An Indirect Route for Ethanol Production

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by

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Executive Summary

The ZeaChem indirect method is a radically new approach to producing fuel ethanol from renewable resources. Sugar and syngas processing platforms are combined in a novel way that allows all fractions of biomass feedstocks (e.g. carbohydrates, lignins, etc.) to contribute their energy directly into the ethanol product via fermentation and hydrogen based chemical process technologies.

The goals of this project were: 1) Collect engineering data necessary for scale-up of the indirect route for ethanol production, and 2) Produce process and economic models to guide the development effort. Both goals were successfully accomplished.

The projected economics of the Base Case developed in this work are comparable to today's corn based ethanol technology. Sensitivity analysis shows that significant improvements in economics for the indirect route would result if a biomass feedstock rather that starch hydrolyzate were used as the carbohydrate source.

The energy ratio, defined as the ratio of green energy produced divided by the amount of fossil energy consumed, is projected to be 3.11 to 12.32 for the indirect route depending upon the details of implementation. Conventional technology has an energy ratio of 1.34, thus the indirect route will have a significant environmental advantage over today's technology. Energy savings of 7.48 trillion Btu/yr will result when 100 MMgal/yr (neat) of ethanol capacity via the indirect route is placed on-line by the year 2010.

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Project Description

Existing technologies for fuel ethanol production all rely on direct fermentation of carbohydrates derived from corn, sugar cane and other sources. All direct fermentation routes suffer from low carbon efficiency. For example, when the fermentable sugar is dextrose:

Direct Fermentation:

$$\underset{\textit{Dextrose}}{C_6H_{12}O_6} \longrightarrow 2\ \underset{\textit{Ethanol}}{CH_3CH_2OH} + 2\ CO_2$$

two of the six carbon atoms in the substrate are converted into carbon dioxide, giving a maximum carbon efficiency of only 67%. From a chemical energy perspective, direct fermentation is actually quite efficient. The ratio of higher heating values for ethanol and dextrose is (2 x 1369 kJ/mol)/(2807 kJ/mol) * 100 = 98%, which means that most of the chemical energy stored in the starting dextrose is preserved in the final product. However, throwing away carbon in the form of CO_2 restricts the ability of direct fermentation processes to derive chemical energy from sources other than fermentable carbohydrates.

What are the consequences of this limitation? Consider processing a typical lignocellulosic biomass such as corn stover into ethanol. Roughly one-third of the energy content of the feed is present in the form of cellulose, which can be converted into dextrose with appropriate pretreatment and hydrolysis of the feedstock and then fermented with traditional direct fermentation yeasts or similar micro-organisms. Lignin and other non-fermentable materials account for approximately 40% of the energy content of the feedstock. None of this energy can be used directly for ethanol production; it can only be burned and the heat released used to generate steam and power for the plant. The balance of the feedstock is in the form of hemicellulose, which produces a mixture of five and six carbon sugars upon pretreatment and hydrolysis of the biomass feedstock. Genetically engineered micro-organisms that produce ethanol from both five and six carbon sugars must be utilized to obtain high yield from the hemicellulose derived sugars since no wild type micro-organisms exist that are capable of converting mixed sugars. Thus 40-60% of the chemical energy of the starting material (i.e. all of the lignin plus any unfermented materials from the cellulose and hemicellulose fractions of the biomass) is not available for ethanol production via direct fermentation. Designs for lignocellulosic based ethanol plants are usually net exporters of electrical power because of inherent limitations of their process chemistry.

The ZeaChem indirect method is a radically new approach to producing fuel ethanol from renewable resources. Sugar and syngas processing platforms are combined in a novel way to preserve carbohydrate carbon in the ethanol product, allowing lignin and other non-fermented fractions to contribute their energy directly into the ethanol product via hydrogen based chemical process technologies. Our core chemistry can be broken down into three steps, as illustrated for the case of dextrose as the fermentable carbohydrate:

Indirect Ethanol Production Route

Fermentation:

$$\underset{\textit{Dextrose}}{C_6H_{12}O_6} \longrightarrow 3\ \underset{\textit{Acetic Acid}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}OH}$$

Esterification:

$$3\ \underset{\textit{Acetic Acid}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}OH} + \underset{\textit{Alcohol}}{3\ ROH} \longrightarrow 3\ \underset{\textit{Acetate Ester}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}OR} + 3\ H_2O$$

Hydrogenolysis:

$$3\ \underset{\textit{Acetate Ester}}{CH_3\overset{\overset{\displaystyle O}{\|}}{C}OR} + 6\ H_2 \longrightarrow 3\ \underset{\textit{Ethanol}}{CH_3CH_2OH} + \underset{\textit{Alcohol}}{3\ ROH}$$

Net:

$$\underset{\textit{Dextrose}}{C_6H_{12}O_6} + 6\ H_2 \longrightarrow 3\ \underset{\textit{Ethanol}}{CH_3CH_2OH} + 3\ H_2O$$

In the first step, a homoacetogenic fermentation is used to produce acetic acid from carbohydrates at near 100% carbon yield. The homoacetogens are well studied micro-organisms and many wild-type strains are known to ferment both five and six carbon sugars. In the second step, the acetic acid is esterified with an alcohol to produce an ester. Esterification is a widely practiced chemical process technology. For example, Eastman Chemical produces over 400 MM lb/yr of methyl acetate using methanol and acetic acid as feedstocks. In the third step, the ester undergoes hydrogenoloysis to produce the desired ethanol product and the recycle alcohol for the esterification step. Like esterification, hydrogenolysis of esters is a well-known chemical process technology. For example, the majority of new plants built in the last twenty years for the production of 1,4-butanediol (a monomer used mostly in automotive plastics) utilized a route based on the hydrogenolysis of dimethyl maleate or a similar ester.

The net result of the indirect route for ethanol production is a 50% improvement in molar yield compared to conventional direct fermentation technologies (i.e. 3 moles of ethanol per mole of six carbon sugar versus 2 moles ethanol per mole of six carbon sugar). The energy for the third mole of ethanol is supplied by hydrogen. Biomass gasification is a particularly attractive means of hydrogen production since it converts the chemical energy stored in lignin and other non-fermentables into hydrogen, which in turn can be converted into the chemical energy stored in the ethanol product. This, combined with the fact that many homoacetogens metabolize both five and six carbon sugars, means that the chemical energy of all three major biomass fractions can be converted into ethanol at high overall energy efficiency with the indirect route.

Project Goals and Objectives

The goal of this project is to collect engineering data necessary for scale-up of the indirect route for ethanol production. A significant portion of this grant was spent on laboratory scale experiments necessary to support scale-up to pilot operations. By necessity, the scope of the project was narrowed to consider a specific application: integration of the indirect ethanol route with an existing corn wet milling facility, though much of what was learned is directly transferable to other potential applications such as corn dry milling, sugar cane processing and lignocellulosic feedstock facilities.

Figure 1 is a simplified block flow diagram for the base case considered in this grant. A portion of the starch hydrolyzate and light steep water streams from an existing corn wet mill are used as carbohydrate and nutrient sources for the fermentation step. The acetate is recovered from the broth and an acetate ester is produced by esterification with the recycle alcohol. This ester then undergoes hydrogenolysis to produce the desired ethanol product plus the recycle alcohol. Hydrogen is provided by gasification of corn stover. A portion of the syngas produced by the gasifier is diverted to the cogeneration unit to produce steam and power.

The experimental program was limited to work on the fermentation and recovery sections of the proposed flowsheet. Modeling efforts cover all of the units shown in Figure 1 except for the corn wet mill. Development of a detailed process and economic model for a corn wet milling operation was placed outside the scope of work. Starch hydrolyzate and light steep water are assumed to be supplied to the ethanol facility at a negotiated transfer price.

Tasks

Task 1 is the experimental program for the fermentation step. A homoacetogenic bacteria strain was adapted to use glucose as the main carbon and energy source and light steep water as the main nutrient source. Performance of the adapted strain was compared with performance on a traditional yeast extract based media. No strain selection or other media development work was included in the scope of work for this task.

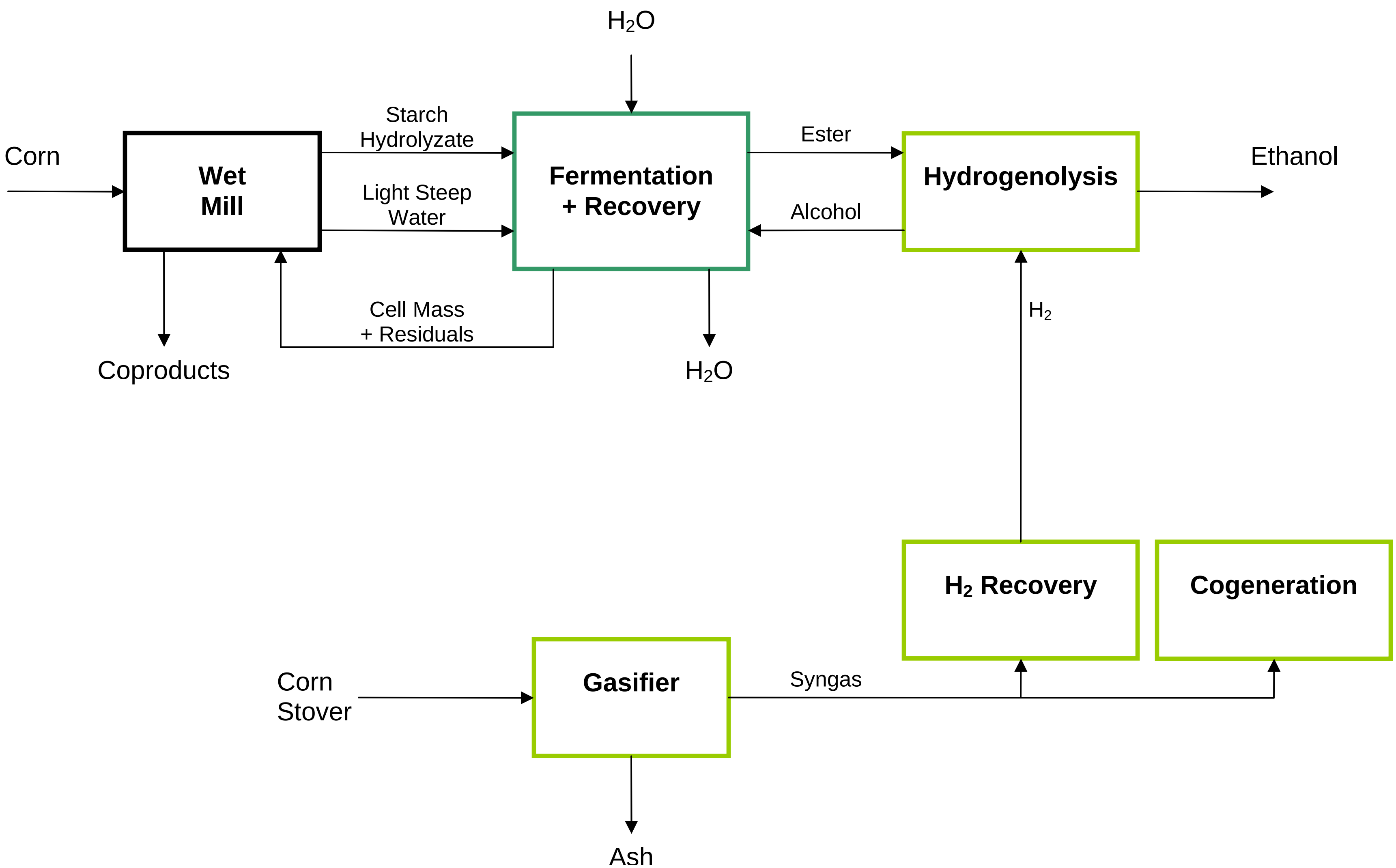
Task 2 is the experimental program for the esterification recovery step. The sub-tasks are concerned with the details of acidification via formation of the amine complex with concurrent precipitation of calcium carbonate, extraction of the amine complex from aqueous solution, and formation of the ester directly from the extract.

Task 3 is the computer modeling task. A process model was generated for the indirect route represented in Figure 1. Results from the process model were used to support the energy savings metrics given in Appendix D. The economic model, derived from the process model, was used to make economic projections for the indirect route.

Task 4 covers the reporting requirements for the grant.

To simplify presentation, the report is divided into stand-alone sections for each task. Reference lists, supporting figures and tables, etc. for each task are presented at the end of each section.

Figure 1 – Base Case Block Flow Diagram



Task 1 – Fermentation Step

Background

Acetogens and methanogens are two types of bacteria capable of fixing carbon dioxide and incorporating it into either cell mass or potentially useful primary metabolic products. Our interest lies with the acetogens, and more specifically with the homoacetogens. Drake (1) defines the acetogens as follows:

> **Acetogens** are obligately anaerobic bacteria that can use the acetyl-CoA pathway as their predominant:
> (i) mechanism for the reductive synthesis of acetyl-CoA from CO_2,
> (ii) terminal electron-accepting, energy-conserving process, and
> (iii) mechanism for the synthesis of cell carbon from CO_2.

Homoacetogens are acetogens that form acetate as the major reduced metabolic product.

Homoacetogens have found competitive niches in many anaerobic environments such as freshwater and marine sediments, deep subsurface sediments associated with oil fields, sewers, anaerobic digesters, and the gastrointestinal tracts of termites, cockroaches, ruminants, and monogastric animals including humans. The acetate produced by the acetogen is a key intermediate in these environments. It is often utilized directly as an energy source by the host animal or further converted into methane by methanogenic bacteria.

Acetogens compete in these environments because of the remarkably diverse range of substrates they consume. Sugars (both six carbon sugars like glucose, and five carbon sugars like xylose), carbon monoxide, H_2/CO_2 mixtures, alcohols (methanol, ethanol, 2,3-butanediol, glycerol), organic acids (formate, lactate, citrate, malate), and lignin breakdown products (methoxylated aromatics, syringate, vanillate) are among the substrates frequently metabolized.

Figure 1.1a is a simplified sketch of the pathways used by homoacetogenic bacteria for the catabolism of glucose and lactate. Glucose is converted to pyruvate using the Embden-Meyerhof glycolytic pathway. Lactic acid is also metabolized by first converting it back to pyruvate. Pyruvate is decarboxylated and then oxidized to acetate with the concurrent production of ATP. The main distinguishing feature of acetogenic bacteria is that CO_2, either from the CO_2 released in the decarboxylation step or from the environment, is fixed via the acetyl-CoA pathway and is used to produce an additional mole of acetic acid. In contrast, non-acetogenic micro-organisms that produce acetic acid are only capable of producing a maximum of two moles of acetate per mole of glucose consumed

Figure 1.1b is a simplified sketch of the pentose phosphate pathway used by acetogens to metabolize five carbon sugars such as xylose. The skeletons of the five carbon sugars are re-arranged into either three or six carbon sugar intermediates which are then fed to glycolysis and further converted into acetate as shown previously in Figure 1.1a. Mixotrophic growth (i.e. the concurrent consumption of two or more substrates) among acetogens is common. This feature is particularly important when considering fermentation of mixed sugar substrates such as lignocellulose hydrolyzates.

The potential for very high carbon utilization is the driving force behind much of the interest in acetogenic metabolism. The net stoichiometry for the three substrates shown in Figure 1.1 is:

$$\begin{gathered} \textit{Glucose} \rightarrow \textit{3 Acetic Acid} \\ \textit{2 Lactic Acid} \rightarrow \textit{3Acetic Acid} \\ \textit{3 Xylose} \rightarrow \textit{5 Acetic Acid} \end{gathered}$$

Notice in all three reactions there is no net production of carbon dioxide. All of the feedstock carbon is converted into acetate. Ignoring the effects of cell mass production, homoacetogens are capable of converting these substrates into acetic acid at 100% theoretical mass yield. In practice, fermentation yields have exceeded 85% in many studies.

The acetogenic bacteria include members in the Clostridium, Acetobacterium, Peptostreptococcus, Sporomusa and a couple of other lesser known species. Drake (1) lists at least 60 strains of homoacetogens. Many of the homoacetogens were originally classified in the genus Clostridium. However, the genus Clostridium has recently been reorganized based on modern genetic understanding and many acetogens have been renamed (2).

