational Safety and Health
NOIC	Notice of Intended Change (proposed change to ACGIH TLV)
NTP	National Toxicology Program
OPA	Oil Pollution Act of 1990
OSHA	U.S. Occupational Safety & Health Administration
PEL	Permissible Exposure Limit (OSHA)
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit (NIOSH)
SARA	Superfund Amendments and Reauthorization Act of 1986 Title III
SCBA	Self-Contained Breathing Apparatus
SPCC	Spill Prevention, Control, and Countermeasures
STEL	Short-Term Exposure Limit (generally 15 minutes)
TLV	Threshold Limit Value (ACGIH)
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average (8 hr.)
WEEL	Workplace Environmental Exposure Level (AIHA)
WHMIS	Workplace Hazardous Materials Information System (Canada)

DISCLAIMER OF EXPRESSED AND IMPLIED WARRANTIES

Information presented herein has been compiled from sources considered to be dependable, and is accurate and reliable to the best of our knowledge and belief, but is not guaranteed to be so. Since conditions of use are beyond our control, we make no warranties, expressed or implied, except those that may be contained in our written contract of sale or acknowledgment.

Vendor assumes no responsibility for injury to vendee or third persons proximately caused by the material if reasonable safety procedures are not adhered to as stipulated in the data sheet. Additionally, vendor assumes no responsibility for injury to vendee or third persons proximately caused by abnormal use of the material, even if reasonable safety procedures are followed. Furthermore, vendee assumes the risk in their use of the material.

Creation Date: 03-26-2002
Revision Date: 03-10-2003

Material Safety Data Sheet

1. CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Material Name	**GLYCEROL, [14C(U)]-**
Version #	01
Item #	NEC441X000MC
Manufacturer Information	PerkinElmer Life Sciences 549 Albany Street Boston, MA 02118 CHEMTREC 800-424-9300 Technical Support 800-446-0035

2. COMPOSITION / INFORMATION ON INGREDIENTS

Hazardous ingredient(s)	CAS #	Percent	PEL	TLV
ETHANOL	64-17-5	40 - 60	1000 ppm	1000

Non-hazardous ingredient(s)	CAS #	Percent
WATER	7732-18-5	40 - 60
GLYCEROL	56-81-5	0.01 - 0.1

3. HAZARDS IDENTIFICATION

Emergency Overview

Flammable.
Irritating to respiratory system and skin.

4. FIRST AID MEASURES

First Aid

Skin contact

Wash off immediately with soap and plenty of water.

Eye contact

Rinse immediately with plenty of water for at least 15 minutes.

Inhalation

Move to fresh air.

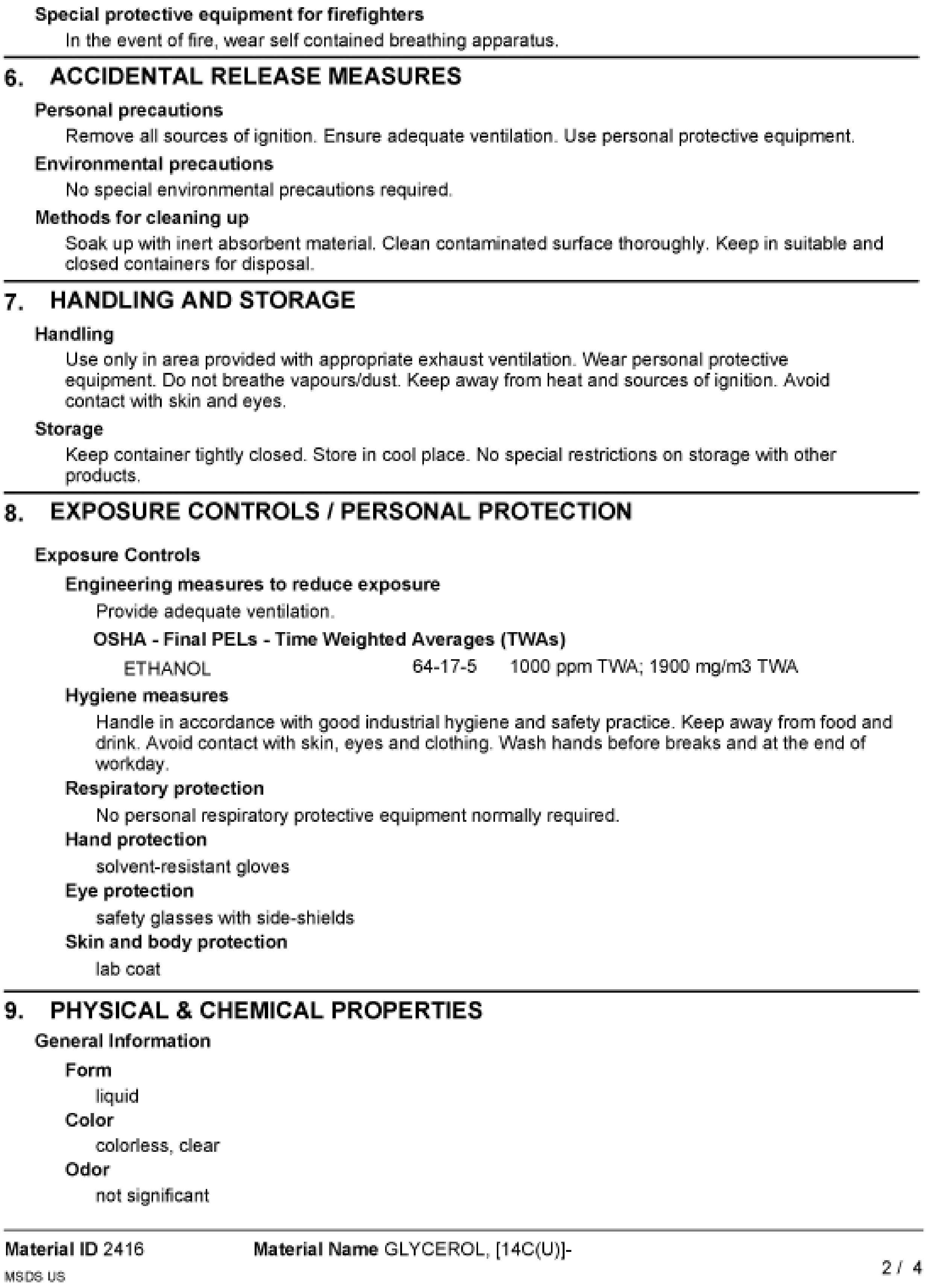
Ingestion

Clean mouth with water and drink afterwards plenty of water. Never give anything by mouth to a unconscious person.

5. FIRE FIGHTING MEASURES

Suitable extinguishing media

use dry chemical, CO2, water spray or "alcohol" foam



Special protective equipment for firefighters

In the event of fire, wear self contained breathing apparatus.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions

Remove all sources of ignition. Ensure adequate ventilation. Use personal protective equipment.

Environmental precautions

No special environmental precautions required.

Methods for cleaning up

Soak up with inert absorbent material. Clean contaminated surface thoroughly. Keep in suitable and closed containers for disposal.

7. HANDLING AND STORAGE

Handling

Use only in area provided with appropriate exhaust ventilation. Wear personal protective equipment. Do not breathe vapours/dust. Keep away from heat and sources of ignition. Avoid contact with skin and eyes.

Storage

Keep container tightly closed. Store in cool place. No special restrictions on storage with other products.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

Exposure Controls

Engineering measures to reduce exposure

Provide adequate ventilation.

OSHA - Final PELs - Time Weighted Averages (TWAs)

ETHANOL	64-17-5	1000 ppm TWA; 1900 mg/m3 TWA

Hygiene measures

Handle in accordance with good industrial hygiene and safety practice. Keep away from food and drink. Avoid contact with skin, eyes and clothing. Wash hands before breaks and at the end of workday.

Respiratory protection

No personal respiratory protective equipment normally required.

Hand protection

solvent-resistant gloves

Eye protection

safety glasses with side-shields

Skin and body protection

lab coat

9. PHYSICAL & CHEMICAL PROPERTIES

General Information

Form

liquid

Color

colorless, clear

Odor

not significant

Flash Point	24 - 26 °C (75.2 - 78.8 °F)
Flammability Class	Flammable IC

10. CHEMICAL STABILITY & REACTIVITY INFORMATION

Stability

Stable

Hazardous decomposition products

carbon oxides

Conditions to avoid

Heat, flames and sparks.

Incompatibility

oxidizing agents; alkaline metals; ammonia

11. TOXICOLOGICAL INFORMATION

Acute Toxicity

Skin irritation, Eye irritation, irritation of mucous membranes
May be harmful by inhalation, ingestion, skin adsorption.

NIOSH - Selected LD50s and LC50s

ETHANOL	64-17-5	Inhalation LC50 Rat: 20000 ppm/10H; Inhalation LC50 Mouse: 39 gm/m3/4H; Oral LD50 Rat: 7060 mg/kg; Oral LD50 Mouse: 3450 mg/kg

ETHANOL	ACGIH Not Classified Carcinogen

Symptoms and Target Organs

NIOSH - Pocket Guide - Target Organs

ETHANOL	64-17-5	respiratory system, skin, eyes, CNS, liver, blood, reproductive system

12. ECOLOGICAL INFORMATION

Ecotoxicity

Not available

13. DISPOSAL CONSIDERATIONS

Disposal Instructions

In accordance with local and national regulations.

Waste from residues / unused products

Dispose of in accordance with local regulations

14. TRANSPORTATION INFORMATION

15. REGULATORY INFORMATION

SARA TITLE III RATINGS

Immediate Hazard, Delayed Hazard, Fire Hazard

State Regulations

California - Prop. 65 - Developmental Toxicity

ETHANOL	64-17-5	developmental toxicity (when in alcoholic beverages); initial date 10/1/87

Florida - Substance List

ETHANOL	64-17-5	[present]

Massachusetts - Right To Know List

ETHANOL	64-17-5	teratogen

New Jersey - Department of Health RTK List

ETHANOL	64-17-5	sn 0844

Pennsylvania - Right to Know List

ETHANOL	64-17-5	[present]