By far the most work to date has been done with *Moorella thermoacetica*, formerly *Clostridium thermoaceticum*. *M. thermacetica* is a gram variable, spore forming, thermophilic homoacetogen originally isolated from horse manure. *M. thermoacetica* has a temperature growth optimum around 58 °C and an optimal pH for growth around 7.0 (see Figure 1.2). This acetogen is sensitive to product inhibition and requires a low redox potential for growth. Maximum acetate tolerance for growth is about 30-50 g/l in batch fermentation. Typically, a reduced medium is prepared by including a reducing agent in the formulation (e.g. Na_2S, Na_2SO_3, cystiene, or thioglycolate) and purging the medium of all oxygen by using an inert gas. Although the acetogens are classified as strict or obligate anaerobes, previous work shows some oxygen tolerance and that many strains are capable of lowering the redox potential of their medium once growth is initiated (4).

Several kinetic studies have been conducted to examine the effects of pH and acetate levels on both cell growth and acid production for *M. thermoacetica* and related homoacetogens (5-9). In general, these studies have shown that acetate production is mostly growth associated, with a relatively small amount of acetate production occurring during cell maintenance. Quite a bit of work has focused on the development of low pH tolerant acetogens, perhaps best illustrated by the work at Union Carbide and later at CPC International (10-13). These researchers used classical mutagenesis and selection techniques to obtain an isolate of *M. thermoacetica* capable of growth at pH 4.5. However, growth completely ceased at acetate levels above 2.2 g/l (as acetate). In contrast, Wang and Wang (6) showed that *M. thermoacetica* is capable of growth at pH 7 at acetate levels up to 45 g/l (as acetate). These results suggest that industrially useful final concentrations of acetate in the fermentation broth can only be obtained at near neutral pH with the current state of the art, although it does not exclude the possible future development of an acid tolerant acetogen. More advanced genetic engineering methods may prove to be more useful should future work be pursued along these lines.

The literature is replete with experimental trials of acetogenic fermentations with various fermentor configurations. Batch, fed-batch, continuous, various configurations using membrane based cell recycle, and immobilized cell configurations have all been tested. Table 1.1 compares selected results from the literature. To date, the best results have been obtained using either a fed-batch or fed-batch with cell recycle configuration. In both of these configurations the fermentable sugar, usually glucose, is kept at 5-10 g/l by periodic addition of substrate and nutrients. This suggests that the strain displays substrate inhibition, however as discussed later, a poorly formulated medium may also play a role.

Most previous fermentation trials have used either glucose or starch hydrolyzate as the primary carbon and energy source. These materials are relatively easy to handle since they are completely soluble at the substrate concentration levels of interest and contain high concentrations of a single monomeric sugar (i.e. glucose) that is readily fermented. A few researchers have examined "dirtier" feedstocks such as biomass hydrolyzates (21-22). These materials have additional complicating factors such as the need to pretreat and enzymatically digest the feedstock, resulting in a mixed sugar product from the starting feedstock. Both Sequential Hydrolysis and Fermentation (SHF) and Simultaneous Saccharification and Fermentation (SSF) methods have been tired with favorable results; yields range from 70-100% of theoretical depending upon the details of the experimental trial. SSF is a particularly attractive option since there appears to be a good match between the working ranges of temperature and pH between the enzymes and the fermentation organism, plus the metabolic versatility of acetogens results in high yield of acetate from the mixed sugar substrate.

The identity of the base used for pH control affects both fermentation performance and downstream recovery operations. When the desired final product is a salt, it makes sense to choose the base so that the salt is made directly in the fermentor. For example, when producing calcium magnesium acetate (CMA – a de-icing agent used for environmentally sensitive applications), it makes sense to neutralize the fermentation with dolomite ($CaCO_3 \cdot MgCO_3$) or dolime ($Ca(OH)_2 \cdot Mg(OH)_2$). When acetic acid or another acidified derivative (e.g. acetate esters) is the desired product, an industrially viable processing scheme has to regenerate the base after recovery of the relevant cation from the broth. The alternative, stoichiometric production of a salt coproduct, is not practical at the projected production scale.

Sodium hydroxide has been a popular choice of base by previous investigators since it provides for good fermentation performance. However, downstream recovery operations are faced with the task of having to recover sodium acetate and regenerate sodium hydroxide from the broth. Sodium salts are very soluble in water and there are a limited number of technical options available for recovery and regeneration. Bipolar electrodialysis could potentially be used, but the electricity cost required for regenerating sodium hydroxide would contribute ~$0.20-$0.25 per gallon of ethanol, leading to questionable economics for biocommodity production if NaOH is selected as the base.

As shown in Figure 1.3, Wang and Wang (6) found that both potassium and ammonium cations are inhibitory to *M. thermoacetica*. Other research has shown good fermentation performance using calcium carbonate, dolomite or related derivatives for pH control. For example, Parekh and Cheryan (23) were able to achieve final broth concentrations of 102 g/l (as HAc) with 93% conversion of the glucose feedstock using dolime for pH control in a fed batch fermentation with cell recycle provided by cross-flow membrane filtration. As will be discussed later in Task 2, it is relatively easy to regenerate calcium carbonate in the downstream recovery operation. Unfortunately a calcium based system suffers from the need to handle solid slurries, which is difficult for laboratory experiments, but could be handled in an industrial scale operation. Our initial laboratory work focused on sodium hydroxide as the base, but we also showed that good fermentation performance and adequate pH control could be maintained using calcium carbonate as the neutralizing base.

This grant considers integration of an acetogenic fermentation with a corn wet milling operation. Glucose, in the form of starch hydrolyzate, is the primary carbon and energy source. The primary nutrient source is assumed to be either light steep water or corn steep liquor. Light steep water is the aqueous product of the steeping operation used to soften the kernels prior to grinding. It typically contains ~6 wt% solids. Corn steep liquor is light steep water that has been evaporated to ~50 wt% solids. The normal outlet for corn steep liquor in a wet milling operation is corn gluten feed (i.e. a mixture of the fiber fraction of the corn, corn germ meal when oil recovery is practiced on-site, plus corn steep liquor - an animal feed ingredient for cattle and other ruminants) although corn steep liquor is also sold in relatively small quantities as a nutrient source for industrial fermentations such as penicillin production.

Several previous researchers (14, 16-18) have shown that corn steep liquor can provide nutrients for an acetogenic fermentation. The experimental work in this grant builds upon the previous work of others to show potential integration issues for an acetogenic fermentation with a host corn wet milling operation. As will be discussed later, the strain and media formulation used in the experimental portion of this work still results in a broth that is too rich in nutrients to be considered viable for an industrial fermentation. The results of this study suggest that R&D activities in strain selection and media development are prerequisites for any future development work.

Methods and Materials

Moorella thermoacetica ATCC 39073 (previously *Clostridium thermoaceticum* ATCC 39073) was acquired from the American Type Culture Collection (Manassas, VA) and successfully revived and cultured in shake flasks using the medium and conditions recommended by the American Type Culture Collection.

The maintenance media was a modification of that used by Wang et. al. (5). The composition of the modified base medium, in g/L, was as follows: Bacto yeast extract, 10.0; glucose, 20; KH_2PO_4, 1.0; $MgCl_2$-$6H_2O$, 0.33; $CaCl_2$- $2H_2O$, 0.05; sodium thioglycolate (a reductant), 0.5; resazurin (a redox potential indicator), 0.05. A trace mineral mixture known as Wolfe's mineral solution (Table 1.2) was added at 1 g/l. The pH of the media was adjusted to 7.25 using $NaHCO_3$. This required the addition of approximately 7g/L $NaHCO_3$.

Following preparation, 40 ml of the media was added into 50 ml Wheaton bottles, sealed with a butyl rubber septum and aluminum crimp retainer, and autoclaved for 30 minutes at 20 psi (121 °C). After cooling, the bottles were flushed with instrument grade CO_2 (O_2 < 10ppm, Airgas Corp.) supplied from a cylinder and gas regulator, through Tygon by using a needle inserted through the septum and vented with a second needle in order to remove oxygen and fully reduce the medium. After flushing, the bottles were pressured to 15 psia by removing the vent needle. Under these conditions, the final pH of the media was approximately 6.85. The bottles were inoculated with 10% vol/vol of a 3 day culture. Maintenance cultures were grown unshaken at 58 °C by placing the bottles in an incubator. Cultures were passed every 3 days.

A series of batch fermentations was done using either yeast extract or corn steep liquor (Sigma) as a nutrient source. Corn steep liquor is a very complex mixture containing complex ammonia, organic nitrogen, minerals, vitamins, lactic acid and sugars. It is produced from light steep water by evaporation to about 50 wt% total solids, during which some solids precipitate from the solution. Some of the precipitated solids are not soluble upon dilution. In the cases where corn steep liquor-based media was used, the solids were removed by diluting the nutrient to the desired concentration and then centrifugation at 3000 x g prior to the addition of salts or glucose. About 90% of the raw corn steep liquor is soluble. Correction was made for the solids removal in media formulation.

The pH of corn steep liquor is about 4.5, so the pH was brought to 6.25 with 10N NaOH prior to adjusting the pH to 7.25 with $NaHCO_3$ for culture adaptation and maintenance. Cultures were adapted over several weeks to grow at increasing concentrations of both nutrients. In the cases where medium was prepared in Wheaton bottles, we were unable to control pH and it was necessary to add significantly more $NaHCO_3$ to buffer the effects of the lactic acid present in the corn-based media.

Fermentation was carried out in a modified 3L Bellco spinner flask. The flask was modified to permit the addition and venting of CO_2, and the addition of base for pH control. Sampling of fermentation broth was carried out via a septum cap and syringe. CO_2 (instrument grade with O_2 < 10 ppm) was added to the fermentor continuously to maintain the medium in a reduced state and to exclude oxygen. CO_2 was provided from a cylinder with a gas regulator, a needle valve for fine control and was measured with a rotameter. Prior to inoculation, the fermentor was sparged with CO_2, at 1 L/min, for 2-4 hr, to fully reduce the media. During the run the CO_2 flow rate was reduced to about 0.1 vol/vol/min.

The pH of the fermentation was maintained at 6.90 by the controlled addition of 10N NaOH. A pH probe (Hanna Instruments pH 500) was inserted into the fermentor. The probe was connected to a pH controller that controlled an on/off peristaltic pump (Cole-Parmer Masterflex L/S). The pump delivered NaOH solution from a sterile media bottle with sterile vent filter through Teflon tubing to the fermentor. pH was controlled to within +/- 0.05 units.

The entire flask was placed in an incubator held at 58 °C to maintain temperature control during the runs. Figure 1.4 contains photos of the incubator and fermentor flask. The gas cylinder to the left of the incubator provided carbon dioxide. The pH control system is on top of the incubator. The small bottles to the left of the fermentor are the maintenance cultures.

The base media was prepared as described above, however, the yeast extract (or corn steep liquor), glucose, and salts were each autoclaved separately and then combined in the fermentor. In addition, trace mineral salts (1ml/L) were added by syringe through the sample septum. Each fermentation was inoculated with 200 ml (10% v/v) of a 32-40 hr culture grown in 50 ml Wheaton bottles, as described above.

Acetate and glucose in the culture supernatant were analyzed by Waters HPLC. The Waters 2690 separation module was fitted with both a Waters 2410 refractive index detector for sugars, and a Waters 996 photodiode array detector for organic acids. The column was a BioRad Aminex HPX-87H column. Samples were injected and eluted in an isocratic mode using 10mM H_2SO_4 as the mobile phase, at a flow rate of 0.6 ml/min, at 35 °C. Both acetate concentration and glucose concentration were determined from standard curves prepared by running samples of known concentration.

Optical density measurements of the fermentation broths were made by spectrophotometry (Beckman DU 640) at 600 nm.

Results

We found it was necessary to adapt the strain to the medium prior to attempting a batch fermentation run. Even for yeast extract, several passes were required. Strain adaptation was even slower for the corn steep liquor based media; sometimes several weeks were required. Table 1.3 lists all of the fermentation runs attempted with either yeast extract or corn steep liquor media. Comments are included in the table to indicate some of the key observations including the troublesome and aborted runs.

Fermentation Runs with Yeast Extract Media Neutralized with NaOH

Figure 1.5 displays the batch fermentation results using yeast extract (10 g/l) media. The lag period for this run was slightly less than one day, after which the glucose concentration fell and the acetate concentration rose. The sum of the glucose and acetate concentrations is relatively constant over the course of the fermentation, indicating a good material balance.

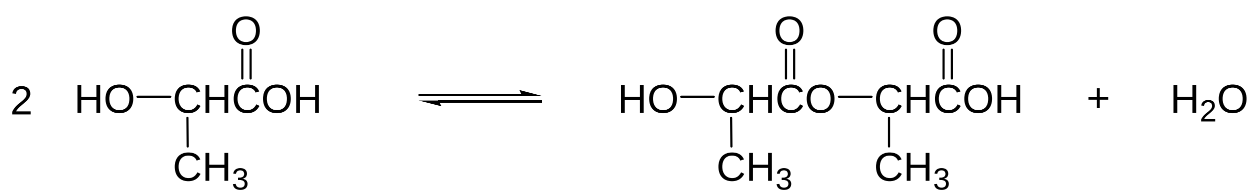
Fermentation Runs with Corn Steep Liquor Media Neutralized with NaOH

The objective for these runs was to demonstrate that a corn-based medium could be used to obtain a final acetate concentration and fermentation rate that was comparable to the yeast extract medium. Figure 1.6 displays the batch fermentation results for a run with corn steep liquor (100 g/l wet) media. As expected, the glucose concentration fell over time while the acetate concentration rose. Unfortunately, all our batch fermentations with corn steep liquor media produced precipitates, so cell density could not be readily monitored by spectrometry.

Another difference we observed with the corn steep liquor media was that the sum of the concentration of glucose+acetate was not constant over time. Rather than being an issue with the fermentation procedure or analytical method, we believe the cause of the apparent non-closure in the material balance was the fact that the organism was synthesizing acetate from other components in the corn steep liquor (e.g. sugars other than glucose, lactate, etc.)

Figures 1.7 and 1.8 compares chromatograms for sugars and organic acid analyses of batch fermentation runs using both the yeast extract and corn steep liquor media. The figures are arranged to allow qualitative comparisons between start of run and end of run for each media, plus comparison between the two media. Several observations can be made:

1) The lactic acid peak (Figure 1.8, retention time = 12.9 min) is much smaller at the end of the CSL media run than at the beginning, suggesting that lactate was being consumed. We established a calibration curve for lactate and tracked its concentration over the course of the fermentation. Lactate levels generally decreased over the course of the fermentations, however there were periods were the lactate levels actually increased. There are several possible explanations. One likely reason is that corn steep liquor contains both lactic acid/lactate and higher internal esters of lactic acid (i.e. lactolylactic acid and higher oligomers) which are formed during the evaporation of light steep water:



Lactic Acid *Lactolylactic Acid*

In a dilute aqueous solution at near neutral pH, the lactolylactic acid and higher oligomers will slowly hydrolyze back to monomeric lactate. A temporary increase in the amount of lactate present in the broth would be observed if the oligomer hydrolysis reaction is faster than the rate at which the organism consumes lactate. If true, this complicates the material balance since lactate and all associated oligomers have to be measured and accounted. Yeast extract does not contain a significant amount of lactic acid, so material balances for runs with yeast extract media are much less complicated.

2) The sugar chromatograms (Figure 1.7) at the end of run for both the yeast extract and corn steep liquor media showed a significant peak at a retention time of 16 minutes that was not present at the start of either fermentation. Previous investigators (14, 16) have suggested that that batch fermentations of glucose using non-adapted library strains begin to accumulate fructose once the cells stop growing. Fructose does not elute at 16 minutes with our HPLC method, so the identity of this compound is still unknown. Nonetheless, this undesirable trait can probably be eliminated by strain development or handled by a fermentation design that maintains the cells in log phase growth.

Figure 1.9 compares acetate production curves for batch fermentations at various corn steep liquor concentrations. The starting medium in all cases was formulated at a constant initial glucose concentration of 50 g/l, without correction for the additional glucose contained in the corn steep liquor. The data shown in Figure 1.9 have had the lag time removed to facilitate comparisons. The initial log phase volumetric productivity ranged from 0.025 – 0.75 g/l/hr; final acetate concentration ranged from 2.5 – 38 g/l (as HAc). Both volumetric productivity and final acetate concentrations increased with increasing corn steep liquor concentration in the media.

Figure 1.10 compares acetate production for the yeast extract and corn steep liquor media. The performance of the 40 g/l (wet) corn steep liquor (~20 g/l dry basis) medium was about the same as the performance of the 10 g/l yeast extract medium. This suggests that, on a per mass basis, yeast extract is twice as effective as a nutrient source when compared to corn steep liquor.

Use of $CaCO_3$ for Neutralization

One of the goals of the study was to show that $CaCO_3$ could be used as the neutralizing base for the fermentation. We conducted a series of bottle cultures using the yeast extract media augmented with various levels of $CaCO_3$. As shown in Figure 1.11, higher levels of $CaCO_3$ resulted in higher concentrations of acetate in the bottle culture. Several reasons for improved performance with $CaCO_3$ could be postulated. For example, the pH of the bottle cultures is not controlled; higher levels of $CaCO_3$ could just be increasing the buffering capacity of the media. Nonetheless, the data of Figure 1.11 suggests there is no need for adaptation of the strain when switching from sodium to calcium as the neutralizing base cation.

Unfortunately, our batch fermentation equipment was not designed for sterile addition of solid or slurried $CaCO_3$. For purposes of demonstrating pH control with a calcium based system, we decided to conduct a simplified experiment to show that the pH of an aqueous solution containing acetic acid and calcium carbonate could be controlled by manipulating the partial pressure of CO_2 in the headspace.

Prior to any experimental work, we set-up an aqueous electrolyte model that related pH of the solution to variations in the total acetate concentration and CO_2 partial pressure at 25 °C (see Figure 1.12). The resulting set of non-linear algebraic equations was then solved, producing the curves shown in Figure 1.13. Although this simplified model does not take into account the buffering effects of other media components or temperature, the curves in Figure 1.13 show that pH can be controlled by manipulating the CO_2 partial pressure in the headspace.

We experimentally tested pH control of an aqueous calcium acetate/calcium carbonate slurry by varying the composition of the headspace gas. Approximately 30 grams of calcium carbonate were added to 710 ml of a 0.0117 g/l (as acetate) calcium acetate solution. The flask was initially gassed with pure CO_2 at about 0.5 lpm. The pH reached an equilibrium value of 6.01, which agrees with the prediction in Figure 1.13 after accounting for the fact that atmospheric pressure at our lab in Colorado is about 0.83 atm. The flask was then gassed with pure nitrogen. The pH increased quickly at first followed by a slower asymptotic rise. After two hours, the pH of the solution was 8.07, again in agreement with the prediction of Figure 1.13.

We found that by varying the ratio of CO_2 to N_2 in the gas mixture, the pH could be set at any desired level between these two limits and could be controlled to within +/- 0.05 units.

The gas ratio was then set to give a pH of 6.95. To simulate a fermentation, we continuously added to the flask a dilute aqueous solution of acetic acid at a rate equivalent to 1 g/l/hr, roughly corresponding to the volumetric productivity of an acetogenic fermentation. The gas ratio was manually adjusted with needle valves and the pH of the solution was successfully controlled between 6.84 and 6.95 over a period of 1 hour, thus demonstrating pH control in the simplified experimental apparatus.

Discussion

The fermentation results presented here are in qualitative agreement with the prior literature. We found the strain was quite adaptable to new fermentation conditions and capable of metabolizing a variety of substrates. As in the literature, using the depository type strains and standard media formulations without extensive adaptation/selection procedures results in batch fermentations that give reasonable final acetate concentrations but often fail to extinguish fermentable sugars in the media. Two critical issues need to be addressed in future work: strain adaptation/selection and media formulation. Parallel development has to be done because of interaction between the strain and its media. Furthermore, additional constraints arise because of integration issues with downstream recovery operations and overall process economics.

Prior work in the literature has recognized the importance of strain adaptation and selection. The paper by Parekh and Cheryan (15) is especially good at pointing out the need for strain adaptation/selection. They showed incomplete batch fermentations result when using four different depository strains in a medium with 20 g/l of glucose and a yeast extract+tryptone nutrient source. But, by applying adaptation and selection procedures, they were able to produce a strain that completely converted a 35 g/l glucose medium, producing a final broth concentration of 29 g/l of acetate. Classical mutagenesis methods have also been used by several researchers to produce improved strains (10, 19).

We feel that inadequate attention has been paid in the literature to the impact of media formulation on downstream recovery operations and overall process economics. No truly industrial media formulations have been developed for an acetogenic fermentation. Most prior studies use a complex undefined media containing yeast extract or a combination of yeast extract and a proteolyzed protein source such as tryptone (proteolyzed casein protein from milk). A typical formulation contains 10-50 g/l of glucose plus 10 g/l of the undefined nutrient source. The cost of just the undefined media component alone would contribute $9.20 per gallon of ethanol (denatured) at a typical bulk price of $10 per kg for yeast extract.

Just as importantly, the high nutrient loading leads to problems in downstream recovery operations – an issue that has been nearly universally ignored in the prior literature work on acetogenic fermentations. Frankly, based on our laboratory experience the fermented broth is so dark from the high nutrient loadings that it is difficult to conceive of a recovery system capable of producing a high purity product. We initially approached media formulation from the point of view that the economics could be improved just by switching the complex nitrogen source from yeast extract or yeast extract+tyrptone to corn steep liquor. As will be shown in Task 3, this switch does bring the economics in-line with the needs of an industrial fermentation. However, switching the media from high concentrations of one complex nitrogen source to high concentrations of a different complex nitrogen source does nothing to improve integration of the fermentation and recovery steps.

We recommend future work should start with a defined media containing a simple nitrogen source (e.g. ammonia). Combining strain adaptation/selection with a defined media should result in both an improvement in process economics and improved integration with downstream recovery operations. Eliminating undefined media components will also simplify laboratory analytical methods and make it easier to separate the effects of media limitations from substrate/product inhibition.

There is some precedent for believing a defined media is technically feasible. Lundie and Drake (27) developed a minimally defined growth media for *M. thermoacetica* that contains glucose as the carbon and energy source, ammonium sulfate as the nitrogen source, nicotinic acid as the sole essential vitamin, plus other components such as a reductant, trace minerals, inorganic buffers and CO_2 in the headspace. While the minimal media was capable of supporting growth, the performance was much better when the organism was grown on an undefined media containing yeast extract as illustrated in Figure 1.14. A later report (28) states that when the minimal medium is supplemented with biotin (a vitamin) the fermentation performance is essentially identical to the performance of undefined media. A similar study was carried out to find a minimally defined medium for another acetogen, *C. thermoautotrophicum* (28). The results of this study, displayed in Figure 1.15, also show that growth could occur using only ammonium sulfate as the nitrogen source and nicotinic acid as the sole essential vitamin, but in this case the vitamin biotin was stimulatory. The economics of our proposed recommendation are explored later in Task 3.

Sub-Task Review

The description of the sub-tasks, taken from Appendix B Statement of Work in the original proposal, is repeated below:

<u>Task 1.1 Analytical Method Validation</u> – Published HPLC analytical protocols for measuring sugars, especially dextrose, in aqueous solutions will be implemented and validated on our equipment. Likewise, published HPLC analytical protocols for measuring organic acids, especially lactate and acetate, will be implemented and validated. The outcome of this task will be the ability to accurately measure sugars and organic acid content of starch hydrolyzate, corn steep liquor and fermentation broth.

<u>Task 1.2 Construction</u> – Two fully instrumented, temperature and pH controlled, 1 liter batch fermentors will be assembled. Cell mass will be measured off-line by optical density. Fermentation protocols will be established and the ability to generate reproducible runs with good mass balance closure will be demonstrated prior to entering Task 1.4. The media formula given in (17), based on starch hydrolyzate and corn steep liquor provided by our contacts within the wet milling industry, will be used for the shakedown runs. *Clostridium thermoaceticum*

ATCC 39073, *C. thermoaceticum* ATCC 49707, or similar, will be used as the test strain. The outcome of this task will be the assembly and shakedown of the equipment needed to support the testing in Task 1.4.

Task 1.3 Testing – A series of batch fermentation runs designed to obtain the data necessary for creating a kinetic model of the fermentation will be conducted. The effects of temperature, pH, substrate inhibition for both starch hydrolyzate and corn steep liquor, and the effects of product inhibition will be examined. Runs that do not exhibit good mass balance closure will be discarded and the conditions repeated with another run. The outcome of this task will be a set of high quality experimental data that can be used for model development.

Task 1.4 Data Analysis – The data from Task 1.4 will be processed into a kinetic model for cell growth and acetate production. The outcome of this task will be used for further modeling efforts in Task 3.1.

The following discussion compares the work actually accomplished against the original proposal subtasks:

Task 1.1 Analytical Method Validation – Complete.

Task 1.2 Construction – Complete.

Task 1.3 Testing – Complete.

Task 1.4 Data Analysis – Complete.

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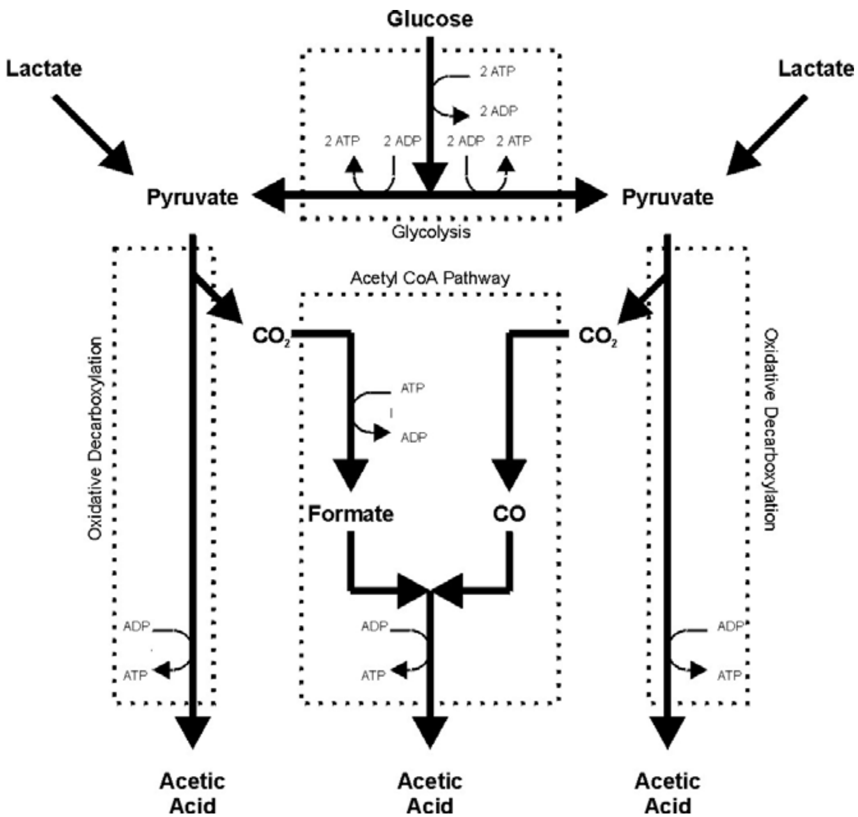
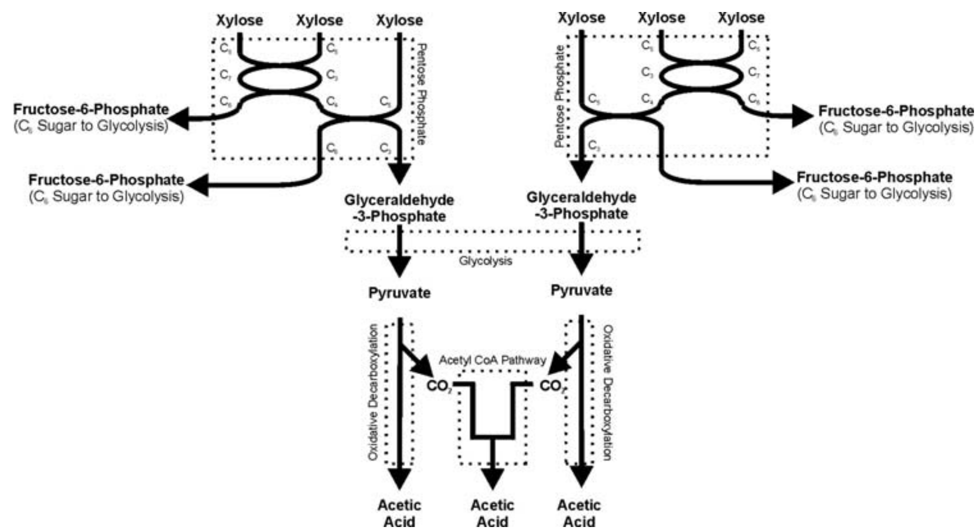


a) C_6 Sugars and Lactate



b) C_5 Sugars

Figure 1.1 – Simplified Catabolic Pathways Used by Acetogens

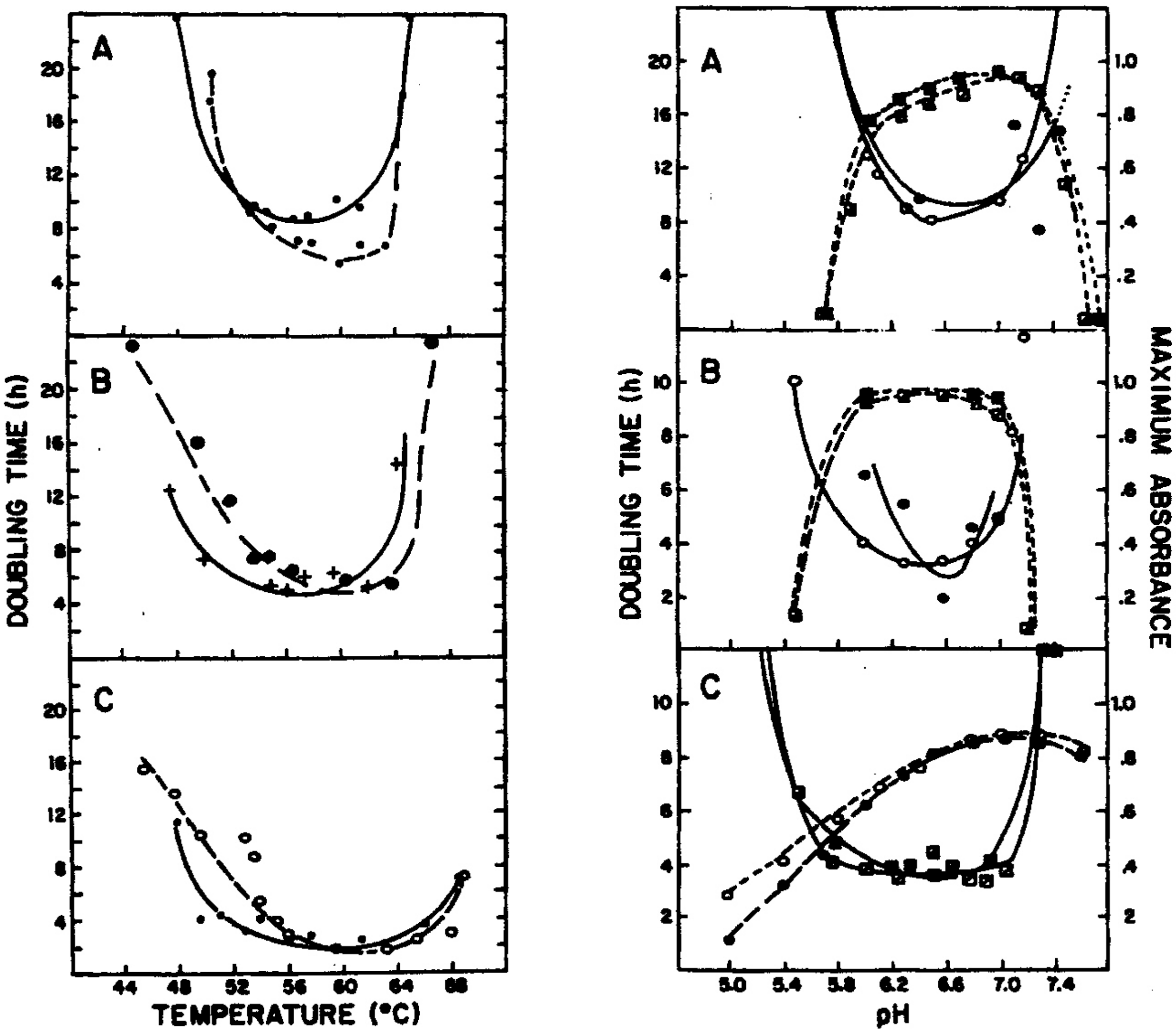


Figure 1.2 – Effect of Temperature and pH on Growth of A) *M. thermoacetica*, B) *M. thermoautotrophicum* and C) *Thermoanaerobacter kivui* (formerly *Acetogenium kivui*)