Rhode Island - Hazardous Substance List

ETHANOL	64-17-5	Toxic, Flammable

Risk Codes

R10

16. OTHER INFORMATION

Risks

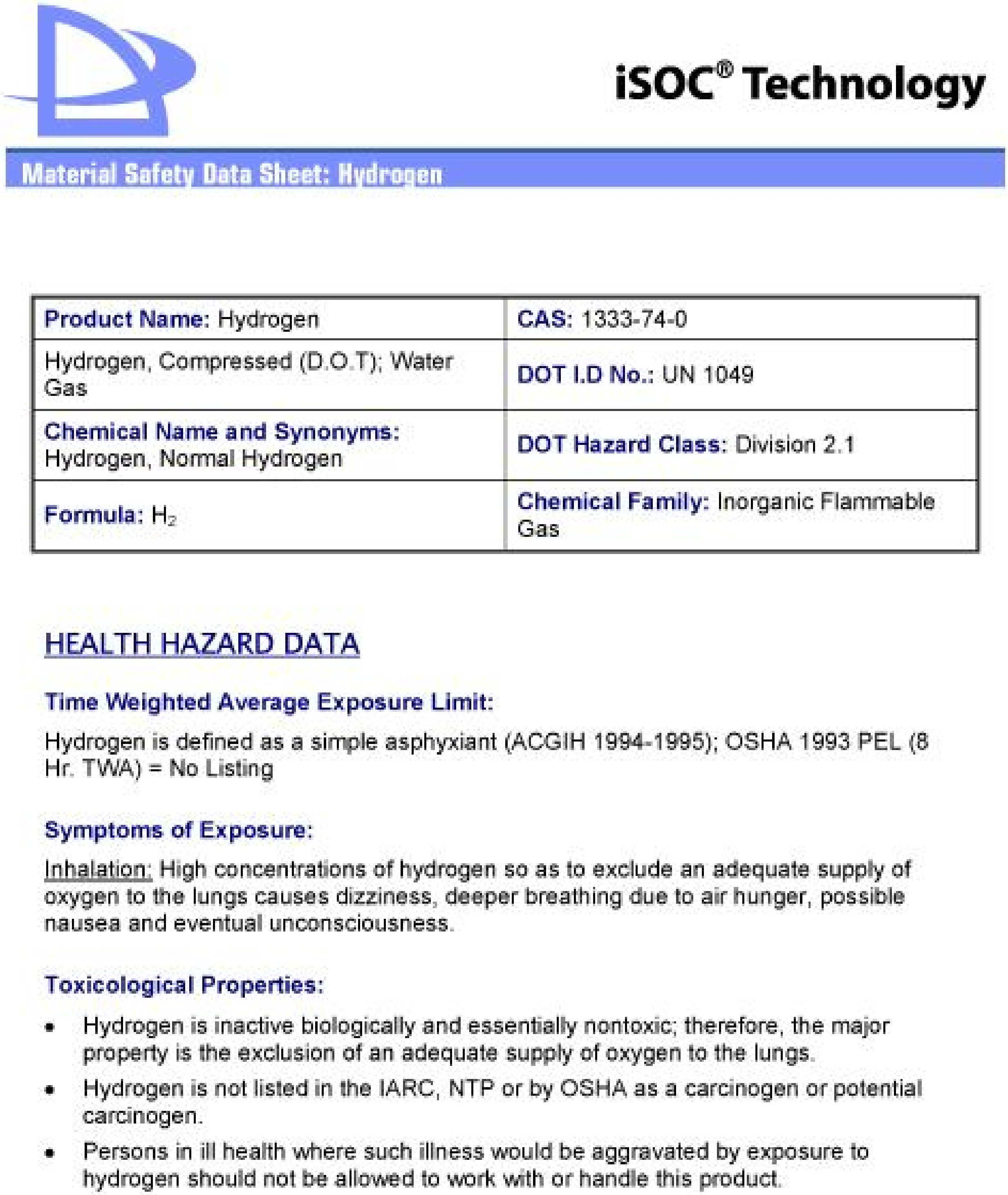
Flammable.

Recommended use

For research use only.

Disclaimer

The information provided in this Material Safety Data Sheet is based on our present knowledge, and believed to be correct at the date of publication. However, no representation is made concerning its accuracy and completeness. It is intended as guidance only, and is not to be considered a warranty or quality specification. All materials may present unknown hazards, and should be used with caution. Although certain hazards are described, we cannot guarantee that these are the only hazards which exist. PerkinElmer Life and Analytical Sciences shall not be held liable for any damage resulting from handling or from contact with the product.



iSOC® Technology

Material Safety Data Sheet: Hydrogen

Product Name: Hydrogen	**CAS:** 1333-74-0
Hydrogen, Compressed (D.O.T); Water Gas	**DOT I.D No.:** UN 1049
Chemical Name and Synonyms: Hydrogen, Normal Hydrogen	**DOT Hazard Class:** Division 2.1
Formula: H_2	**Chemical Family:** Inorganic Flammable Gas

HEALTH HAZARD DATA

Time Weighted Average Exposure Limit:

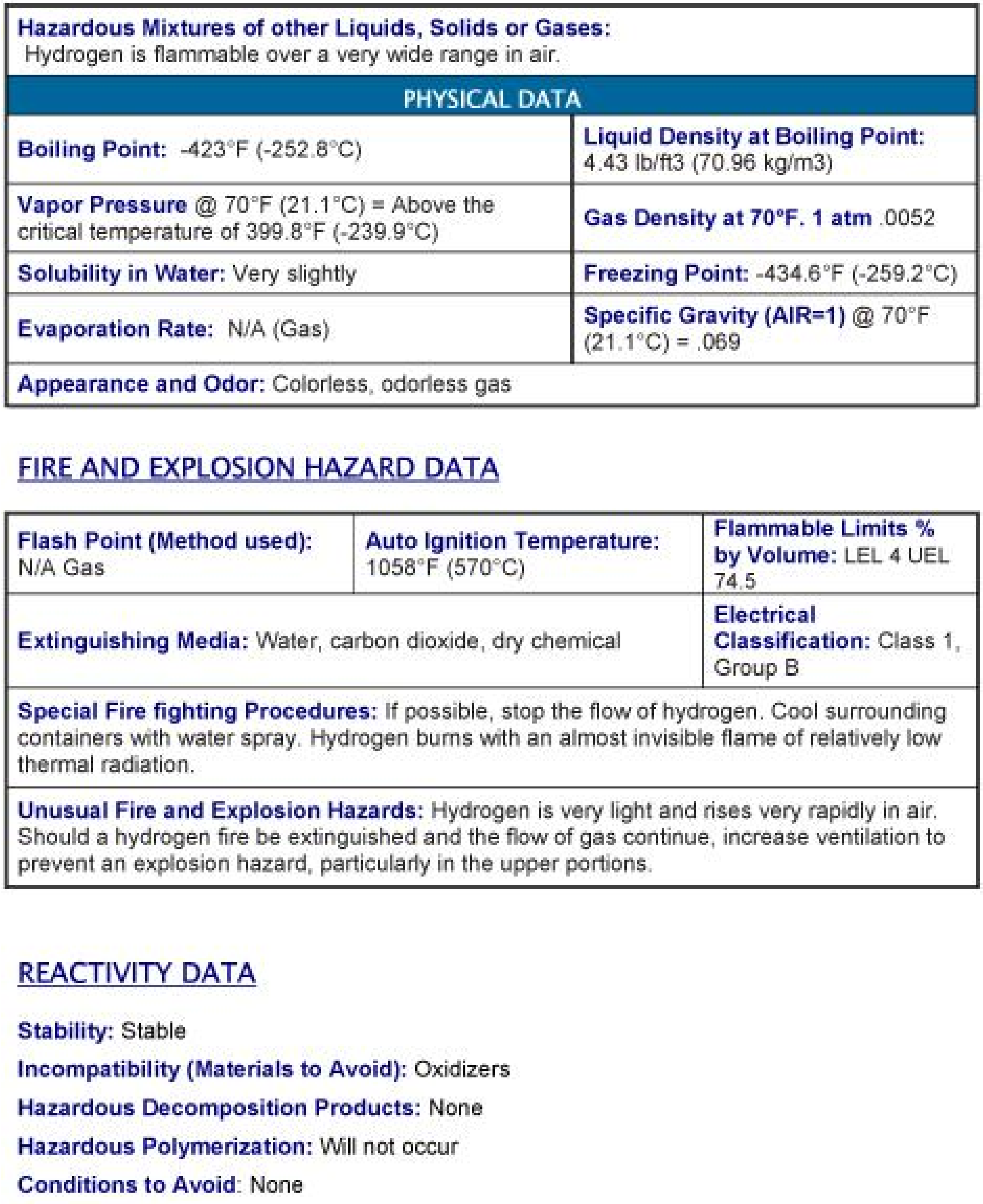
Hydrogen is defined as a simple asphyxiant (ACGIH 1994-1995); OSHA 1993 PEL (8 Hr. TWA) = No Listing

Symptoms of Exposure:

Inhalation: High concentrations of hydrogen so as to exclude an adequate supply of oxygen to the lungs causes dizziness, deeper breathing due to air hunger, possible nausea and eventual unconsciousness.

Toxicological Properties:

- Hydrogen is inactive biologically and essentially nontoxic; therefore, the major property is the exclusion of an adequate supply of oxygen to the lungs.
- Hydrogen is not listed in the IARC, NTP or by OSHA as a carcinogen or potential carcinogen.
- Persons in ill health where such illness would be aggravated by exposure to hydrogen should not be allowed to work with or handle this product.



Hazardous Mixtures of other Liquids, Solids or Gases: Hydrogen is flammable over a very wide range in air.

PHYSICAL DATA	
Boiling Point: -423°F (-252.8°C)	**Liquid Density at Boiling Point:** 4.43 lb/ft3 (70.96 kg/m3)
Vapor Pressure @ 70°F (21.1°C) = Above the critical temperature of 399.8°F (-239.9°C)	**Gas Density at 70°F. 1 atm** .0052
Solubility in Water: Very slightly	**Freezing Point:** -434.6°F (-259.2°C)
Evaporation Rate: N/A (Gas)	**Specific Gravity (AIR=1)** @ 70°F (21.1°C) = .069
Appearance and Odor: Colorless, odorless gas	

FIRE AND EXPLOSION HAZARD DATA

Flash Point (Method used): N/A Gas	**Auto Ignition Temperature:** 1058°F (570°C)	**Flammable Limits % by Volume:** LEL 4 UEL 74.5
Extinguishing Media: Water, carbon dioxide, dry chemical		**Electrical Classification:** Class 1, Group B
Special Fire fighting Procedures: If possible, stop the flow of hydrogen. Cool surrounding containers with water spray. Hydrogen burns with an almost invisible flame of relatively low thermal radiation.		
Unusual Fire and Explosion Hazards: Hydrogen is very light and rises very rapidly in air. Should a hydrogen fire be extinguished and the flow of gas continue, increase ventilation to prevent an explosion hazard, particularly in the upper portions.		