Taken from (3)

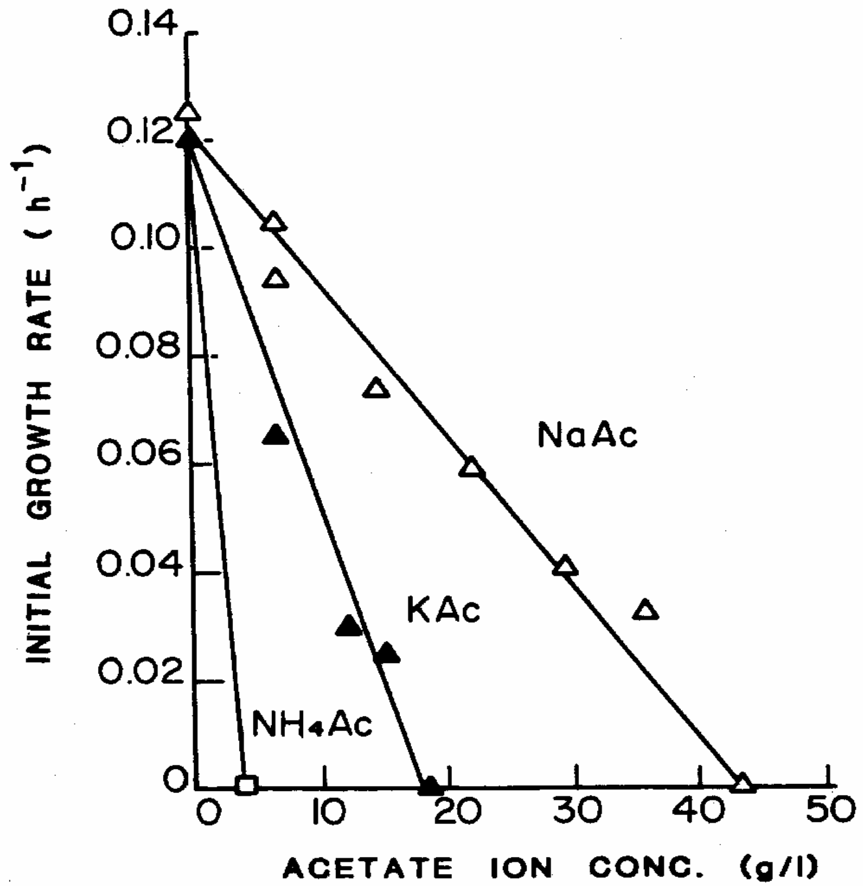


FIG. 6. Comparison of the initial growth rates of *C. thermoaceticum* at different acetate ion concentrations (in grams per liter). Symbols: □, ammonium acetate; ▲, potassium acetate; △, sodium acetate.

Figure 1.3 – Inhibitory Effect of Ammonium and Potassium Cations

Taken from (6)

a) External View of Incubator, CO_2 Supply and pH Control System

b) Modified 3 L Spin Flask, Stirrer, and Maintenance Cultures

Figure 1.4 – Fermentation Apparatus

Figure 1.5 - Batch Fermenation using Yeast Extract (10 g/l) Media

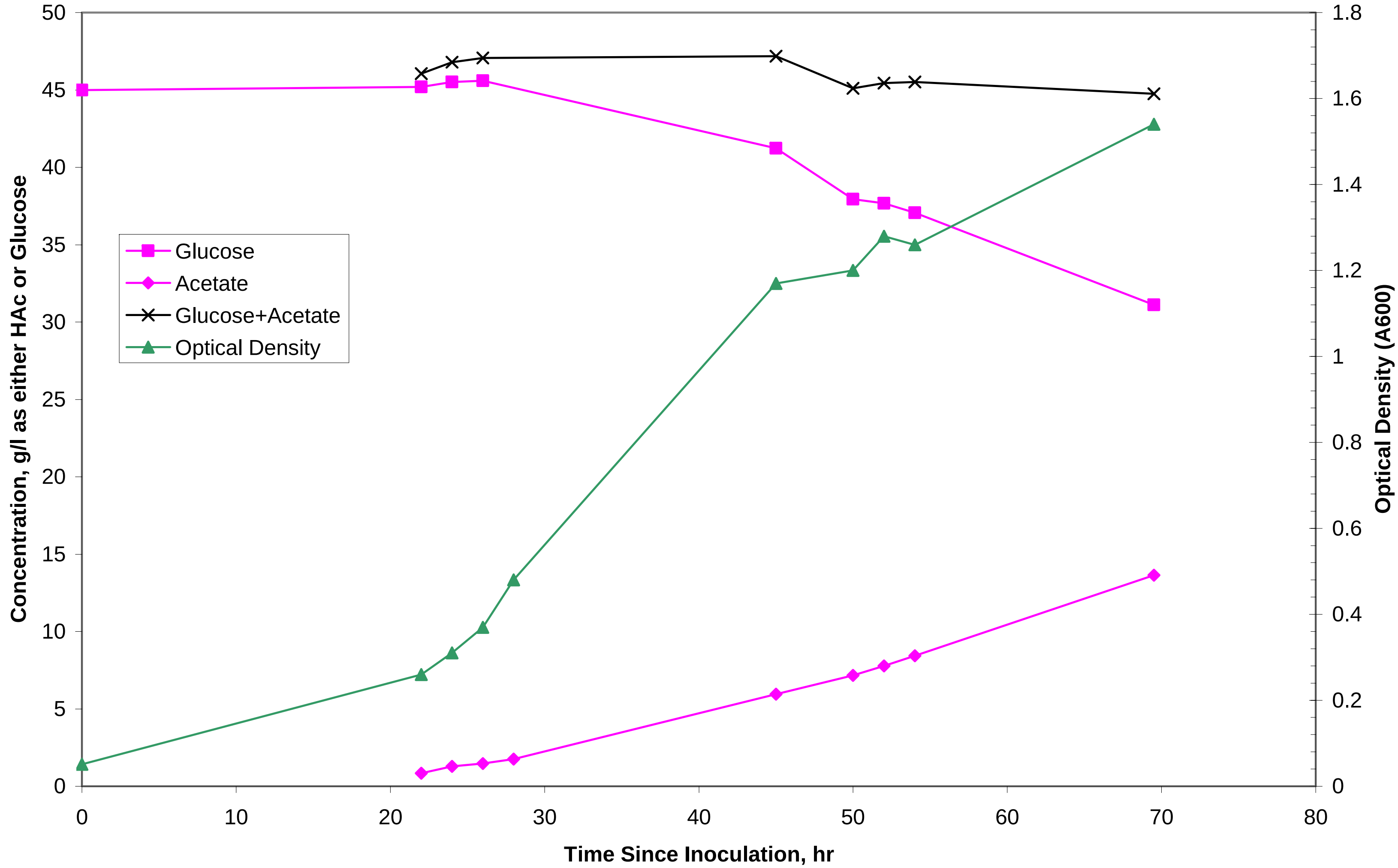


Figure 1.6 - Batch Fermentation Using Corn Steep Liquor (100 g/l) Media

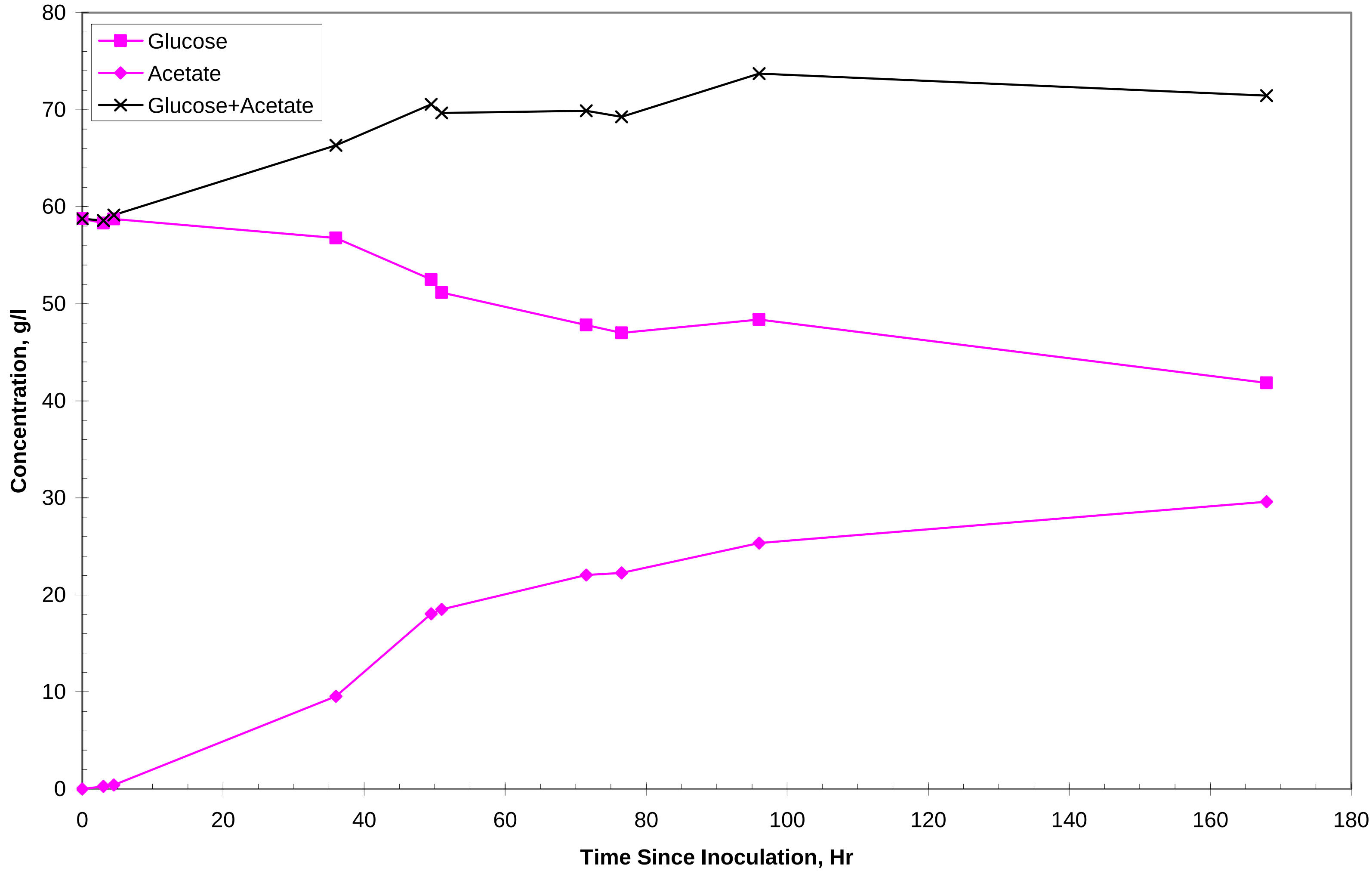
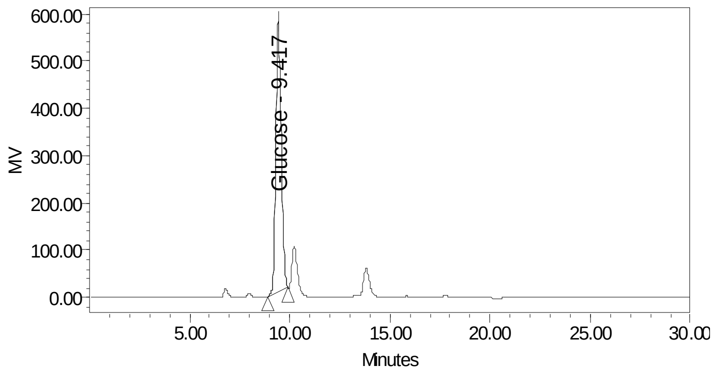
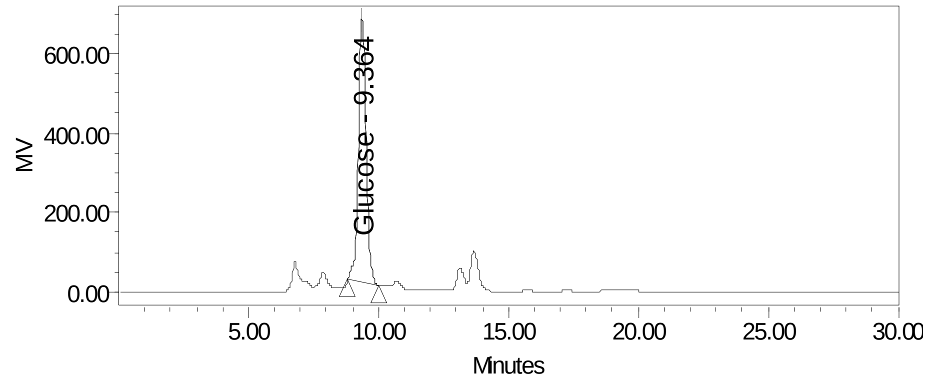


Figure 1.7 – Example Chromatograms for Sugars Analyses

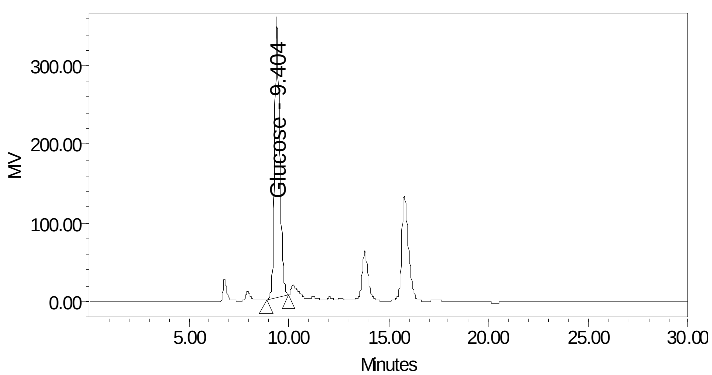
a) YE Media at T = 0 hr



c) CSL Media (100 g/l) at T = 0 hr



b) YE Media at T = 69.5 hr



d) CSL Media (100 g/l) at T = 168 hr

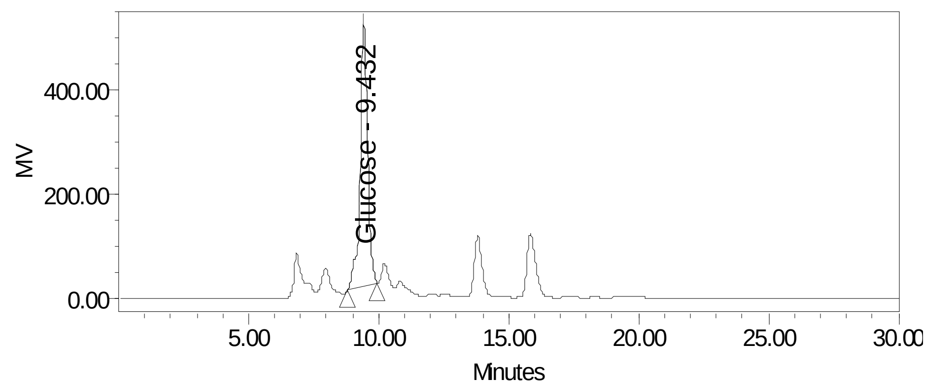
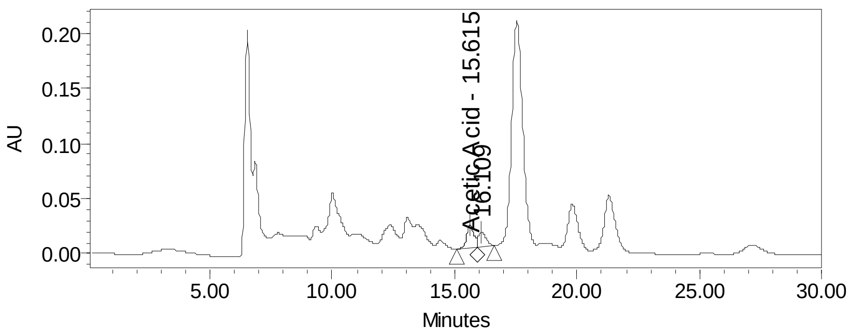
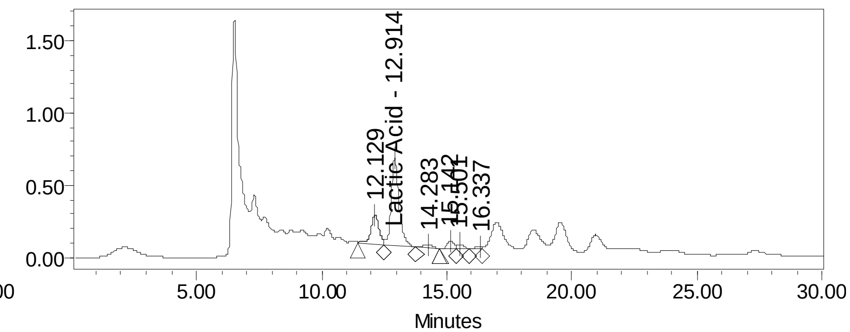