REACTIVITY DATA

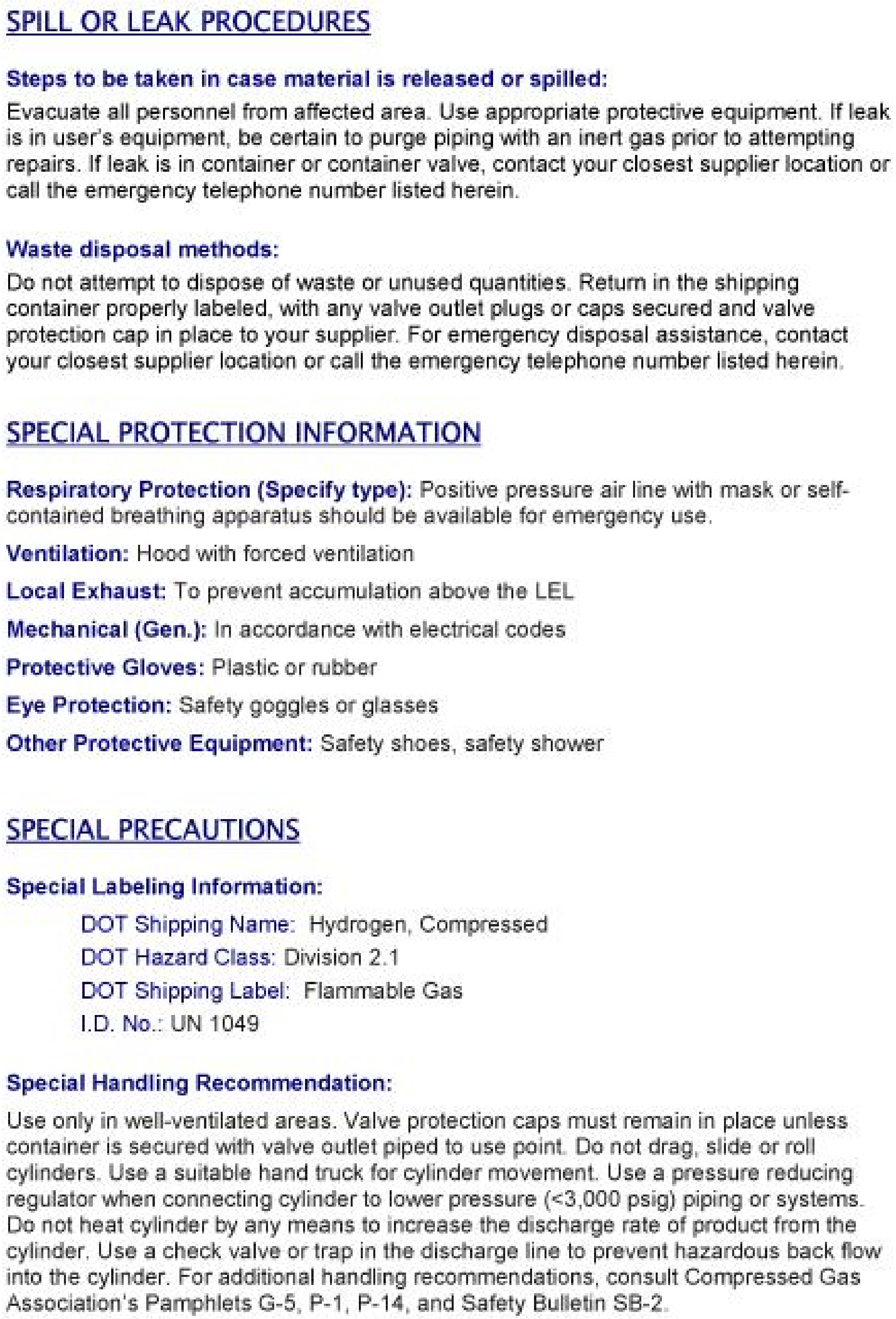
Stability: Stable

Incompatibility (Materials to Avoid): Oxidizers

Hazardous Decomposition Products: None

Hazardous Polymerization: Will not occur

Conditions to Avoid: None



SPILL OR LEAK PROCEDURES

Steps to be taken in case material is released or spilled:

Evacuate all personnel from affected area. Use appropriate protective equipment. If leak is in user's equipment, be certain to purge piping with an inert gas prior to attempting repairs. If leak is in container or container valve, contact your closest supplier location or call the emergency telephone number listed herein.

Waste disposal methods:

Do not attempt to dispose of waste or unused quantities. Return in the shipping container properly labeled, with any valve outlet plugs or caps secured and valve protection cap in place to your supplier. For emergency disposal assistance, contact your closest supplier location or call the emergency telephone number listed herein.

SPECIAL PROTECTION INFORMATION

Respiratory Protection (Specify type): Positive pressure air line with mask or self-contained breathing apparatus should be available for emergency use.

Ventilation: Hood with forced ventilation

Local Exhaust: To prevent accumulation above the LEL

Mechanical (Gen.): In accordance with electrical codes

Protective Gloves: Plastic or rubber

Eye Protection: Safety goggles or glasses

Other Protective Equipment: Safety shoes, safety shower

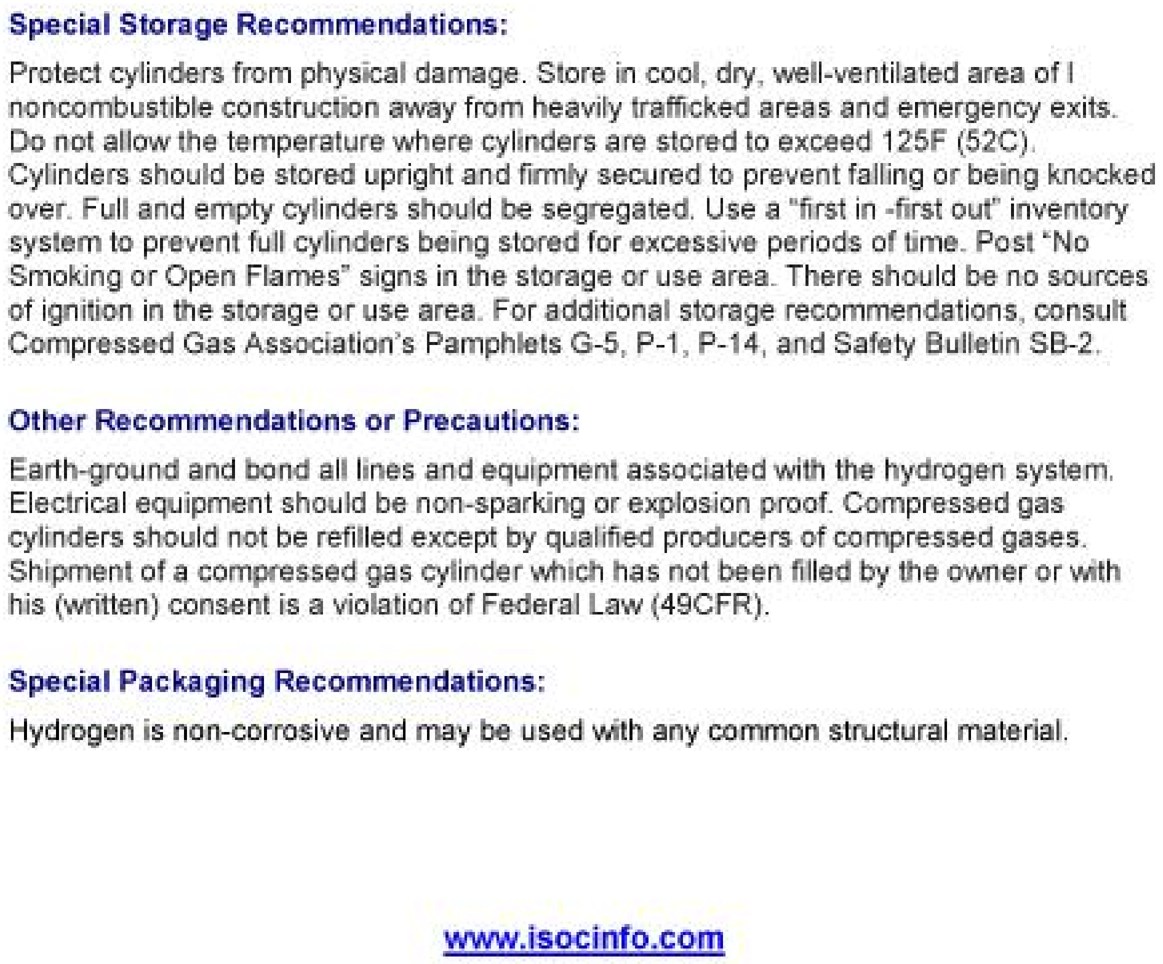
SPECIAL PRECAUTIONS

Special Labeling Information:

DOT Shipping Name: Hydrogen, Compressed
DOT Hazard Class: Division 2.1
DOT Shipping Label: Flammable Gas
I.D. No.: UN 1049

Special Handling Recommendation:

Use only in well-ventilated areas. Valve protection caps must remain in place unless container is secured with valve outlet piped to use point. Do not drag, slide or roll cylinders. Use a suitable hand truck for cylinder movement. Use a pressure reducing regulator when connecting cylinder to lower pressure (<3,000 psig) piping or systems. Do not heat cylinder by any means to increase the discharge rate of product from the cylinder. Use a check valve or trap in the discharge line to prevent hazardous back flow into the cylinder. For additional handling recommendations, consult Compressed Gas Association's Pamphlets G-5, P-1, P-14, and Safety Bulletin SB-2.



Special Storage Recommendations:

Protect cylinders from physical damage. Store in cool, dry, well-ventilated area of I noncombustible construction away from heavily trafficked areas and emergency exits. Do not allow the temperature where cylinders are stored to exceed 125F (52C). Cylinders should be stored upright and firmly secured to prevent falling or being knocked over. Full and empty cylinders should be segregated. Use a "first in -first out" inventory system to prevent full cylinders being stored for excessive periods of time. Post "No Smoking or Open Flames" signs in the storage or use area. There should be no sources of ignition in the storage or use area. For additional storage recommendations, consult Compressed Gas Association's Pamphlets G-5, P-1, P-14, and Safety Bulletin SB-2.

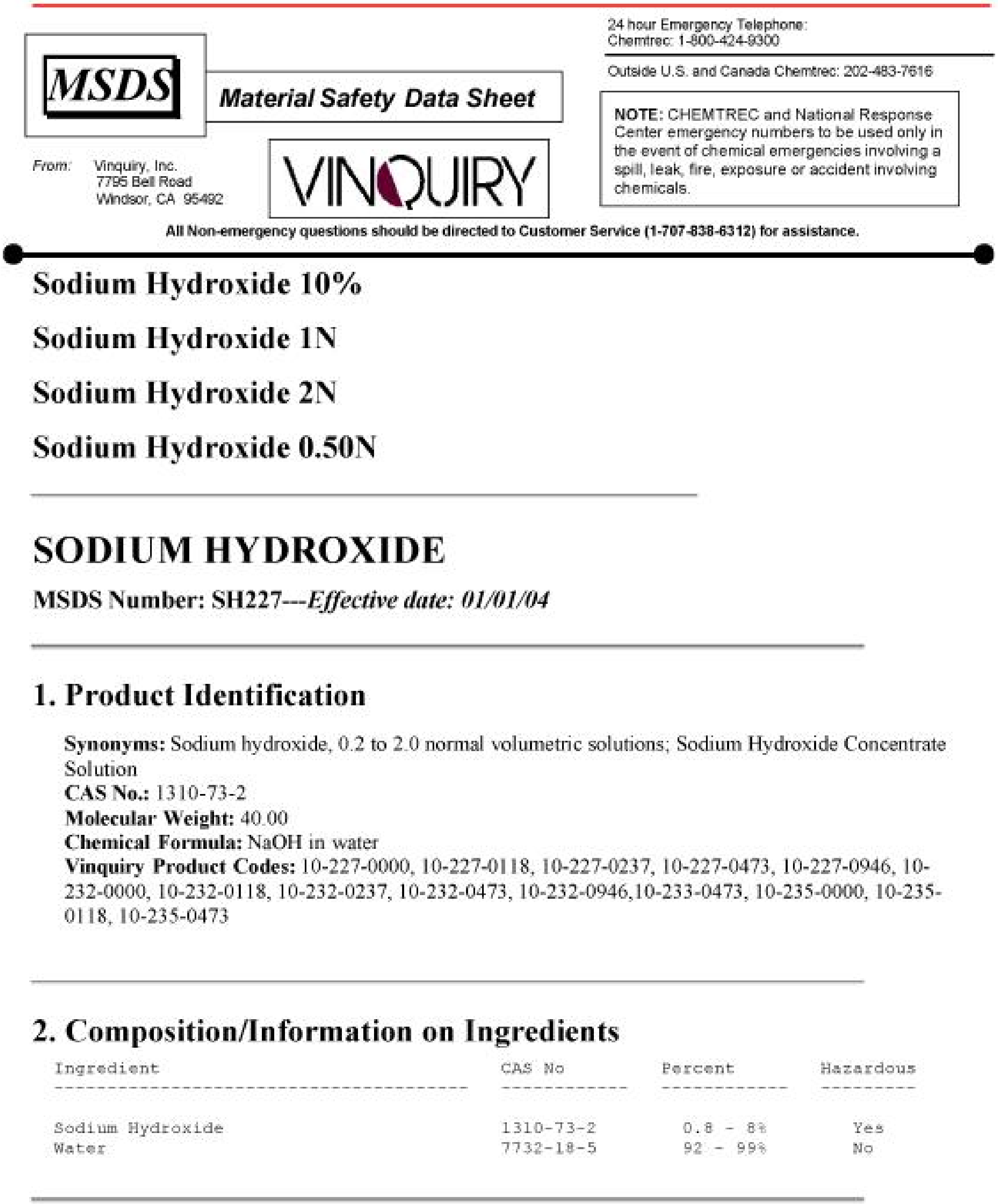
Other Recommendations or Precautions:

Earth-ground and bond all lines and equipment associated with the hydrogen system. Electrical equipment should be non-sparking or explosion proof. Compressed gas cylinders should not be refilled except by qualified producers of compressed gases. Shipment of a compressed gas cylinder which has not been filled by the owner or with his (written) consent is a violation of Federal Law (49CFR).

Special Packaging Recommendations:

Hydrogen is non-corrosive and may be used with any common structural material.

www.isocinfo.com



24 hour Emergency Telephone:
Chemtrec: 1-800-424-9300

Outside U.S. and Canada Chemtrec: 202-483-7616

MSDS *Material Safety Data Sheet*

NOTE: CHEMTREC and National Response Center emergency numbers to be used only in the event of chemical emergencies involving a spill, leak, fire, exposure or accident involving chemicals.

From: Vinquiry, Inc.
7795 Bell Road
Windsor, CA 95492

VINQUIRY

All Non-emergency questions should be directed to Customer Service (1-707-838-6312) for assistance.

Sodium Hydroxide 10%

Sodium Hydroxide 1N

Sodium Hydroxide 2N

Sodium Hydroxide 0.50N

SODIUM HYDROXIDE

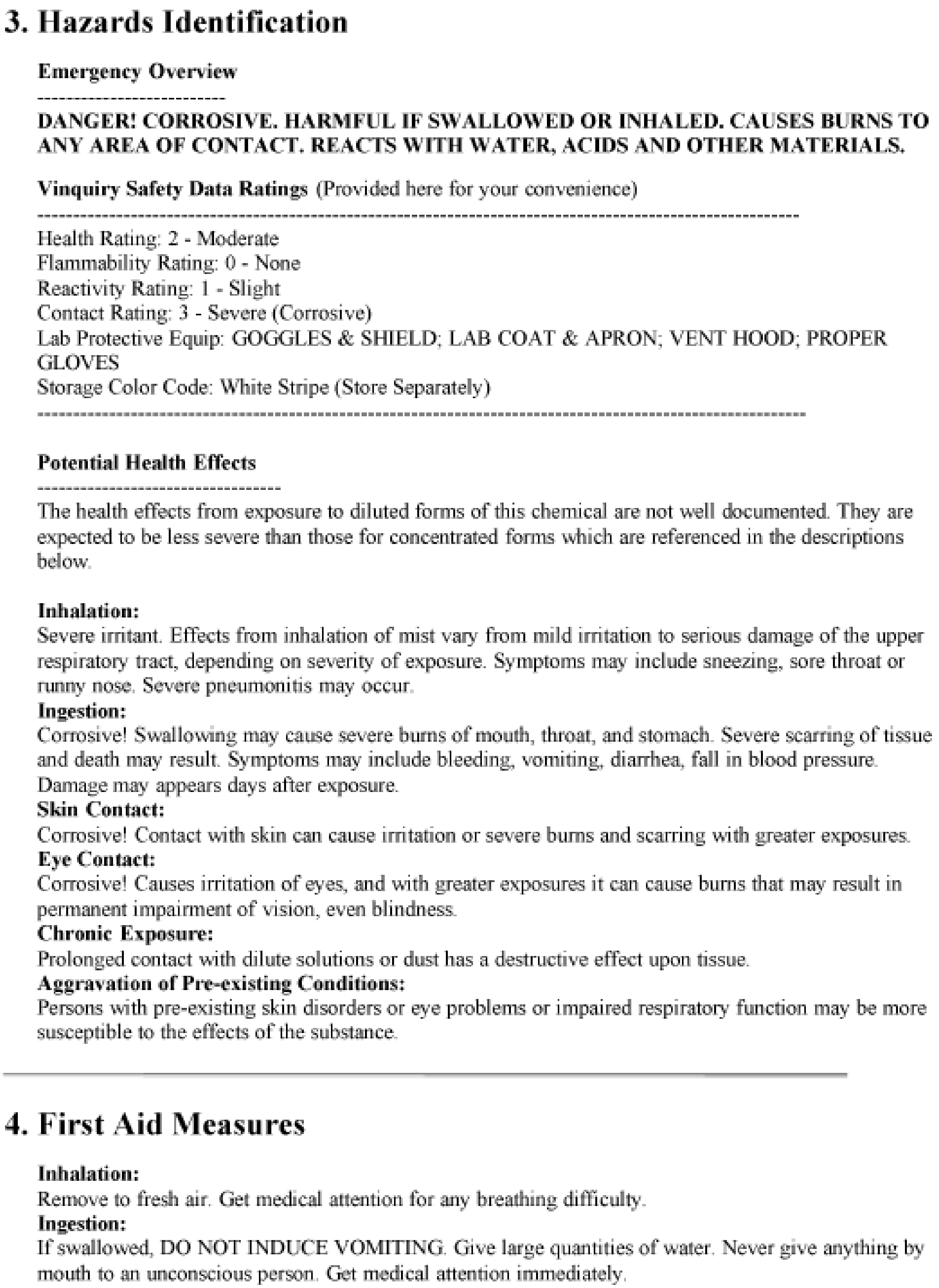
MSDS Number: SH227---*Effective date: 01/01/04*

1. Product Identification

Synonyms: Sodium hydroxide, 0.2 to 2.0 normal volumetric solutions; Sodium Hydroxide Concentrate Solution
CAS No.: 1310-73-2
Molecular Weight: 40.00
Chemical Formula: NaOH in water
Vinquiry Product Codes: 10-227-0000, 10-227-0118, 10-227-0237, 10-227-0473, 10-227-0946, 10-232-0000, 10-232-0118, 10-232-0237, 10-232-0473, 10-232-0946,10-233-0473, 10-235-0000, 10-235-0118, 10-235-0473

2. Composition/Information on Ingredients

Ingredient	CAS No	Percent	Hazardous
Sodium Hydroxide	1310-73-2	0.8 - 8%	Yes
Water	7732-18-5	92 - 99%	No



3. Hazards Identification

Emergency Overview

DANGER! CORROSIVE. HARMFUL IF SWALLOWED OR INHALED. CAUSES BURNS TO ANY AREA OF CONTACT. REACTS WITH WATER, ACIDS AND OTHER MATERIALS.

Vinquiry Safety Data Ratings (Provided here for your convenience)

Health Rating: 2 - Moderate
Flammability Rating: 0 - None
Reactivity Rating: 1 - Slight
Contact Rating: 3 - Severe (Corrosive)
Lab Protective Equip: GOGGLES & SHIELD; LAB COAT & APRON; VENT HOOD; PROPER GLOVES
Storage Color Code: White Stripe (Store Separately)

Potential Health Effects

The health effects from exposure to diluted forms of this chemical are not well documented. They are expected to be less severe than those for concentrated forms which are referenced in the descriptions below.

Inhalation:
Severe irritant. Effects from inhalation of mist vary from mild irritation to serious damage of the upper respiratory tract, depending on severity of exposure. Symptoms may include sneezing, sore throat or runny nose. Severe pneumonitis may occur.
Ingestion:
Corrosive! Swallowing may cause severe burns of mouth, throat, and stomach. Severe scarring of tissue and death may result. Symptoms may include bleeding, vomiting, diarrhea, fall in blood pressure. Damage may appears days after exposure.
Skin Contact:
Corrosive! Contact with skin can cause irritation or severe burns and scarring with greater exposures.
Eye Contact:
Corrosive! Causes irritation of eyes, and with greater exposures it can cause burns that may result in permanent impairment of vision, even blindness.
Chronic Exposure:
Prolonged contact with dilute solutions or dust has a destructive effect upon tissue.
Aggravation of Pre-existing Conditions:
Persons with pre-existing skin disorders or eye problems or impaired respiratory function may be more susceptible to the effects of the substance.

4. First Aid Measures

Inhalation:
Remove to fresh air. Get medical attention for any breathing difficulty.
Ingestion:
If swallowed, DO NOT INDUCE VOMITING. Give large quantities of water. Never give anything by mouth to an unconscious person. Get medical attention immediately.

Skin Contact:
Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Call a physician, immediately. Wash clothing before reuse.
Eye Contact:
Immediately flush eyes with plenty of water for at least 15 minutes, lifting lower and upper eyelids occasionally. Get medical attention immediately.

Note to Physician:
Perform endoscopy in all cases of suspected sodium hydroxide ingestion. In cases of severe esophageal corrosion, the use of therapeutic doses of steroids should be considered. General supportive measures with continual monitoring of gas exchange, acid-base balance, electrolytes, and fluid intake are also required.