Figure 1.8 – Example Chromatograms for Organic Acid Analyses

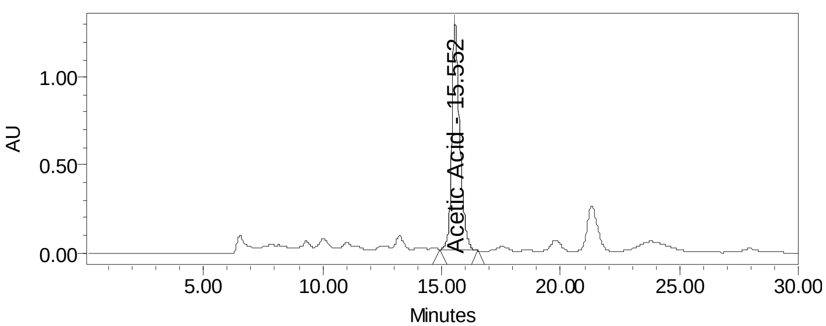
a) YE Media at T = 0 hr



c) CSL Media (100 g/l) at T = 0 hr



b) YE Media at T = 69.5 hr



d) CSL Media (100 g/l) at T = 168 hr

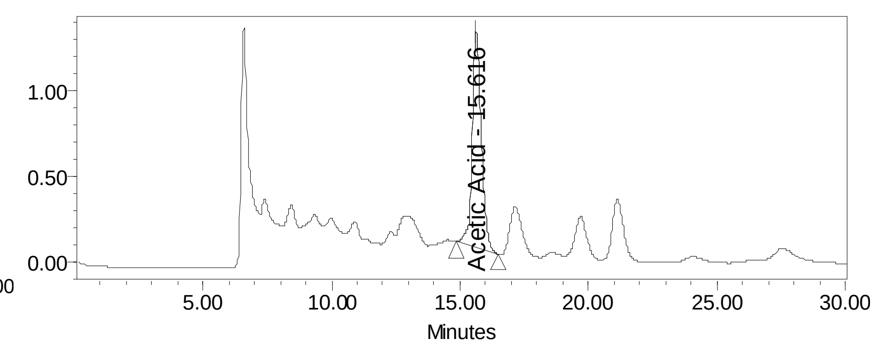


Figure 1.9 - Effect of Corn Steep Liquor on Acetate Production
Corn Steep Liquor (CSL) Concentrations Reported on Wet Basis

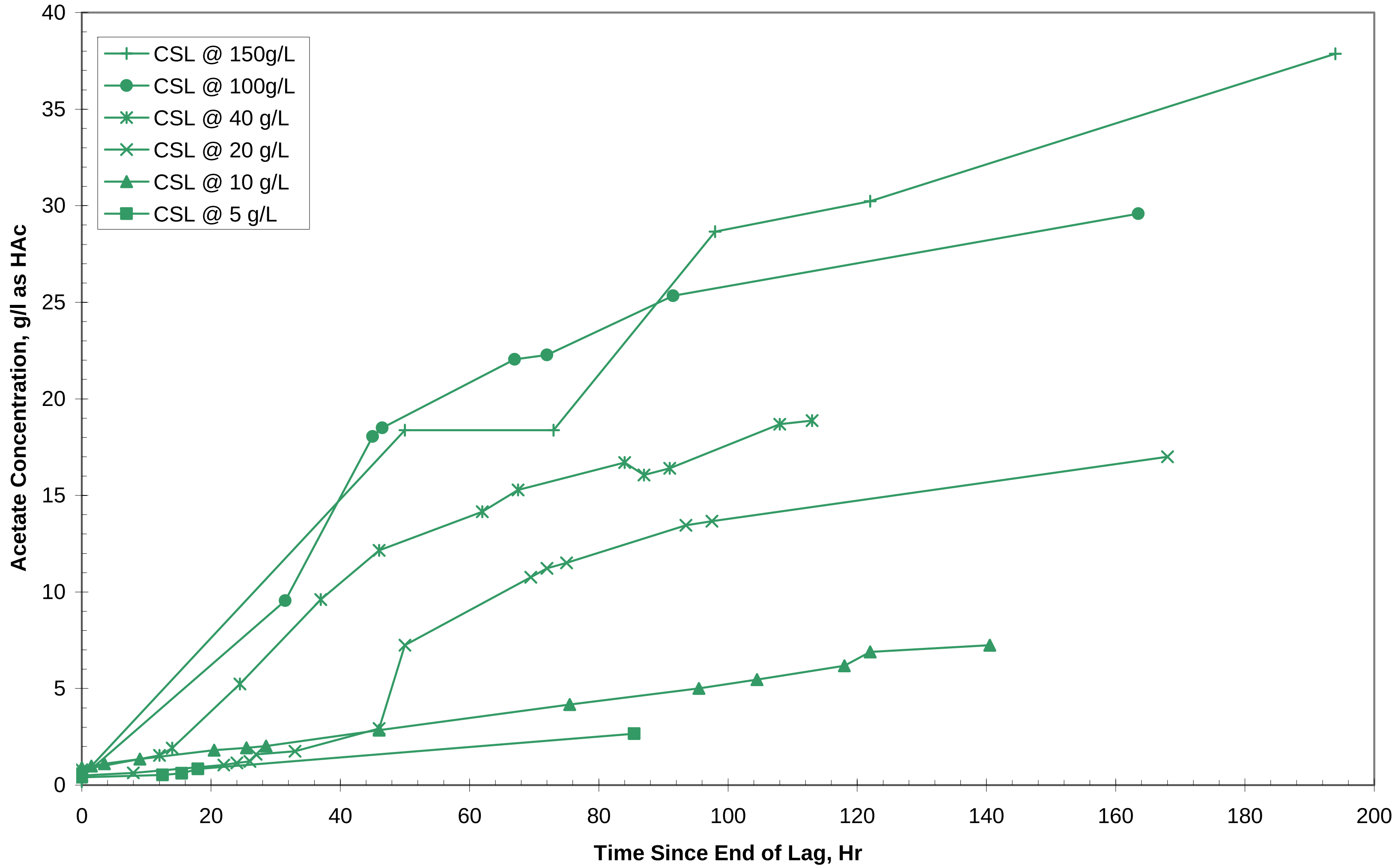


Figure 1.10 - Comparison of Yeast Extract (YE) and Corn Steep Liquor (CSL) Media
Corn Steep Liquor Concentrations Reported on Wet Basis

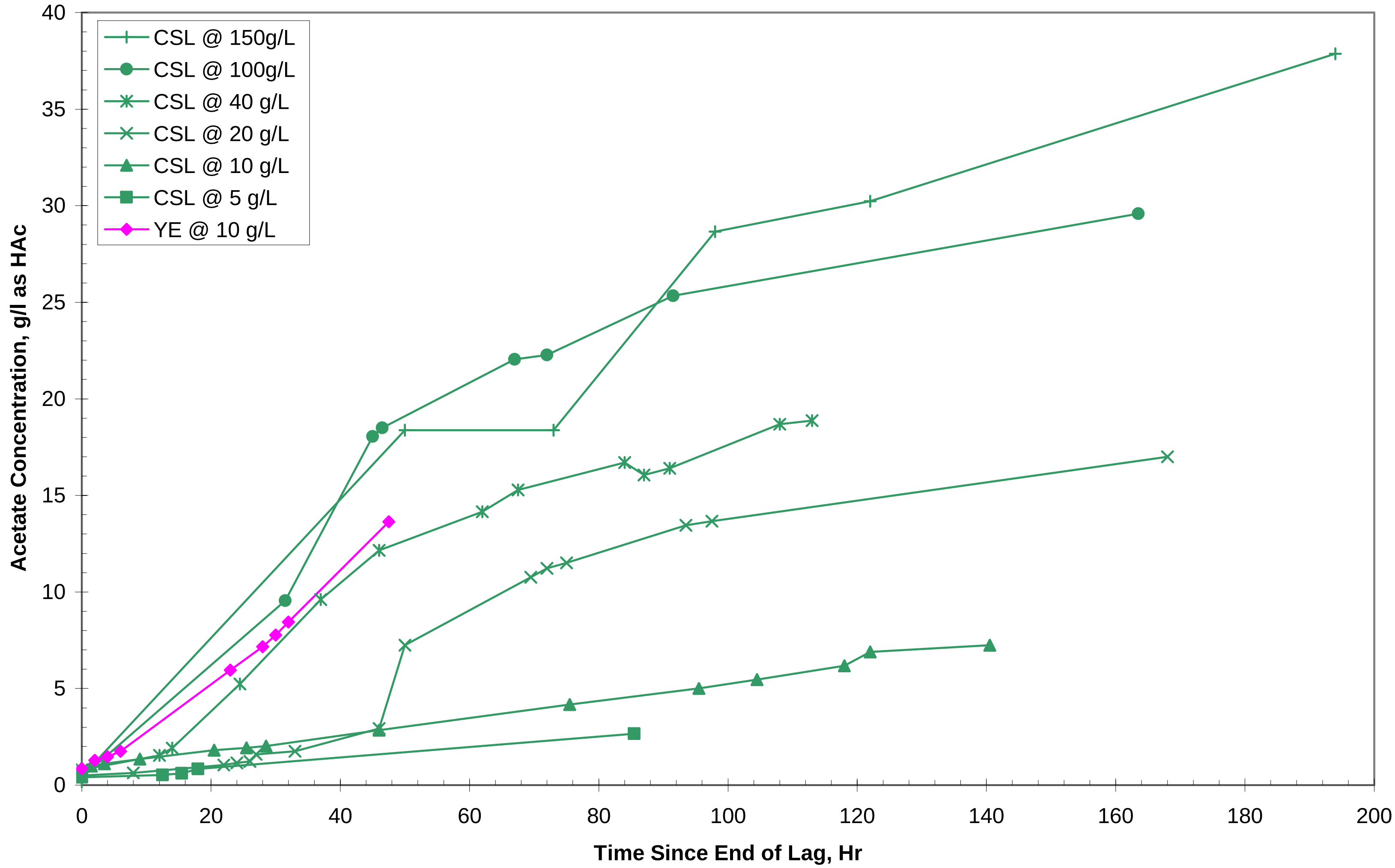


Figure 1.11 - Effect of $CaCO_3$ on Acetate Production in Bottle Cultures

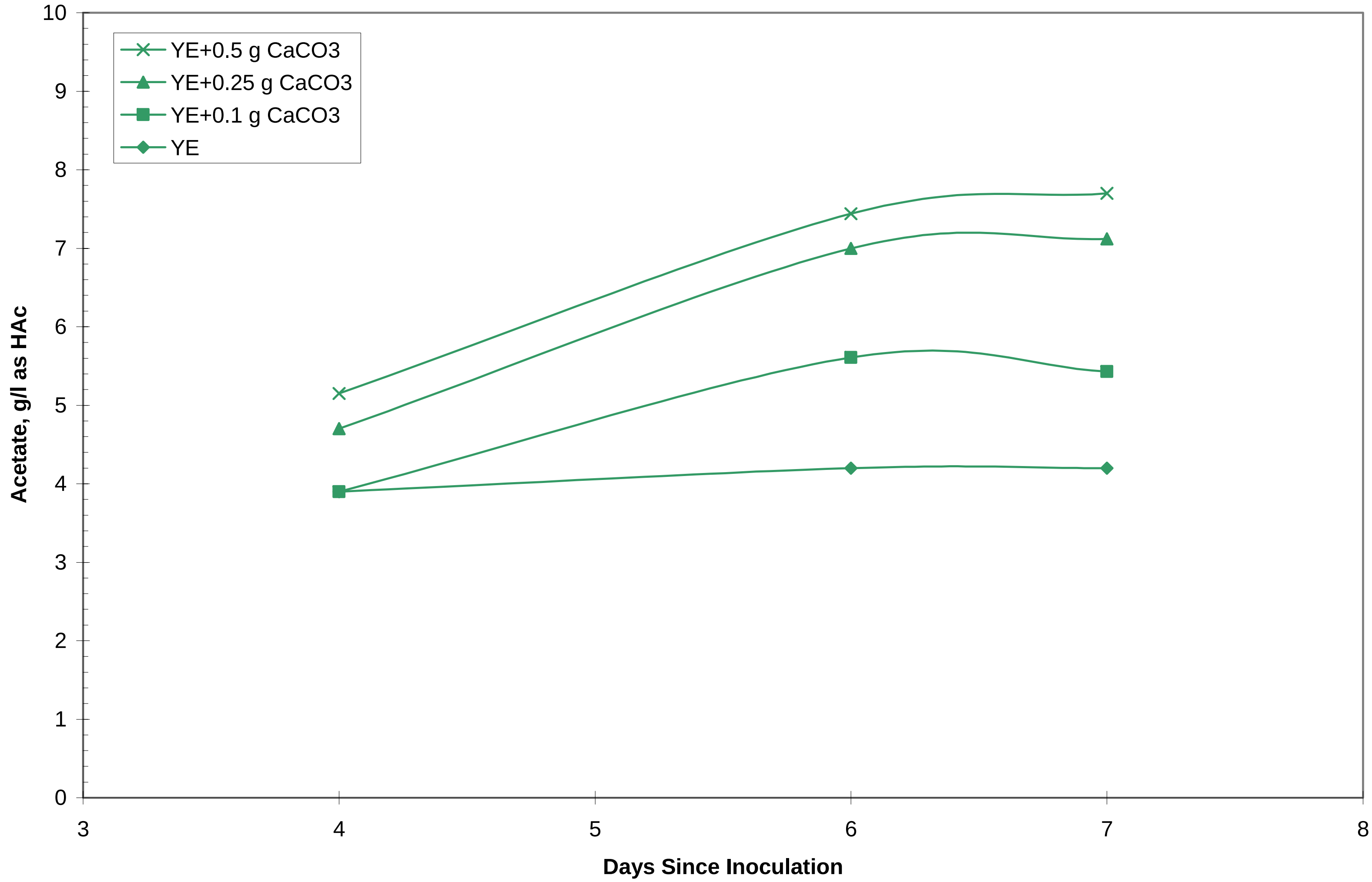


Figure 1.12 - Electrolyte Model for CO_2 + Acetic Acid + $CaCO_3$ System

Equilibrium Relationships:

Use the relation: $\Delta G = -RT \ln K_{eq}$ and the free energy values in Wagman, D.D., et. al., *The NBS Tables of Chemical Thermodynamic Properties*, J Phys Ref Data, Vol. II, Supplement No. 2, 1982. Assume 25 °C, presence of a solid $CaCO_3$ phase, and ignore activity coefficient corrections.

1) $H_2O \Leftrightarrow H^+ + OH^-$

$$\therefore [H^+][OH^-] = 10^{-14}$$

2) $CO_2(g) + H_2O \Leftrightarrow HCO_3^{\ -} + H^+$

$$\therefore \log_{10}[HCO_3^{\ -}] = -\log_{10}[H^+] - 7.8343 + \log_{10}(P_{CO2})$$

3) $CO_2(g) + H_2O \Leftrightarrow CO_3^{\ 2-} + 2H^+$

$$\therefore \log_{10}[CO_3^{\ 2-}] = -2\log_{10}[H^+] - 18.1638 + \log_{10}(P_{CO2})$$

4) $Ca^{2+} + CO_3^{\ 2-} \Leftrightarrow CaCO_3(s)$

$$\therefore -8.3042 = \log_{10}[Ca^{2+}] + \log_{10}[CO_3^{\ 2-}]$$

5) $Ca(OH)^+ + HCO_3^{\ -} \Leftrightarrow CaCO_3(s) + H_2O$

$$\therefore -10.6429 = \log_{10}[Ca(OH)^+] + \log_{10}[HCO_3^{\ -}]$$

6) $HAc \Leftrightarrow H^+ + Ac^-$

$$\therefore \log_{10}(\tfrac{[Ac^-]}{[HAc]}) = -4.7565 - \log_{10}[H^+]$$

7) $Ca^{2+} + Ac^- \Leftrightarrow CaAc^+$

$$\therefore 1.1055 = \log_{10}(\tfrac{[CaAc^+]}{[Ca^{2+}][Ac^-]})$$

Acetate Balance:

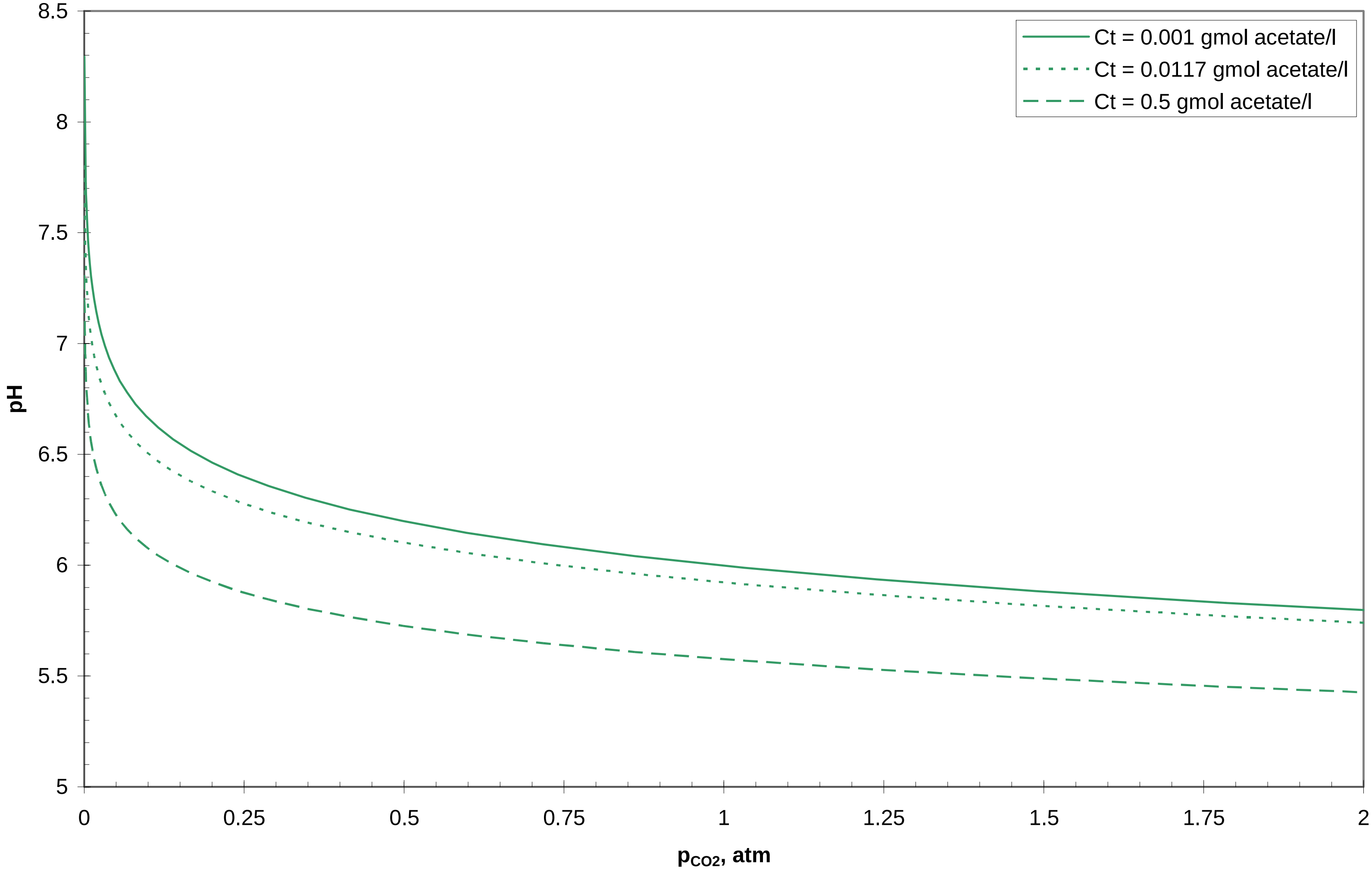
8) $C_t = [HAc] + [Ac^-] + [CaAc^-]$

Charge Balance:

9) $2[Ca^{2+}] + [CaOH^+] + [CaAc^+] + [H^+] = [OH^-] + [HCO_3^{\ -}] + 2[CO_3^{\ 2-}] + [Ac^-]$

Figure 1.13 - Predicted Effect of Headspace CO_2 Partial Pressure on pH

Assumes Presence of Solid $CaCO_3$, Ignores effect of phosphate salts and yeast extract



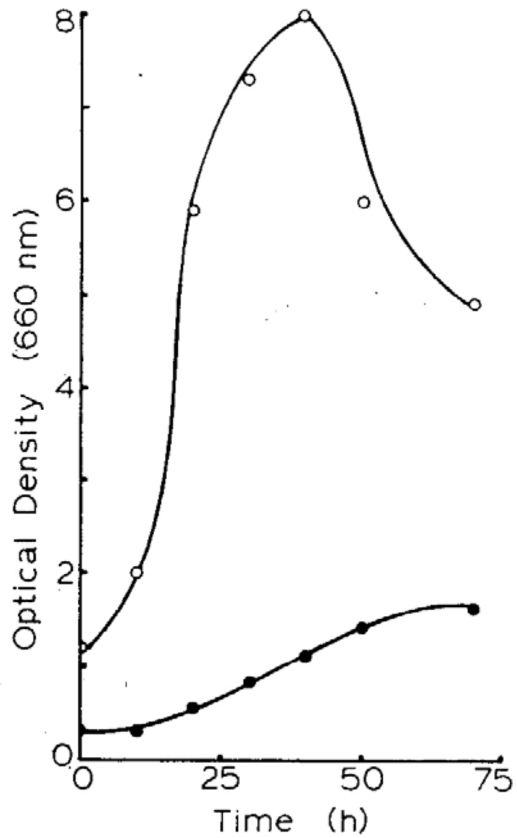


FIG. 2. Growth of UM-maintained cells on UM (○) and MDM-maintained cells on MDM (●).

	Undefined Medium, g/l	Minimally Defined Medium, g/l	Minimally Defined Medium w/ Biotin Supplement g/l	Function
Glucose	18	18	18	Carbon and Energy Source
KH_2PO_4	5.5	5.5	5.5	pH Buffer + Phosphate Source
K_2HPO_4	7	7	7	pH Buffer + Phosphate Source
$NaHCO_3$	16.8	16.8	16.8	pH Buffer + Sodium Source
Phenolphthalein	trace	trace	trace	pH Indicator
Tryptone	5	0	0	Undefined Medium Component
Yeast Extract	5	0	0	Undefined Medium Component
$(NH4)_2SO_4$	0.5	2	2	Nitrogen Source
Sodium Thioglycolate	1	1	1	Reductant
$MgSO_4$	0.3	0.3	0.3	Mineral
$CaCl_2.2H_2O$	0.025	0.025	0.025	Mineral
$Fe(NH_4)_2(SO_4)_2$	0.04	0.04	0.04	Mineral
H_2SeO_4	0.01	0.01	0.01	Mineral
$NaMoO_4.2H_2O$	0.06	0.06	0.06	Mineral
$Na_2WO_4.2H_2O$	0.01	0.01	0.01	Mineral
$CoCl_2.6H_2O$	0.017	0.017	0.017	Mineral
$NiCl_2.6H_2O$	0.005	0.005	0.005	Mineral
H_3BO_3	0.00015	0.00015	0.00015	Mineral
$ZnCl_2$	0.00015	0.00015	0.00015	Mineral
$AlK(SO_4)_2.12H_2O$	0.00015	0.00015	0.00015	Mineral
$CuCl_2.2H_2O$	0.00015	0.00015	0.00015	Mineral
EDTA	0.005	0.005	0.005	Solublizes Metal Salts
Potassium Citrate	0	0.5	0.5	Solublizes Metal Salts
Nicotinic Acid	0	0.002	0.002	Vitamin
Biotin	0	0	0.0005	Vitamin

Summary of Results for Cells Cultured at 55 C with 100% CO_2 Headspace

	Undefined Medium	Minimally Defined Medium	Minimally Defined Medium w/ Biotin Supplement
Initial pH	7.20	7.53	
Final pH	5.84	6.10	
Maximum OD_{660}	8.0	2.2	6.6

Figure 1.14 – Growth Curves for Yeast Extract and Minimally Defined Media for *M. thermoacetica*

Taken from (27,28)

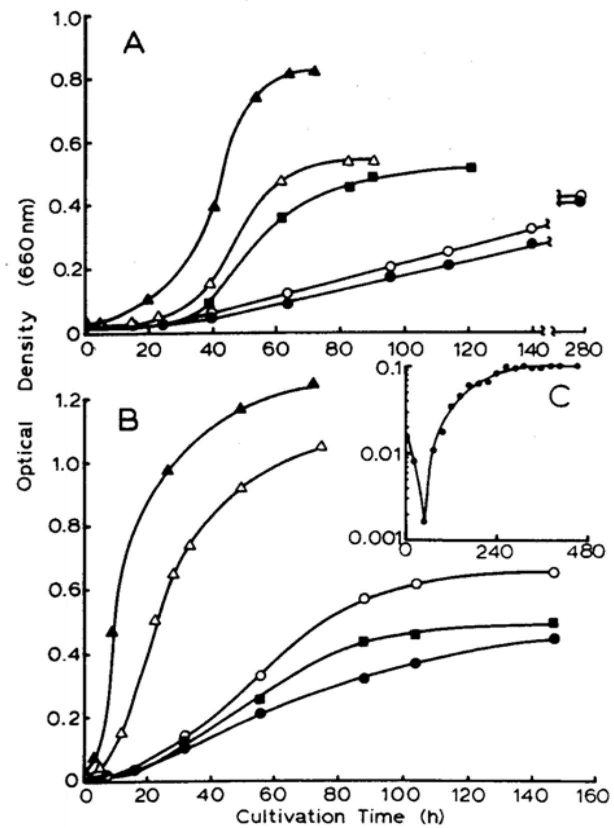


FIG. 1. Growth of *C. thermoautotrophicum* in UM, DM, and MM. Substrates: methanol, A; glucose, B; H_2-CO_2, C. (A and B) Symbols: ▲, UM; △, DM; ■, MM; ●, MM minus cysteine; ○, MM minus cysteine plus biotin (1 mg/liter). Growth profiles are of cultures maintained in each medium for a minimum of 10 sequential transfers, except for the biotin cultures, which were the first transfers from MM minus cysteine. (C) Growth profile of cultures maintained in H_2-CO_2-MM for four sequential transfers; no growth was observed in such cultures in the absence of H_2.

Figure 1.15 – Growth Curves for *M. thermoautotrophicum*

Taken from (28)

Table 1.1 - Selected Literature Results for Acetogenic Fermentations
(Fermentations with *M. thermoacetica* Unless Otherwise Noted)

Configuration	Primary Carbon Source	Primary Nutrient	pH and Base	Initial Fermentables, g/l	Residual Fermentables, g/l	Conversion, %	Final Acetate Concentration, g/l (as HAc)	References	Comments
Batch	Glucose	Yeast Extract+Tryptone	7.0, NaOH	35	~0	100	30	Wang, Fleishchaker, and Wang (5)	Kinetic Study with *M. thermoacetica* , Displayed Both Growth and Non-Growth Associated Acetate Production
	Glucose	Corn Steep Liquor	6.9, NaOH	46	6	87	31	Shah and Cheryan (14)	Fructose Acculumation Observed
	Glucose	Yeast Extract+Tryptone	6.6, NaOH	35	~0	100	29	Parekh and Cheryan (15)	Improved Strain Also Showed Tolerance for Calcium and Magnesium Salts
	Glucose	Yeast Extract+Tryptone	7.1, NaOH	19.6	0	100	13.1	Sugaya, Tuse, and Jones (7)	Poor Material Balance Closure, Possible Problems with Sugar Carmelization
	Glucose	Yeast Extract	6.5, NaOH	50			~37	Witjitra, Shah and Cheryan (16)	
	Glucose	Hydrolyzed Corn Gluten	6.5, NaOH	50	5	~90	22	Witjitra, Shah and Cheryan (16)	
	Glucose	Hydrolyzed Soy Flour	6.5, NaOH	50	2	> 90	30	Witjitra, Shah and Cheryan (16)	
	Glucose	Corn Steep Liquor	6.5, NaOH	45	5	~90	30	Witjitra, Shah and Cheryan (16)	
	Glucose	Ethanol Plant Stillage	6.5, NaOH	47	15	~70	35	Witjitra, Shah and Cheryan (16)	
	Glucose	Condensed Corn Solubles	6.5, NaOH				17	Bock, Fox, and Gibbons (17)	Poor Material Balance Closure
	Xylose	Yeast Extract	6.8, NaOH	15	0	100	15.2	Balasubramanian, Kim and Lee (18)	
	Lactate	Yeast Extract+Trypticase	7.0, NaOH	10.1	0	100	10.1	Yang, Tan, and Okos (8)	Kinetic Study with *C. formicoaceticum*
Fed Batch	Glucose	Yeast Extract+Tryptone	6.9, NaOH	18	< 5	~90	56	Wang and Wang (6)	Glucose Fed to Keep Glucose @ 5-15 g/l
	Glucose	Yeast Extract+Tryptone	6.3, Dolime				55	Parekh and Cheryan (19)	Mutant Derived With Classical Chemical Mutagens
	Glucose	Yeast Extract+Tryptone	6.2, NaOH				53	Parekh and Cheryan (19)	Mutant Derived With Classical Chemical Mutagens
	Glucose	Yeast Extract+Tryptone	6.6, NaOH	20	~0	93	42	Parekh and Cheryan (20)	
	Glucose	Condensed Corn Solubles	6.5, NaOH				32	Bock, Fox, and Gibbons (17)	Poor Material Balance Closure
	Xylose	Yeast Extract	7.0, NaOH				42	Brownell and Nakas (21)	Feedstock Derived from Acid Pretreated and Processed Oat Spelt and Hybrid Poplar
	Xylose	Corn Steep Liquor	6.8, NaOH	20	5		15	Balasubramanian, Kim and Lee (18)	Xylulose Accumulation Observed
	Glucose	Corn Steep Liquor	6.9, NaOH	20	~5	~97	38	Shah and Cheryan (14)	Material Balances Did Not Account for Lactate Conversion from Corn Steep Liquor Nutrient Source
	Glucose	Yeast Extract	6.0, NaOH				30	Borden, Lee and Yoon (22)	SSF of α-Cellulose
	Glucose	Yeast Extract	5.5, NaOH				10	Borden, Lee and Yoon (22)	SSF of Paper Mill Sludge, Comparison with a-Cellulose Run Suggests Paper Sludge Has Inhibitory Impurities
Continuous	Glucose	Yeast Extract+Tryptone	7.1, NaOH	19.6	~2	~90	~12	Sugaya, Tuse, and Jones (7)	65 Day Run w/o Contamination
Fed Batch w/ Cell Recycle	Glucose	Yeast Extract+Tryptone	6.8, Dolime				102	Parekh and Cheryan (23)	
	Glucose	Yeast Extract+Tryptone	6.8, NaOH				83	Parekh and Cheryan (23)	
	Glucose	Yeast Extract+Tryptone	6.1, NaOH	45	< 5	~90	38	Shah and Cheryan (24)	
Continuous w/ Cell Recycle	Glucose	Yeast Extract+Tryptone	6.8, NaOH	58	~0	~100	44	Parekh and Cheryan (25)	Demonstrated 54 Days of Continuous Operation
	Glucose	Yeast Extract+Tryptone	6.1, NaOH	45	5	~90	37.5	Shah and Cheryan (24)	Two Stage CSTR with Membrane for Cell Recycle
Immobilized Cells	Glucose	Yeast Extract	6.95, NaOH	40			19	Wang and Wang (26)	Also Proved Non-Growth Associated Acetate Production with Chloramphenicol Experiment
	Glucose	Yeast Extract	5.0, Buffered				6	Wiegel et. al. (3)	Rotary Fermentor