5. Fire Fighting Measures

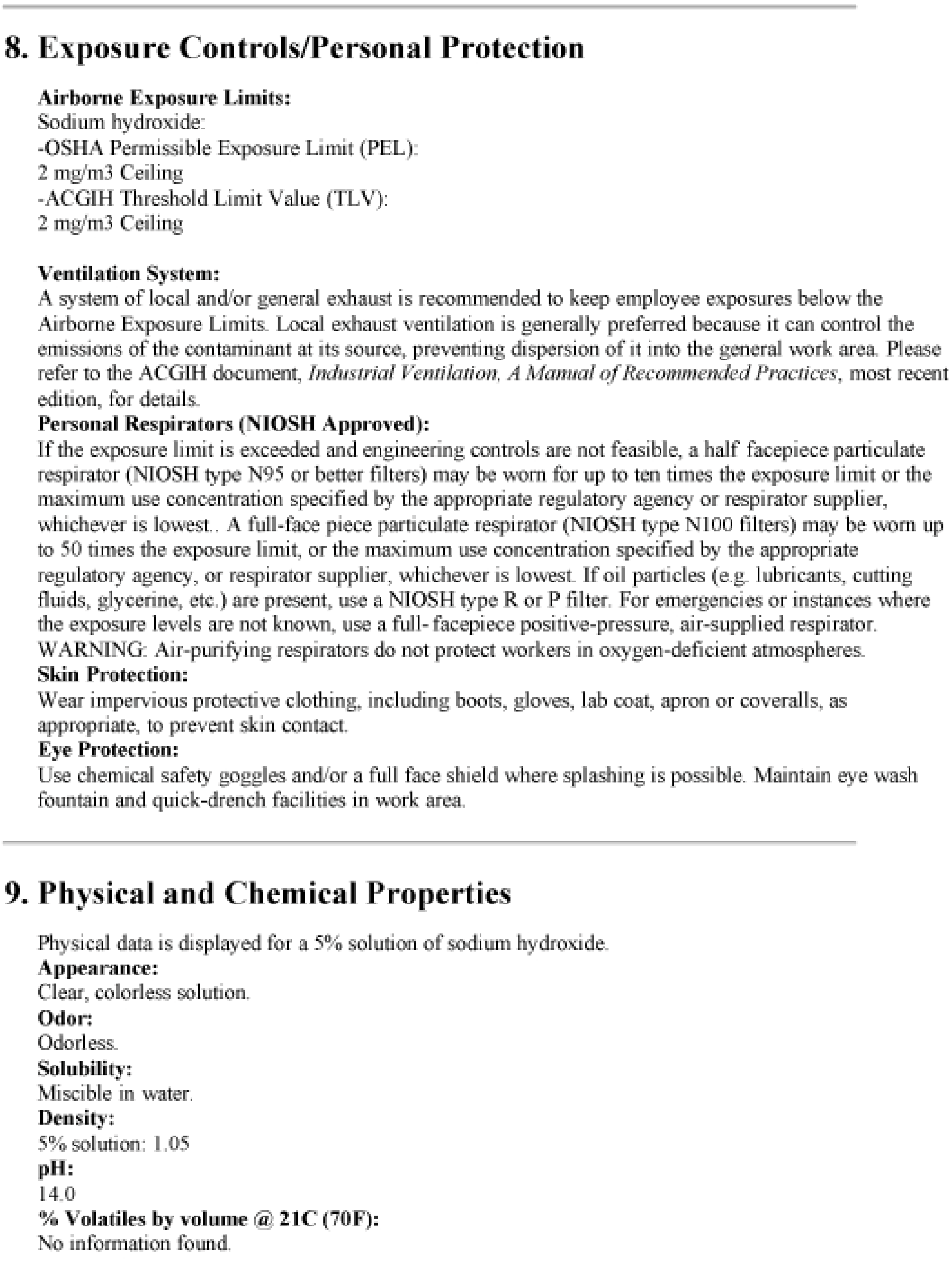
Fire:
Not considered to be a fire hazard.
Explosion:
Not considered to be an explosion hazard.
Fire Extinguishing Media:
Use any means suitable for extinguishing surrounding fire. Adding water to caustic solution generates large amounts of heat.
Special Information:
Use protective clothing and breathing equipment appropriate for the surrounding fire.

6. Accidental Release Measures

Ventilate area of leak or spill. Keep unnecessary and unprotected people away from area of spill. Wear appropriate personal protective equipment as specified in Section 8. Contain and recover liquid when possible. Do not flush caustic residues to the sewer. Residues from spills can be diluted with water, neutralized with dilute acid such as acetic, hydrochloric or sulfuric. Absorb neutralized caustic residue on clay, vermiculite or other inert substance and package in a suitable container for disposal.
US Regulations (CERCLA) require reporting spills and releases to soil, water and air in excess of reportable quantities. The toll free number for the US Coast Guard National Response Center is (800) 424-8802.

7. Handling and Storage

Keep in a tightly closed container. Protect from physical damage. Store in a cool, dry, ventilated area away from sources of heat, moisture and incompatibilities. Protect from freezing. Always add the caustic to water while stirring; never the reverse. Containers of this material may be hazardous when empty since they retain product residues (vapors, liquid); observe all warnings and precautions listed for the product. Do not store with aluminum or magnesium. Do not mix with acids or organic materials.



8. Exposure Controls/Personal Protection

Airborne Exposure Limits:
Sodium hydroxide:
-OSHA Permissible Exposure Limit (PEL):
2 mg/m3 Ceiling
-ACGIH Threshold Limit Value (TLV):
2 mg/m3 Ceiling

Ventilation System:
A system of local and/or general exhaust is recommended to keep employee exposures below the Airborne Exposure Limits. Local exhaust ventilation is generally preferred because it can control the emissions of the contaminant at its source, preventing dispersion of it into the general work area. Please refer to the ACGIH document, *Industrial Ventilation, A Manual of Recommended Practices*, most recent edition, for details.

Personal Respirators (NIOSH Approved):
If the exposure limit is exceeded and engineering controls are not feasible, a half facepiece particulate respirator (NIOSH type N95 or better filters) may be worn for up to ten times the exposure limit or the maximum use concentration specified by the appropriate regulatory agency or respirator supplier, whichever is lowest.. A full-face piece particulate respirator (NIOSH type N100 filters) may be worn up to 50 times the exposure limit, or the maximum use concentration specified by the appropriate regulatory agency, or respirator supplier, whichever is lowest. If oil particles (e.g. lubricants, cutting fluids, glycerine, etc.) are present, use a NIOSH type R or P filter. For emergencies or instances where the exposure levels are not known, use a full- facepiece positive-pressure, air-supplied respirator. WARNING: Air-purifying respirators do not protect workers in oxygen-deficient atmospheres.

Skin Protection:
Wear impervious protective clothing, including boots, gloves, lab coat, apron or coveralls, as appropriate, to prevent skin contact.

Eye Protection:
Use chemical safety goggles and/or a full face shield where splashing is possible. Maintain eye wash fountain and quick-drench facilities in work area.

9. Physical and Chemical Properties

Physical data is displayed for a 5% solution of sodium hydroxide.

Appearance:
Clear, colorless solution.

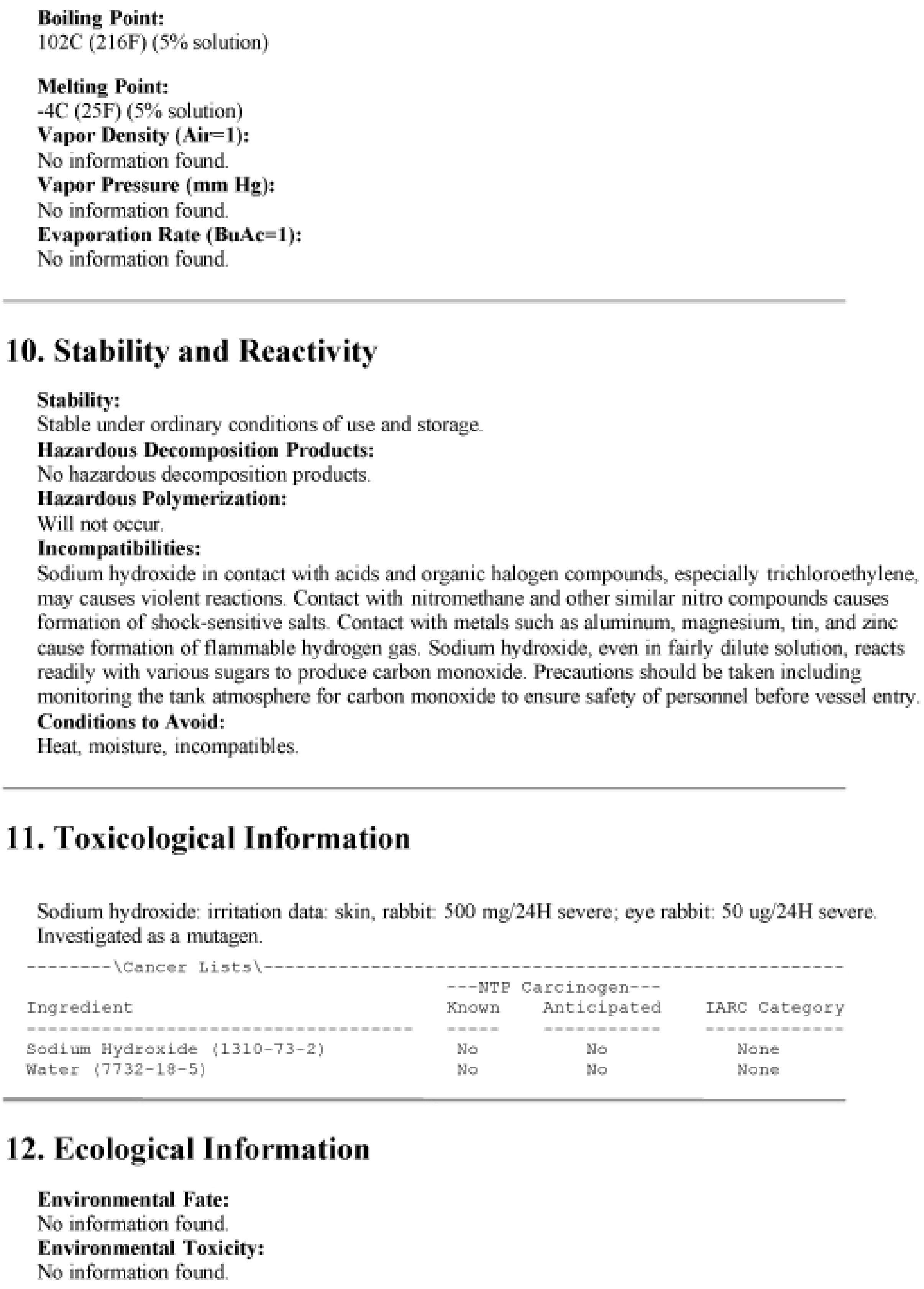
Odor:
Odorless.

Solubility:
Miscible in water.

Density:
5% solution: 1.05

pH:
14.0

% Volatiles by volume @ 21C (70F):
No information found.



Boiling Point:
102C (216F) (5% solution)

Melting Point:
-4C (25F) (5% solution)
Vapor Density (Air=1):
No information found.
Vapor Pressure (mm Hg):
No information found.
Evaporation Rate (BuAc=1):
No information found.

10. Stability and Reactivity

Stability:
Stable under ordinary conditions of use and storage.
Hazardous Decomposition Products:
No hazardous decomposition products.
Hazardous Polymerization:
Will not occur.
Incompatibilities:
Sodium hydroxide in contact with acids and organic halogen compounds, especially trichloroethylene, may causes violent reactions. Contact with nitromethane and other similar nitro compounds causes formation of shock-sensitive salts. Contact with metals such as aluminum, magnesium, tin, and zinc cause formation of flammable hydrogen gas. Sodium hydroxide, even in fairly dilute solution, reacts readily with various sugars to produce carbon monoxide. Precautions should be taken including monitoring the tank atmosphere for carbon monoxide to ensure safety of personnel before vessel entry.
Conditions to Avoid:
Heat, moisture, incompatibles.

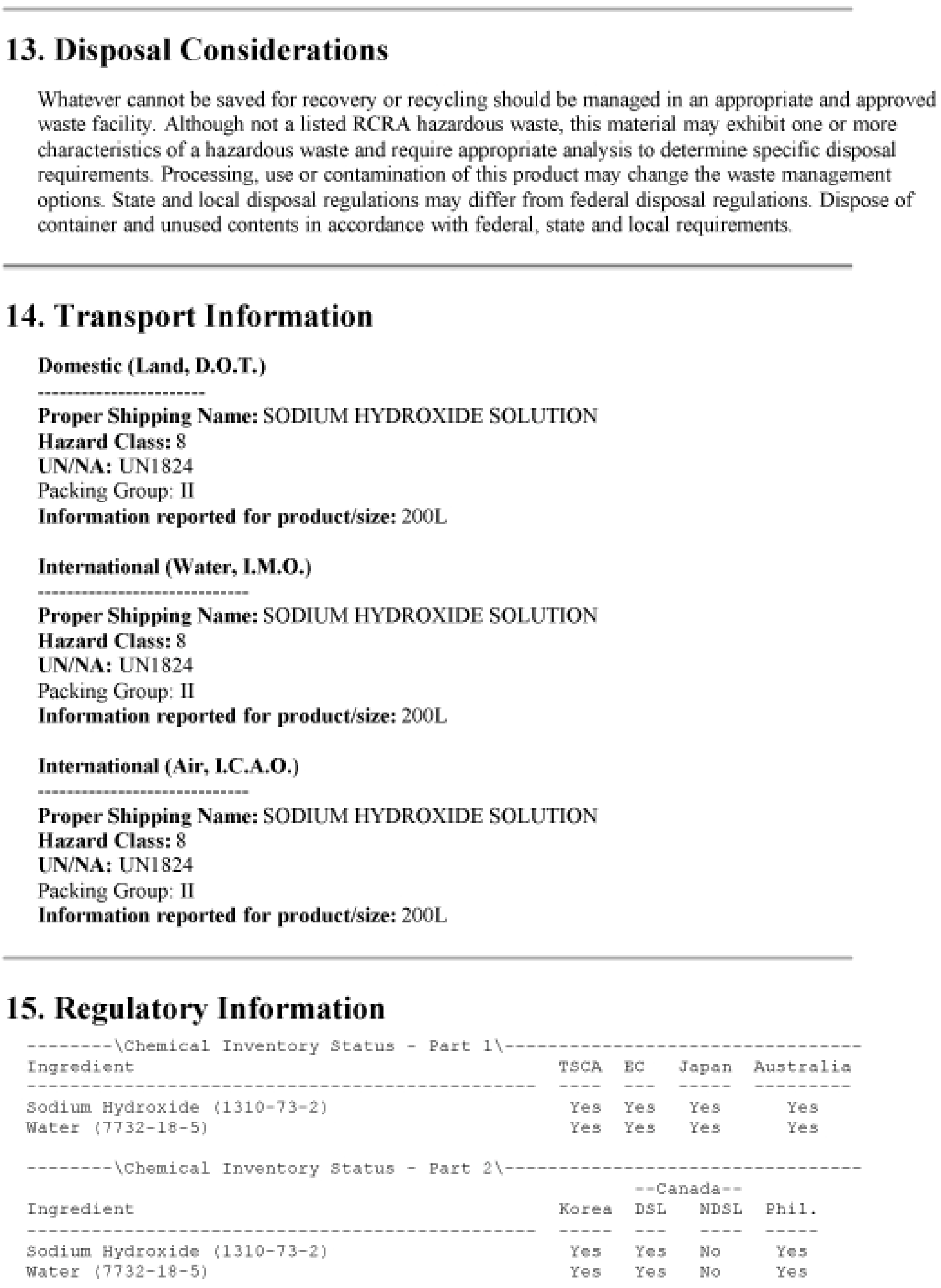
11. Toxicological Information

Sodium hydroxide: irritation data: skin, rabbit: 500 mg/24H severe; eye rabbit: 50 ug/24H severe. Investigated as a mutagen.

```
--------\Cancer Lists\------------------------------------------------------
                                             ---NTP Carcinogen---
Ingredient                                   Known    Anticipated    IARC Category
------------------------------------         -----    -----------    -------------
Sodium Hydroxide (1310-73-2)                  No          No            None
Water (7732-18-5)                             No          No            None
```

12. Ecological Information

Environmental Fate:
No information found.
Environmental Toxicity:
No information found.



13. Disposal Considerations

Whatever cannot be saved for recovery or recycling should be managed in an appropriate and approved waste facility. Although not a listed RCRA hazardous waste, this material may exhibit one or more characteristics of a hazardous waste and require appropriate analysis to determine specific disposal requirements. Processing, use or contamination of this product may change the waste management options. State and local disposal regulations may differ from federal disposal regulations. Dispose of container and unused contents in accordance with federal, state and local requirements.

14. Transport Information

Domestic (Land, D.O.T.)

Proper Shipping Name: SODIUM HYDROXIDE SOLUTION
Hazard Class: 8
UN/NA: UN1824
Packing Group: II
Information reported for product/size: 200L

International (Water, I.M.O.)

Proper Shipping Name: SODIUM HYDROXIDE SOLUTION
Hazard Class: 8
UN/NA: UN1824
Packing Group: II
Information reported for product/size: 200L

International (Air, I.C.A.O.)

Proper Shipping Name: SODIUM HYDROXIDE SOLUTION
Hazard Class: 8
UN/NA: UN1824
Packing Group: II
Information reported for product/size: 200L

15. Regulatory Information

```
--------\Chemical Inventory Status - Part 1\---------------------------------
Ingredient                                       TSCA  EC   Japan  Australia
-----------------------------------------------  ----  ---  -----  ---------
Sodium Hydroxide (1310-73-2)                      Yes  Yes   Yes       Yes
Water (7732-18-5)                                 Yes  Yes   Yes       Yes

--------\Chemical Inventory Status - Part 2\---------------------------------
                                                      --Canada--
Ingredient                                       Korea  DSL   NDSL  Phil.
-----------------------------------------------  -----  ---   ----  -----
Sodium Hydroxide (1310-73-2)                      Yes   Yes   No     Yes
Water (7732-18-5)                                 Yes   Yes   No     Yes
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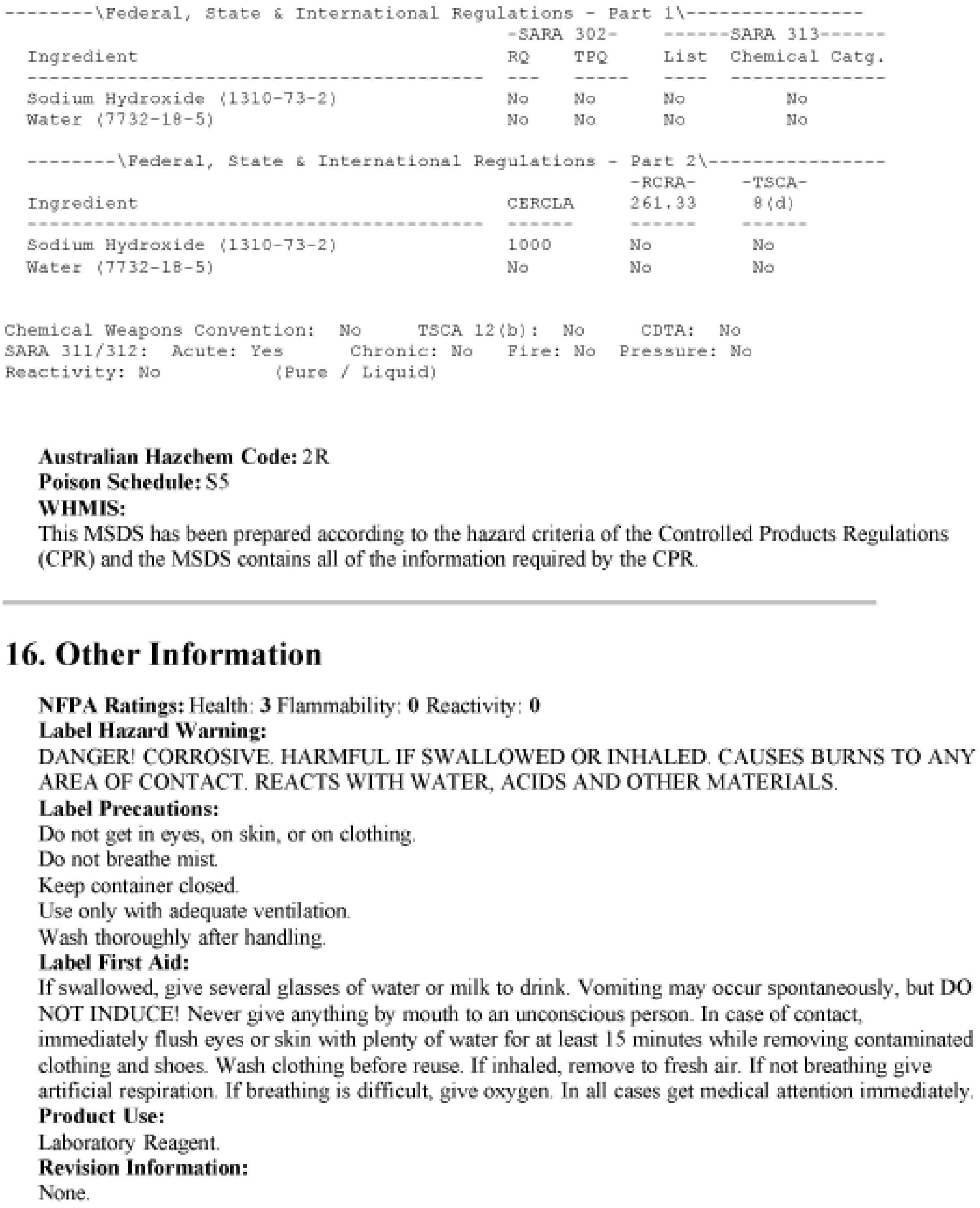

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--------\Federal, State & International Regulations - Part 1\----------------
                                               -SARA 302-    ------SARA 313------
  Ingredient                                   RQ    TPQ     List  Chemical Catg.
  -----------------------------------------    ---   -----   ----  --------------
  Sodium Hydroxide (1310-73-2)                 No    No      No         No
  Water (7732-18-5)                            No    No      No         No

  --------\Federal, State & International Regulations - Part 2\----------------
                                                          -RCRA-    -TSCA-
  Ingredient                                   CERCLA     261.33     8(d)
  -----------------------------------------    ------     ------    ------
  Sodium Hydroxide (1310-73-2)                 1000       No         No
  Water (7732-18-5)                            No         No         No


Chemical Weapons Convention:  No     TSCA 12(b):  No     CDTA:  No
SARA 311/312:  Acute: Yes      Chronic: No   Fire: No  Pressure: No
Reactivity: No          (Pure / Liquid)
```
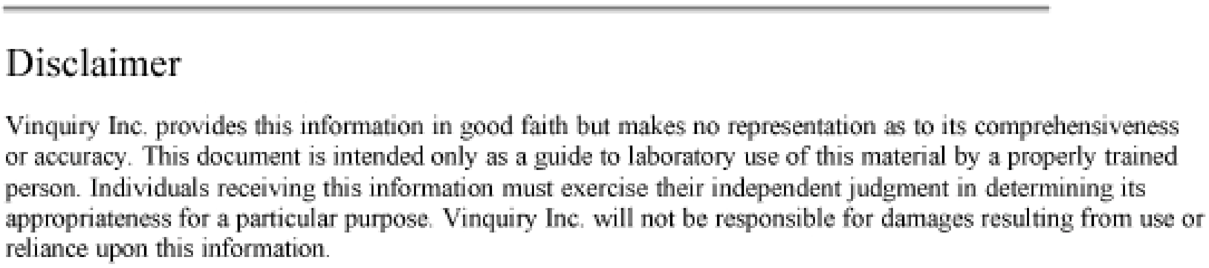