Table 1.2 - Trace Mineral Solution

Component	g/liter
EDTA	0.500
$MgSO_4 \cdot 7H_2O$	3.000
$MnSO_4 \cdot H_2O$	0.500
NaCl	1.000
$FeSO_4 \cdot 7H_2O$	0.100
$Co(NO_3)_2 \cdot 6H_2O$	0.100
$CaCl_2$ (anhydrous)	0.100
$ZnSO_4 \cdot 7H_2O$	0.100
$CuSO_4 \cdot 5H_2O$	0.010
$AlK(SO_4)_2$ (anhydrous)	0.010
H_3BO_3	0.010
$Na_2MoO_4 \cdot 2H_2O$	0.010
Na_2SeO_3 (anhydrous)	0.001
$Na_2WO_4 \cdot 2H_2O$	0.010
$NiCl_2 \cdot 6H_2O$	0.020

Table 1.3 - Description of Fermentation Runs

All fermentations were carried out at an initial [glucose] of 50g/L.

Fermentation Run	Initial [Nitrogen]	Run Time	Final [Acetate]	Comments
1	5g/L Y.E.	168h	28g/L	Maximum rate = 0.25g/L-h
2	5g/L CSL (Sigma)	96h	2.5g/L	This run never took off. Low nitrogen availability/concentration (?)
3	10g/L CSL (Sigma)	168h	7.5g/L	
4	20g/L CSL (Sigma)	168h	17g/L	At 102h, rate shifted from ~0.25g/L to ~0.045g/L-h
5	40g/L CSL (Sigma)	70h	10g/L	The run was terminated due to mechanical malfunction.
6	40g/L CSL (Sigma)	119h	19g/L	Added 60g CSL in a volume of 150 ml @ 84h. Also added 2g phosphate. The rate of Acetate production increased following addition of the CSL, however, the Hlac peak increased also. Shutdown run-contaminated w/ lab (?).
7	80g/L CSL (Sigma)	168h	21.5g/L	At 124h, added 10g/YE in water. The rate of acetate production increased from the prior 12h (0) to ~0.1g/L-h.
8	80g/L CSL (Sigma)			Run terminated after 36h due to mechanical malfunction;pH controller/pump problem.
9	40g/L CSL (CP)	118h	12.7g/L	
10	10g/L Y.E.	92h	19g/L	
11	10g/L Y.E.	44h	9g/L	The run was terminated because the bugs appeared to stop producing acetate-no pH control.
12	11g/L YE	91h	23g/L	Contaminated. Determined that neck of fermentor was cracked. Sent back for repair.
13	10g/L Y.E.			Contaminated run.
14	10g/L Y.E.			600 ml run in small fermentor, utilizing CaCO3. Poor pH control. pH went to 7.8 after 24h. Run terminated
15	10g/L Y.E.			600 ml run in small fermentor. Poor pH control. pH went to 7.8 after 24h. Run terminated
16	10g/L Y.E.	93h	22g/L	This was the first run following repair of the fermentor. At 46h, 97% conversion efficiency.
17	10g/L Y.E.	44h	10g/L	Terminated after 44h after fermenter prove to be running o.k. At 44h, acetate production ~= to 44h on 40g/L CSL.
18	100g/L CSL	168h	30g/L	Best run recorded. Between T30 and T70 the rate of acetate production was ~ 0.5g/L-h. At one point, acetate production was ~0.7g/L-h.
19	150g/L CSL	240	38g/L	The lag period was ~72h. If you back out the 72 hour lag, it puts the run at 168h.
20	150g/L CSL	97	13g/L	The lag period was ~72h. Ran out of CO2.

Task 2 – Esterification Step

Background

A wide range of organic acids can potentially be produced by fermentation using known micro-organisms, yet today nearly all organic acids are produced by synthetic means. Some reasons why fermentation based routes have not been competitive with synthetic routes are related to the technical difficulties associated with recovery of organic acids from fermentation broths. Three common technical issues:

i) High purity specifications for the final product.

ii) Energy efficient means of handling the dilute broths.

iii) Avoidance of the co-production of stoichiometric amounts of salts and other wastes.

have to be addressed to enable commodity scale production of organic acids via fermentation.

Micro-organisms capable of producing organic acids are often product inhibited and inhibited by low pH. In order to achieve high yields, the pH of the fermentation step has to be kept near neutral by the addition of a base such as ammonia, sodium hydroxide/carbonate or calcium hydroxide/carbonate. Thus fermentation routes typically produce a dilute aqueous solution of the organic acid salt rather than the organic acid in its protonated form. The salts are highly water soluble, have a negligible vapor pressure and carbonyl group is unreactive. These properties make recovery of the salt difficult since distillation, extraction, crystallization and other common industrial separation methods for large scale production are either technically or economically infeasible.

One way to ease the recovery of organic acid salts is to add a mineral acid to lower the pH of the broth, thereby converting the organic acid into its protonated form. In its protonated form the organic acid can be more easily recovered by known means such as distillation, extraction or reactive separation processes. Direct acidification with a mineral acid is usually regarded as a troublesome option for recovery of organic acid salts because a salt byproduct is inevitably formed. This byproduct is often of very low value. For example, calcium sulfate in the form of gypsum is historically the salt co-produced during lactic acid recovery (1).

$$\textit{Calcium Lactate} + \textit{Sulfuric Acid} \rightarrow \textit{Lactic Acid} + \textit{Calcium Sulfate}$$

Gypsum markets either have to be found or an environmentally responsible disposal method has to be identified. Because of these limitations, much research has gone into alternative methods to recover lactic acid including: 1) careful selection of cations and anions to give a more desirable salt co-product such as ammonium sulfate (2), 2) recovery schemes that include the use of weakly acidic ion exchange resins to reduce the amount of salt co-product (3,4), 3) recovery schemes based on the thermal decomposition of the ammonium organic acid salt (5,6) 4) the use of bipolar electrodialysis (7), and 5) use of carbon dioxide as an acidulant along with the formation of an amine complex in a reactive extraction process (8).

Recovery of fermentation derived acetate has been summarized by Busche and co-workers at Du Pont (9, 10), Partin and Heise (11) and Eggeman and Verser (12). Here we focus on the work of Urbas at CPC International (13, 14). Urbas used carbon dioxide for acidification and amine complexes for the recovery of acetic acid. Tributylamine (TBA) is normally immiscible with water, but the tributyl amine:acetic acid complex (TBA:HAc) is water soluble. When a dilute aqueous solution of calcium acetate at near neutral pH is mixed with tributyl amine, and then carbon dioxide is bubbled through the mixture, the following reaction occurs at near ambient temperatures:

$$Ca(Ac)_2 + H_2O + CO_2 + 2TBA \rightarrow 2TBA : HAc + CaCO_3$$

Use of a stoichiometric amount of tributyl amine produces a single liquid phase containing the tributyl amine:acetic acid complex. The reaction is driven to the right since calcium carbonate precipitates upon formation.

In one embodiment of the Urbas patents, the aqueous amine complex is extracted into an organic solvent, the solvent is stripped off, and the complex is thermally split apart giving the acetic acid product and regenerating both the solvent and amine for recycle. Urbas preferred the use of low boiling, non-reactive solvents that do not azeotrope with acetic acid, with preference for chloroform because of a favorable distribution coefficient for the extraction step. We have found the thermal regeneration reaction is difficult in practice, leading to a viscous intractable residue and low yield of acetic acid. Furthermore, use of chlorinated solvents such as chloroform, would be problematic at industrial scale.

The work of this grant covers a new scheme for recovery of the amine complex from the aqueous solution. The amine complex is extracted with an alcoholic solvent followed by esterification and distillation of the organic extract. During esterification, the reaction:

$$TBA : HAc + ROH \rightarrow TBA + RAc + H_2O$$

produces the ester directly from the amine complex. The reaction is pulled to the right by continuous removal of water. After completion of the esterification step, the ester is isolated by distillation and the excess alcohol and amine are recycled. The acetate ester can either be sold as a final product or undergo further chemical transformations such as hydrogenolysis to produce ethanol.

Methods and Materials

Materials – Laboratory de-ionized water was used for creating all aqueous feed stocks. Instrument grade CO_2 was used for acidification. All other materials were ACS reagent or standard commercial grades.

Analytical Methods – Concentrations of the amine complex in both aqueous and organic solutions were determined by potentiometric titration of 10-20 ml samples diluted with 30 ml of methanol and titrated with standardized KOH in methanol following the method of Ricker, et. al.

(15). For the solvent screening experiments, the water content of the organic phase was determined by addition of excess toluene to a weighed sample of the organic phase. The resultant water phase was recovered, weighed, and water content of the original sample calculated by mass balance.

For the more detailed phase diagram experiments, careful measurements were made of the phase volumes and phase densities and these values were used in the calculations for data analysis. The density of each phase was determined by weighing a known volume of each phase determined using a volumetric pipette. Concentration of the complex in the organic phase was again determined by titration. The water content of the solvents and organic extracts were measured by Karl Fischer analysis at an outside lab. Residual alcohol in the water phase was estimated using the solubility of the pure alcohol in pure water as the basis. Binary liquid-liquid equilibrium data for alcohols and water are given in (16).

Acidification Experiments – 500 ml of an aqueous calcium acetate solution (50 g/l as acetate) were added to a 1 liter graduated cylinder and the pH was adjusted to 6.9-7.0 using acetic acid. A 5% molar excess of TBA was added, then the solution was sparged with CO_2 for 30 minutes at ambient pressure. The solution was filtered, the $CaCO_3$ cake was washed once with water, washed again with acetone, dried and then weighed.

Extraction Experiments – All extraction experiments were conducted at room temperature (25 °C). For solvent screening with TBA as the amine, 100 g of an aqueous mixture containing 4.08 g of acetic acid (HAc) and 12.56 g of TBA were mixed in a separatory funnel with 100 g of organic solvent. The mixture was shaken by hand and then allowed to separate. Each phase was recovered and weighed. Samples were taken and analyzed for TBA:HAc and water. A similar procedure was used for the tie-line experiments with n-pentanol or n-hexanol as the extractant except the starting concentration of TBA:HAc was varied to generate several tie-lines.

The solvent screening experiments with N,N-diisopropylethylamine started with an aqueous solution made from 200 g of water, 9.95 g of acetic acid, and 20.85 g of the amine. An equal weight of the aqueous mixture and organic solvent were added to a separatory funnel, the solutions were gently shaken, settled, separated and analyzed.

Esterification Experiments – The esterification reactions were conducted at atmospheric pressure (~630 mm Hg at our lab in Colorado) in a glass still consisting of a electric heating mantle, a 1 liter round bottom flask, a vacuum jacketed 30 cm distillation column packed with 4mm x 4mm glass rings, and an overhead condenser and product splitter allowing the removal of a variable amount of distillate and return of reflux to the column. Figure 2.1 is a photo of the laboratory apparatus.

450 g of a room temperature solution containing a 3:1 molar ratio of alcohol to TBA:HAc complex were added to the still. The catalyzed run with n-hexanol included H_2SO_4 in the starting solution at a 0.1:1 mole ratio with respect to the TBA:HAc complex. The heating mantle was turned on and approximately thirty minutes later the solution began to boil. Water formed a second phase in the overheads as the reaction progressed. The water was collected and the volume recorded over time. Conversion was estimated as the percent of the maximum

theoretical water if all of the acetic acid were converted to ester and confirmed by titration of residual TBA:HAc in the still pot samples.

Results

Acidification Experiments

Two distinct liquid phases were formed when tributyl amine was mixed with the aqueous calcium acetate solution. As soon as the flow of CO_2 was started, the mixture became cloudy and as the reaction continued solid $CaCO_3$ was seen in the mixture. The mixture also gradually changed to a single liquid phase with $CaCO_3$ particles suspended by the gas flow. The acidification experiments were conducted four times with $CaCO_3$ yields ranging from 91.0-96.1% of theoretical. The resulting $CaCO_3$ precipitates were easy to filter and wash. A fine white powder was generated in all cases.

Several variations of the experiment were also conducted:

1) The CO_2 blown through the solution was replaced with a ~10:1 mixture of N_2 and CO_2. Although this change resulted in a slightly slower reaction, the experiment still produced copious quantities of the $CaCO_3$ precipitate. This result suggests the rate of reaction is related to the partial pressure of carbon dioxide.

2) The tributyl amine was replaced with a stoichiometric amount of N,N-Diisopropylethylamine (DIEA, also known as Hunig's base). The reaction appeared to proceed faster when compared to the reaction with tributyl amine. Copious quantities of the $CaCO_3$ precipitate were formed.

3) The tributyl amine was replaced with a stoichiometric amount of trioctyl amine. No reaction occurred; No $CaCO_3$ precipitate was formed. The results of this experiment agree with the prior work of Urbas (13, 14).

Extraction Experiments

Primary separation was achieved quickly (< 30 seconds) for all solvents included in the solvent extraction screening experiments. Secondary separation was also very quick for all solvents, only taking a few minutes to obtain clear solutions in both phases. Table 2.1 reports the distribution coefficients and selectivities. The distribution coefficient, K_D – defined as the ratio of the mass fraction of TBA:HAc in the organic phase divided by the mass fraction of TBA:HAc in the aqueous phase, is a measure of the concentrating power of the solvent. Selectivity, defined as the distribution coefficient times the ratio of the mass fraction of water in the aqueous phase divided by the mass fraction of water in the organic phase, is a measure of the solvent's ability to preferentially separate the TBA:HAc complex from water. Higher selectivity implies that less water is dragged along into the organic extract, which in turn means that less energy is needed to remove free water in the downstream esterification step.

Solvents were chosen to represent various classes. Esters, aromatics and ketones were all found to have a low distribution coefficient in the solvent screening experiments. Our results with chloroform essentially agree with the prior work of Urbas, but as mentioned earlier, the use of chlorinated solvents at the industrial scales required for fuel ethanol production would be problematic. The best solvent class appears to be the higher molecular weight alcohols. Within the alcohols, there is a trade-off between distribution coefficient and selectivity. Low molecular weight alcohols have more a favorable distribution coefficient, but the mutual solubility of water with the low molecular weight alcohol lowers selectivity. Both n-pentanol and n-hexanol have favorable distribution coefficients and high selectivity.