Australian Hazchem Code: 2R
Poison Schedule: S5
WHMIS:
This MSDS has been prepared according to the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by the CPR.

16. Other Information

NFPA Ratings: Health: **3** Flammability: **0** Reactivity: **0**
Label Hazard Warning:
DANGER! CORROSIVE. HARMFUL IF SWALLOWED OR INHALED. CAUSES BURNS TO ANY AREA OF CONTACT. REACTS WITH WATER, ACIDS AND OTHER MATERIALS.
Label Precautions:
Do not get in eyes, on skin, or on clothing.
Do not breathe mist.
Keep container closed.
Use only with adequate ventilation.
Wash thoroughly after handling.
Label First Aid:
If swallowed, give several glasses of water or milk to drink. Vomiting may occur spontaneously, but DO NOT INDUCE! Never give anything by mouth to an unconscious person. In case of contact, immediately flush eyes or skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse. If inhaled, remove to fresh air. If not breathing give artificial respiration. If breathing is difficult, give oxygen. In all cases get medical attention immediately.
Product Use:
Laboratory Reagent.
Revision Information:
None.



Disclaimer

Vinquiry Inc. provides this information in good faith but makes no representation as to its comprehensiveness or accuracy. This document is intended only as a guide to laboratory use of this material by a properly trained person. Individuals receiving this information must exercise their independent judgment in determining its appropriateness for a particular purpose. Vinquiry Inc. will not be responsible for damages resulting from use or reliance upon this information.

ScienceLab.com
Chemicals & Laboratory Equipment

Health	2
Fire	1
Reactivity	0
Personal Protection	E

Material Safety Data Sheet
Succinic acid MSDS

Section 1: Chemical Product and Company Identification

Product Name: Succinic acid

Catalog Codes: SLS4558, SLS2344

CAS#: 110-15-6

RTECS: WM4900000

TSCA: TSCA 8(b) inventory: Succinic acid

CI#: Not available.

Synonym: Butanedioic acid

Chemical Formula: $(CH_2COOH)_2$

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Succinic acid	110-15-6	100

Toxicological Data on Ingredients: Succinic acid: ORAL (LD50): Acute: 2260 mg/kg [Rat].

Section 3: Hazards Identification

Potential Acute Health Effects: Hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation.

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available.
MUTAGENIC EFFECTS: Not available.
TERATOGENIC EFFECTS: Not available.
DEVELOPMENTAL TOXICITY: Not available.
Repeated or prolonged exposure is not known to aggravate medical condition.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. Immediately flush eyes with running water for at least 15 minutes, keeping eyelids open. Cold water may be used. Do not use an eye ointment. Seek medical attention.

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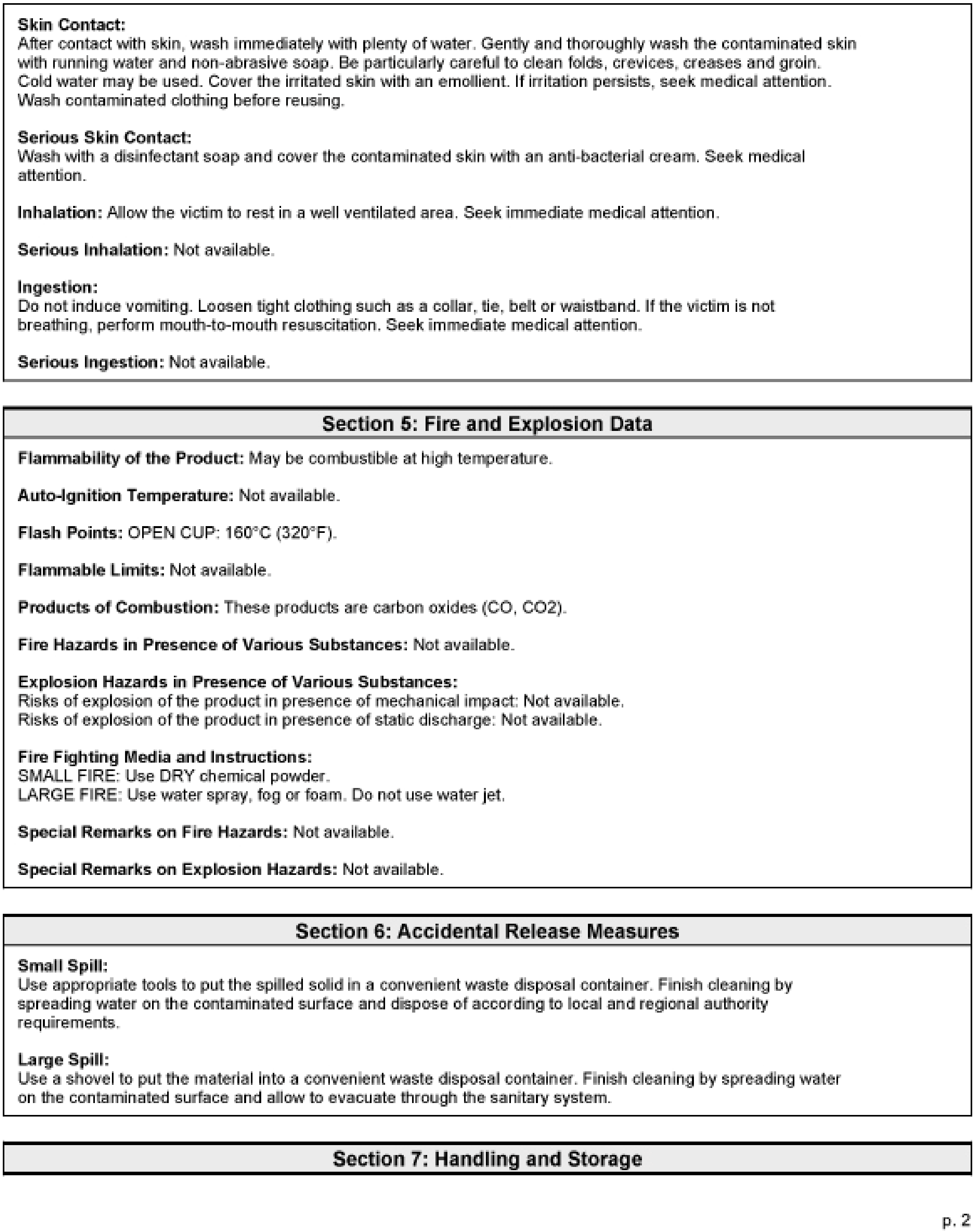


Skin Contact:
After contact with skin, wash immediately with plenty of water. Gently and thoroughly wash the contaminated skin with running water and non-abrasive soap. Be particularly careful to clean folds, crevices, creases and groin. Cold water may be used. Cover the irritated skin with an emollient. If irritation persists, seek medical attention. Wash contaminated clothing before reusing.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek medical attention.

Inhalation: Allow the victim to rest in a well ventilated area. Seek immediate medical attention.

Serious Inhalation: Not available.

Ingestion:
Do not induce vomiting. Loosen tight clothing such as a collar, tie, belt or waistband. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek immediate medical attention.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: Not available.

Flash Points: OPEN CUP: 160°C (320°F).

Flammable Limits: Not available.

Products of Combustion: These products are carbon oxides (CO, CO2).

Fire Hazards in Presence of Various Substances: Not available.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available.
Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder.
LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: Not available.

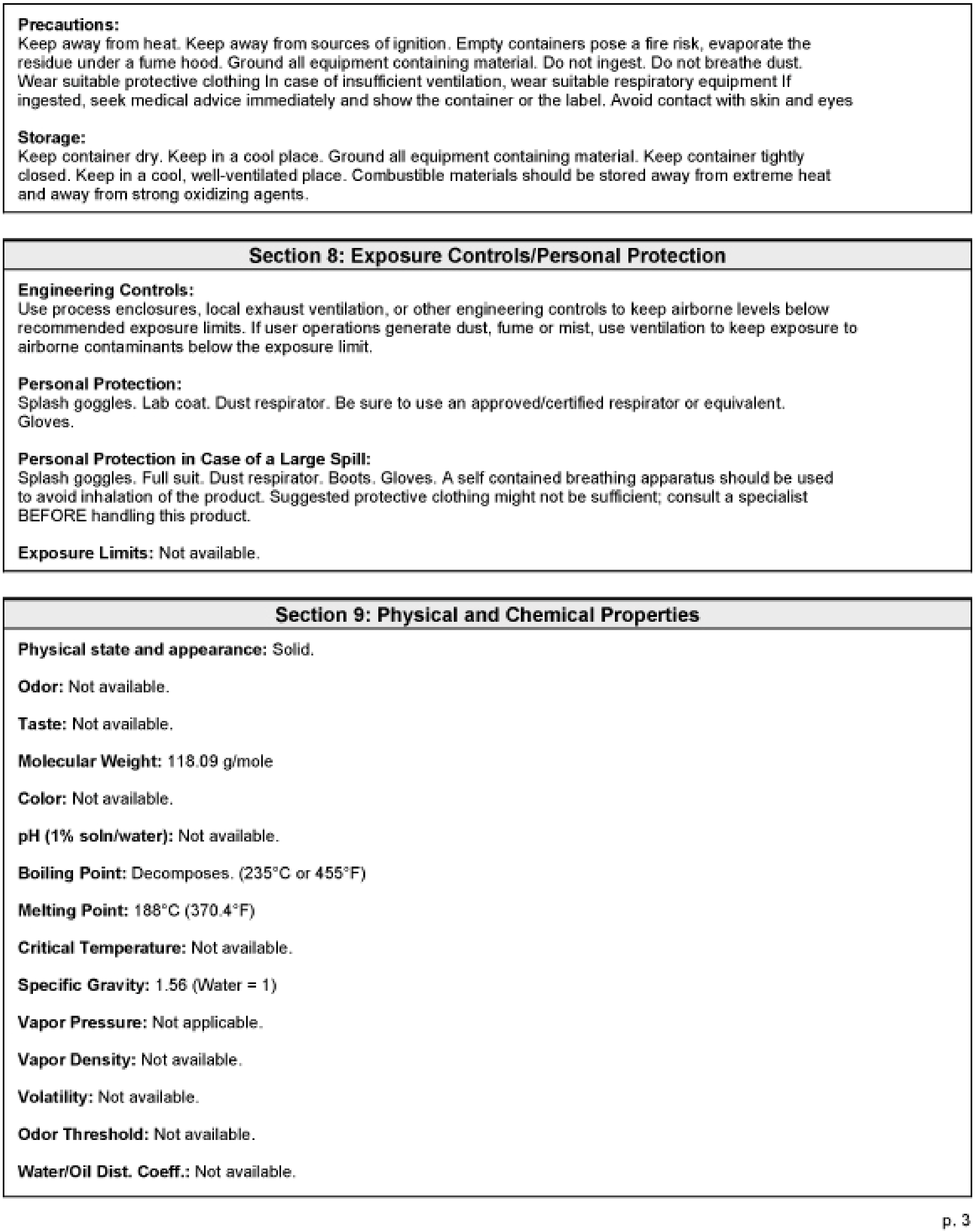
Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system.

Section 7: Handling and Storage



Precautions:
Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not ingest. Do not breathe dust. Wear suitable protective clothing In case of insufficient ventilation, wear suitable respiratory equipment If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes

Storage:
Keep container dry. Keep in a cool place. Ground all equipment containing material. Keep container tightly closed. Keep in a cool, well-ventilated place. Combustible materials should be stored away from extreme heat and away from strong oxidizing agents.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits: Not available.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid.

Odor: Not available.

Taste: Not available.

Molecular Weight: 118.09 g/mole

Color: Not available.

pH (1% soln/water): Not available.

Boiling Point: Decomposes. (235°C or 455°F)

Melting Point: 188°C (370.4°F)

Critical Temperature: Not available.

Specific Gravity: 1.56 (Water = 1)

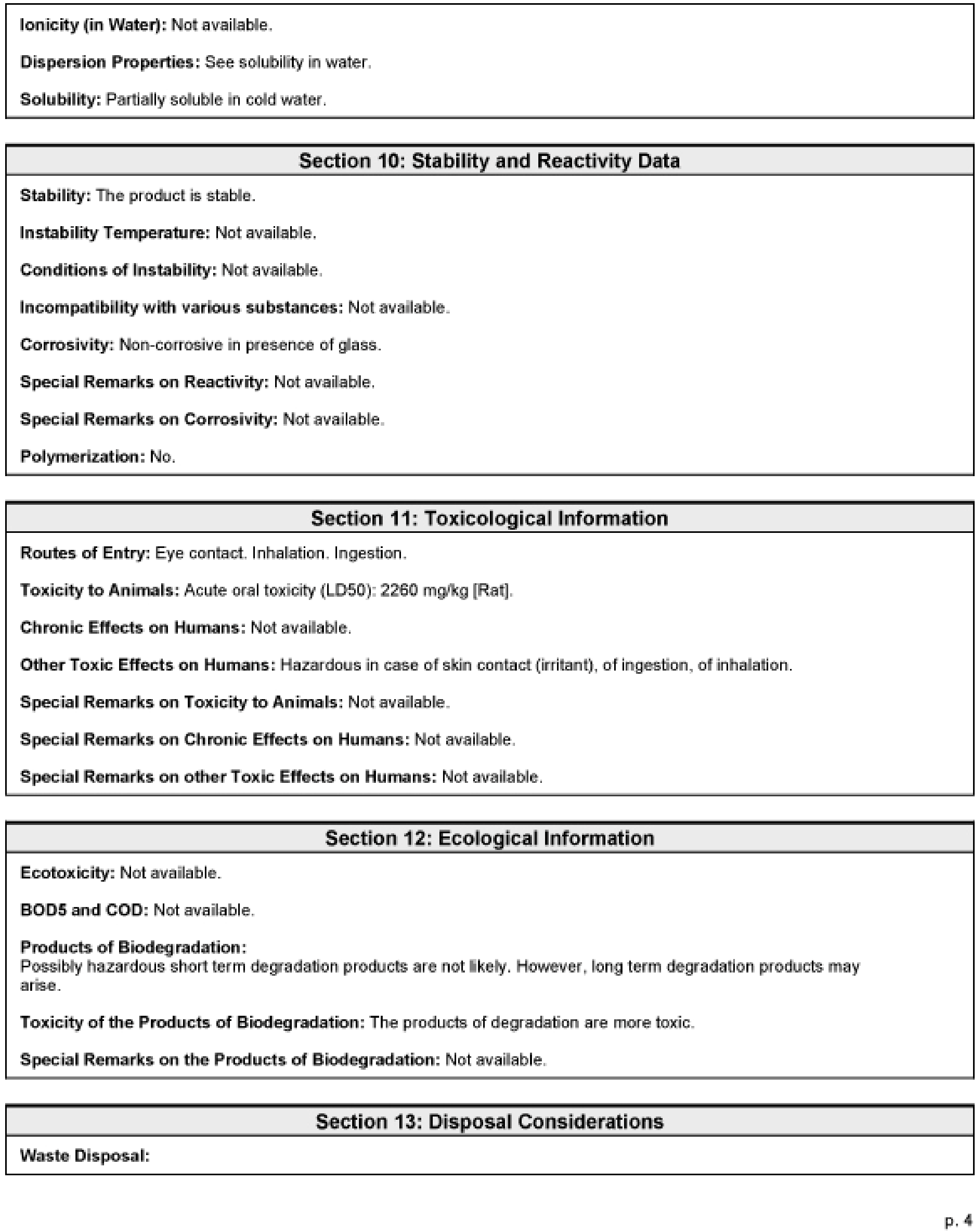
Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.



Ionicity (in Water): Not available.

Dispersion Properties: See solubility in water.

Solubility: Partially soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Not available.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: No.

Section 11: Toxicological Information

Routes of Entry: Eye contact. Inhalation. Ingestion.

Toxicity to Animals: Acute oral toxicity (LD50): 2260 mg/kg [Rat].

Chronic Effects on Humans: Not available.

Other Toxic Effects on Humans: Hazardous in case of skin contact (irritant), of ingestion, of inhalation.

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Not available.

Special Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

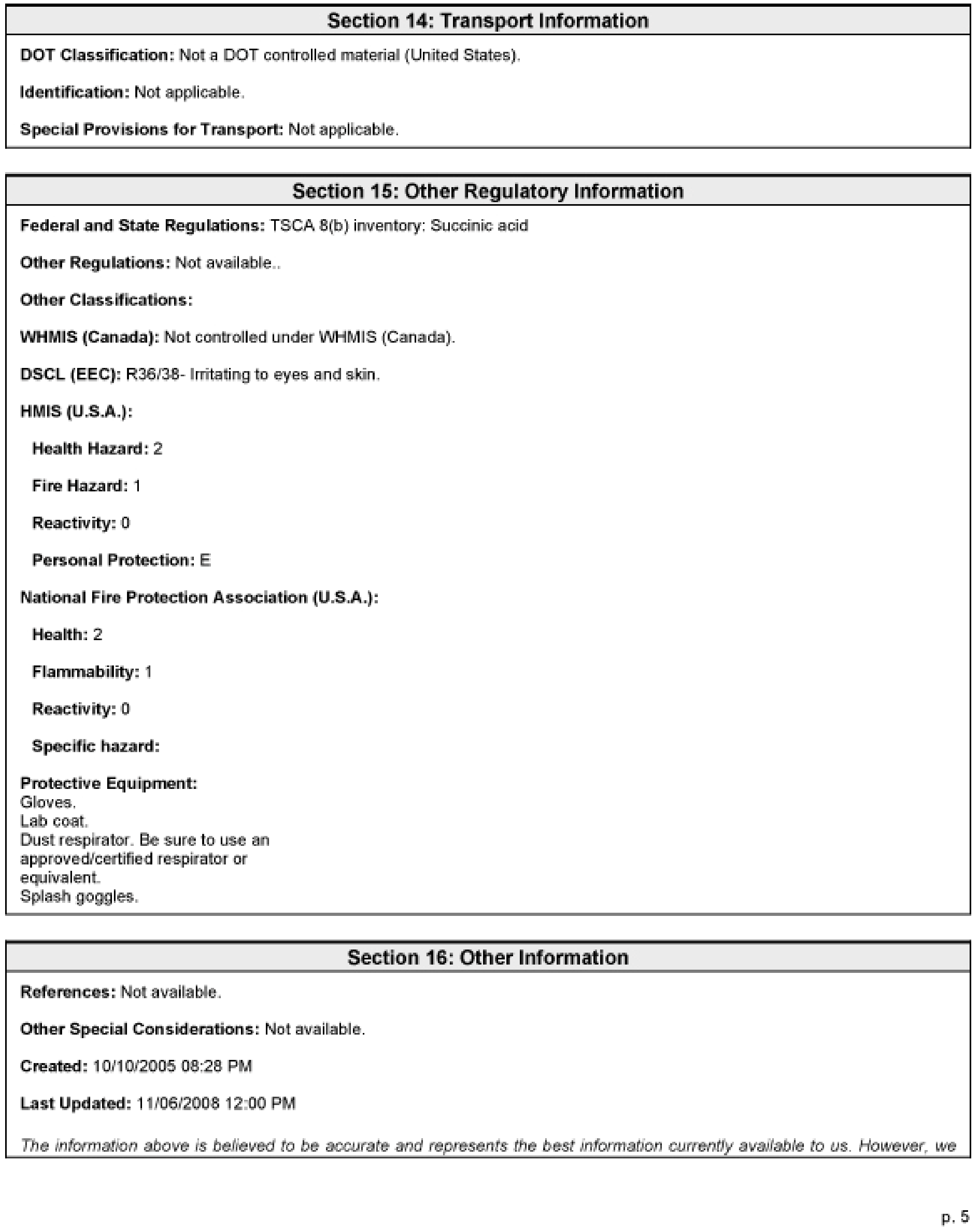
Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are more toxic.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:



Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Not applicable.

Section 15: Other Regulatory Information

Federal and State Regulations: TSCA 8(b) inventory: Succinic acid

Other Regulations: Not available..

Other Classifications:

WHMIS (Canada): Not controlled under WHMIS (Canada).

DSCL (EEC): R36/38- Irritating to eyes and skin.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 1

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves.
Lab coat.
Dust respirator. Be sure to use an
approved/certified respirator or
equivalent.
Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/10/2005 08:28 PM

Last Updated: 11/06/2008 12:00 PM

The information above is believed to be accurate and represents the best information currently available to us. However, we

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