Figure 2.2 presents the experimentally measured liquid-liquid equilibria for the water + TBA:HAc + n-pentanol system at 25 °C. Also shown are the predictions from HYSYS's Generalized NRTL activity coefficient model where the interaction parameters were obtained by regression of the experimental data. The agreement between the experimental values and the generalized NRTL model is quite good. The shape of the two phase region was experimentally checked by titration of several TBA:HAc + n-pentanol mixtures with water, and by titration of several TBA:HAc + water mixtures with n-pentanol (data not shown). The results of these titrations qualitatively confirmed the HYSYS predictions. We do not include these data with Figure 2.2 since our titrations tended to overshoot the two phase cloud point; their inclusion reduces the clarity of Figure 2.2.

Figure 2.3 presents the experimentally measured liquid-liquid equilibria for the water + TBA:HAc + n-hexanol system at 25 °C. The distribution coefficients are lower for n-hexanol when compared to n-pentanol, but the n-hexanol system does have a slight advantage in selectivity as illustrated by the lower water contents of the organic phases.

In both Figures 2.2 and 2.3, the two phase region is fairly broad and the tie-lines have a favorable slope. Distribution coefficients become more favorable at higher TBA:HAc concentrations, which leads to a concave-up equilibrium line when the data are plotted as mass fraction TBA:HAc in the organic layer (y axis) vs. mass fraction TBA:HAc in the aqueous layer (x axis). Nonetheless, as shown later in Task 3, a good process design will avoid the potential pinch between the equilibrium curve and the operation line and requires only a few stages to produce a concentrated TBA:HAc extract from a dilute aqueous solution.

The results of the initial solvent screening experiments and the phase diagram data in Figures 2.2 and 2.3 differ, with the phase diagram experiments giving lower distribution coefficients than observed in the initial solving screening experiments. Data analysis for the phase diagram experiments included corrections for the phase volume change and phase densities, thus the phase diagram results are of higher accuracy than the initial solvent screening experiments.

The observed distribution coefficients for the solvent screening experiments with N,N-diisopropyethylamine were 0.092 with n-pentanol and 0.0487 with n-hexanol as the solvent. This amine is slightly more water soluble than TBA, so the fall-off in distribution coefficient was not surprising. No further work was pursued with this amine.

Esterification Experiments

The extracts produced by mixing the alcohols with the acid amine complex in water contain a small amount of water depending on the alcohol used. This free water is removed by azeotropic distillation using the alcohol itself as the drying solvent for the extract producing a dry solution of the amine complex in the alcohol solvent. Alcohols in the range of interest form heterogeneous azeotropes with water allowing easy separation of the water from the distillate. After the extract is dried, the reaction is continued, and there is a continuous slow production of water overhead in the still from the esterification reaction. The overhead splitter is configured so that the water is removed continuously as it is produced and the solvent is returned to the still as reflux.

Figure 2.4 plots the water generated during esterification and reports the observed range of pot temperatures during the time the solutions were boiling. The pot temperature rose over time, further evidence of reaction. The curves in Figure 2.4 are useful for comparing rates, but can only be qualitatively used to compare yield since different molar amounts of TBA:HAc were present in the starting solutions, differing amounts of materials were taken for samples over the course of the experiment, and the starting solvents had different levels of initial free water. The conversion values in Table 2.2, estimated from the water production and confirmed by titration, are more useful for comparing yields.

Both esterification rate and yield increased with increasing molecular weight of the alcohol. Rather than being related to the chain length of the alcohol, this improvement in performance was probably caused by the higher boiling point and thus higher reaction temperature for the higher molecular weight alcohols. Adequate esterification rate and yield could probably be achieved with the lower molecular weight alcohols if the reaction was conducted at elevated pressure. The pressures required are not extreme. For example, n-butanol will boil at 170 °C and 482.6 kPa, well within the range of industrial importance.

Esterification rate and yield can also be improved by using a catalyst. Comparison of the non-catalyzed n-hexanol run with the catalyzed run shows that sulfuric acid is potentially a good catalyst, although the ultimate fate of any homogeneous catalyst has to be worked out for any potential industrial process. Solid catalysts, both Brønsted and Lewis acids, may be easier to work with since catalyst recovery is not an issue.

Discussion

We selected n-pentanol as the extraction and esterifying alcohol for the work of Task 3. The extraction performance of n-pentanol it is a good compromise between distribution coefficient and selectivity. The esterification rate should be reasonable provided the reaction is operated at slight pressure.

Figure 2.5 is a simplified process sketch of the proposed recovery process. A clarified broth containing calcium acetate is fed to the acidification step where the aqueous TBA:HAc complex is formed. Next the precipitated calcium carbonate is removed by filtration and recycled for use as the neutralizing base in fermentation. The TBA:HAc complex is then extracted from the filtrate using n-pentanol as the solvent. The extract is esterified. It is further fractionated to give a stream rich in n-pentyl acetate/n-pentanol and a recycle stream of TBA. During our modeling efforts in Task 3 we found that the fractionation of n-pentyl acetate and n-pentanol is difficult. It is more efficient to send the entire mixture downstream to hydrogenolysis. The hydrogenolysis step regenerates the n-pentanol used in the extraction step and also produces the desired ethanol product. While the surrounding fermentation, hydrogenolysis and water treatment steps required for a fully integrated system are not shown in Figure 2.5, these steps are included in the model discussed later in Task 3.

The proposed process addresses all three technical issues for organic acid recovery outlined in the Background section for this task. The combination of extraction and fractionation generates a high purity product since the desired compound, in this case the n-pentyl acetate intermediate, is selectively transferred from one phase to another in each of the unit operations leaving behind undesired impurities. Extraction is an energy efficient means for removing the TBA:HAc complex from a dilute broth without having to boil large amounts of water. Finally, no net salt co-product is generated since the calcium carbonate produce in the recovery step is used as the neutralizing base for fermentation. A well integrated fermentation and recovery scheme results from our systems level approach.

Sub-Task Review

The description of the sub-tasks, taken from Appendix B Statement of Work in the original proposal, is repeated below:

<u>Task 2.1 Analytical Method Validation</u> – Published analytical HPLC methods for measuring ethanol, acetic acid and ethyl acetate will be implemented and validated on our equipment. The outcome of this task will be the ability to accurately measure the levels of these species in samples produced by our later experimental runs.

<u>Task 2.2 Construction</u> – A fully instrumented 1 liter batch pressure reactor suitable for conducting the acidification and esterification reactions will be assembled. A laboratory scale microfiltration unit will also be assembled and shakedown runs for clarifying fermentation broth will be conducted. The ability to generate reproducible runs with good mass balance closure will be demonstrated prior to further experimental work. The outcome of this task will be the assembly and shakedown of equipment needed for Tasks 2.3 and 2.4.

<u>Task 2.3 Testing - Acidification</u> – A series of batch acidification runs will be conducted to study the effects of key process variables on the yield of acidified acetic acid from clarified fermentation broth. Partial pressure of CO_2, acetate to amine mole ratio and amine selection will be among the variables studied. The need for any additional pretreatment of the broth, such as nanofiltration, will be established. Regeneration of the amine per the method outlined in (13, 14) will also be verified. Runs that do not exhibit good mass balance closure will be discarded and the conditions repeated with another run. The outcome of this task will be a set of high quality experimental data that can be used for model development.

Task 2.4 Testing - Esterification – In parallel with the acidification experiments, a series of batch esterification runs on acidified fermentation broth will be conducted to collect the data required for a kinetic model of the esterification step. Concentration and temperature will be among the key variables studied. Runs that do not exhibit good mass balance closure will be discarded and the conditions repeated with another run. The outcome of this task will be a set of high quality experimental data that can be used for model development.

Task 2.5 Data Analysis – The data from Tasks 2.3 and 2.4 will be processed into forms that can be used for further modeling efforts in Task 3.1.

The following discussion compares the work actually accomplished against the original proposal subtasks:

Task 2.1 Analytical Method Validation – We found that HPLC would be a poor choice of analytical methods for our work since amines, such as tributyl amine and the TBA:HAc complex, are poisons for many HPLC columns. We tried some quantitative analyses based gas chromatographic separations, with marginal success. We eventually found that all of our analytical needs could be satisfied by titration of the amine complex according to the method of Ricker (15), supplemented with water determinations either using toluene as an anti-solvent or by Karl Fischer titrations performed at an outside lab.

Task 2.2 Construction – We found that good yields for the acidification step could be obtained at atmospheric pressure, obviating the need for a pressure vessel for the acidification experiments. The effect of pressure on the esterification experiments can be inferred from Figure 2.4. Thus, all of the information of interest was obtained using standard laboratory glassware.

Task 2.3 Testing - Acidification – Complete. Regeneration of the amine per the method of Urbas (13, 14) was not performed since we could not reproduce the prior thermal splitting step, as discussed in the Background section.

Task 2.4 Testing - Esterification – Complete.

Task 2.5 Data Analysis – Complete.

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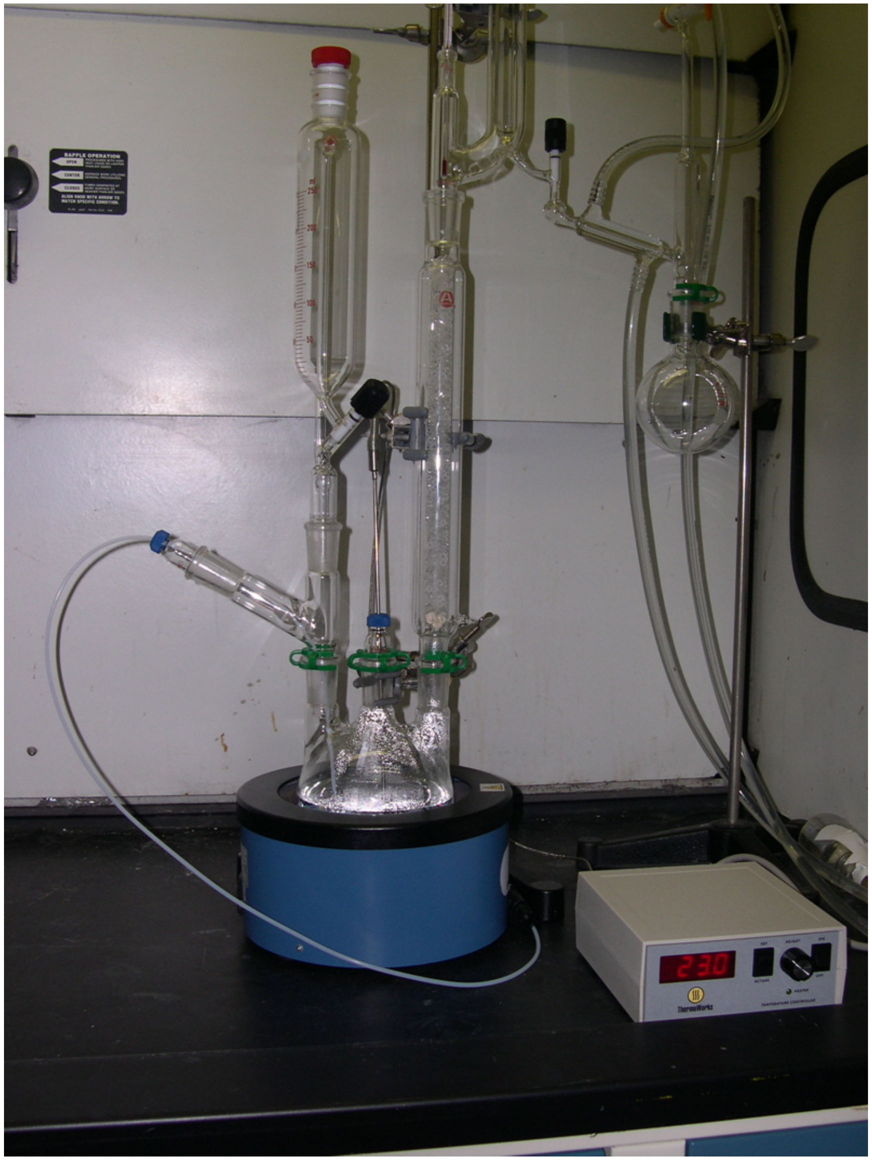
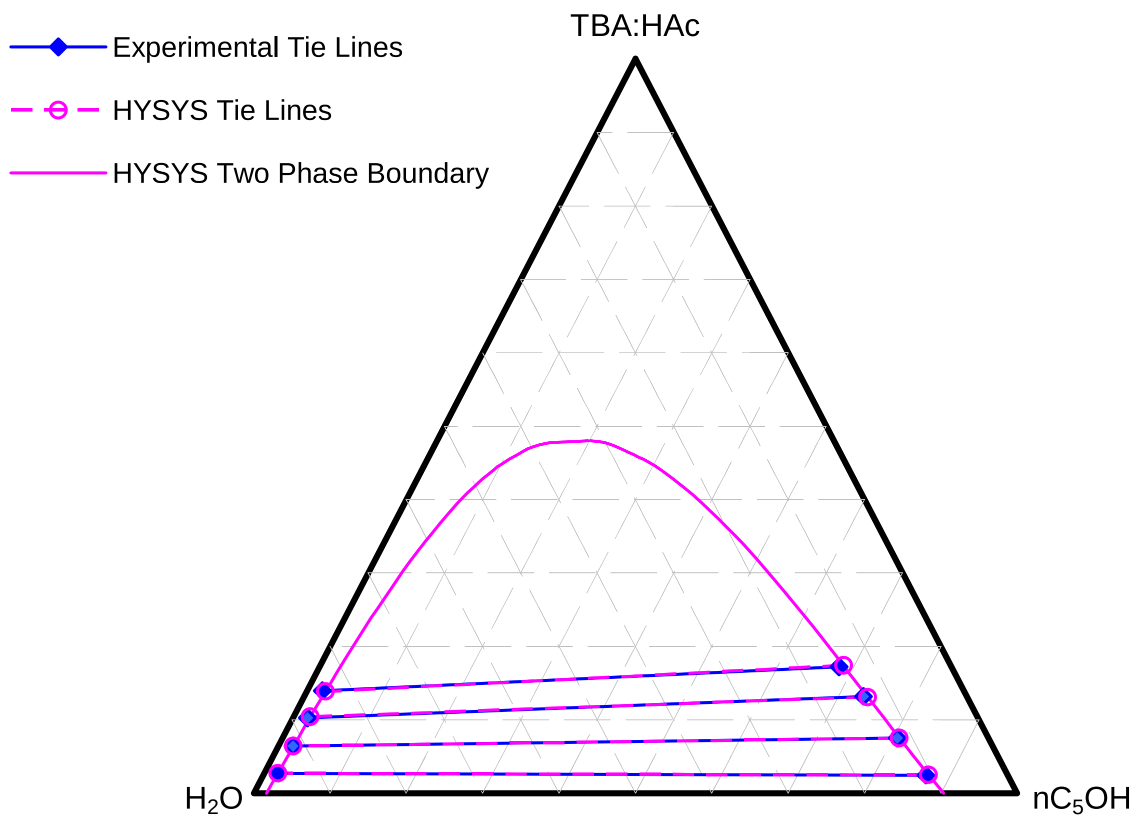


Figure 2.1 - Laboratory Apparatus for Esterification Experiments

Organic Layer Mass Fractions						Aqueous Layer Mass Fractions					
Experimental			HYSYS Gen NRTL			Experimental			HYSYS Gen NRTL		
H2O	nC5OH	TBA:HAc	H2O	nC5OH	TBA:HAc	H2O	nC5OH	TBA:HAc	H2O	nC5OH	TBA:HAc
0.1074	0.8678	0.0248	0.1038	0.8710	0.0252	0.9540	0.0185	0.0275	0.9550	0.0178	0.0272
0.1197	0.8051	0.0752	0.1168	0.8079	0.0753	0.9166	0.0190	0.0645	0.9157	0.0199	0.0644
0.1353	0.7325	0.1322	0.1302	0.7387	0.1311	0.8779	0.0195	0.1027	0.8736	0.0223	0.1040
0.1471	0.6806	0.1723	0.1405	0.6854	0.1741	0.8399	0.0200	0.1401	0.8364	0.0248	0.1388



(25 °C, Mass Fraction Basis)

Figure 2.2 – Phase Diagram for the Water + TBA:HAc + n-Pentanol System

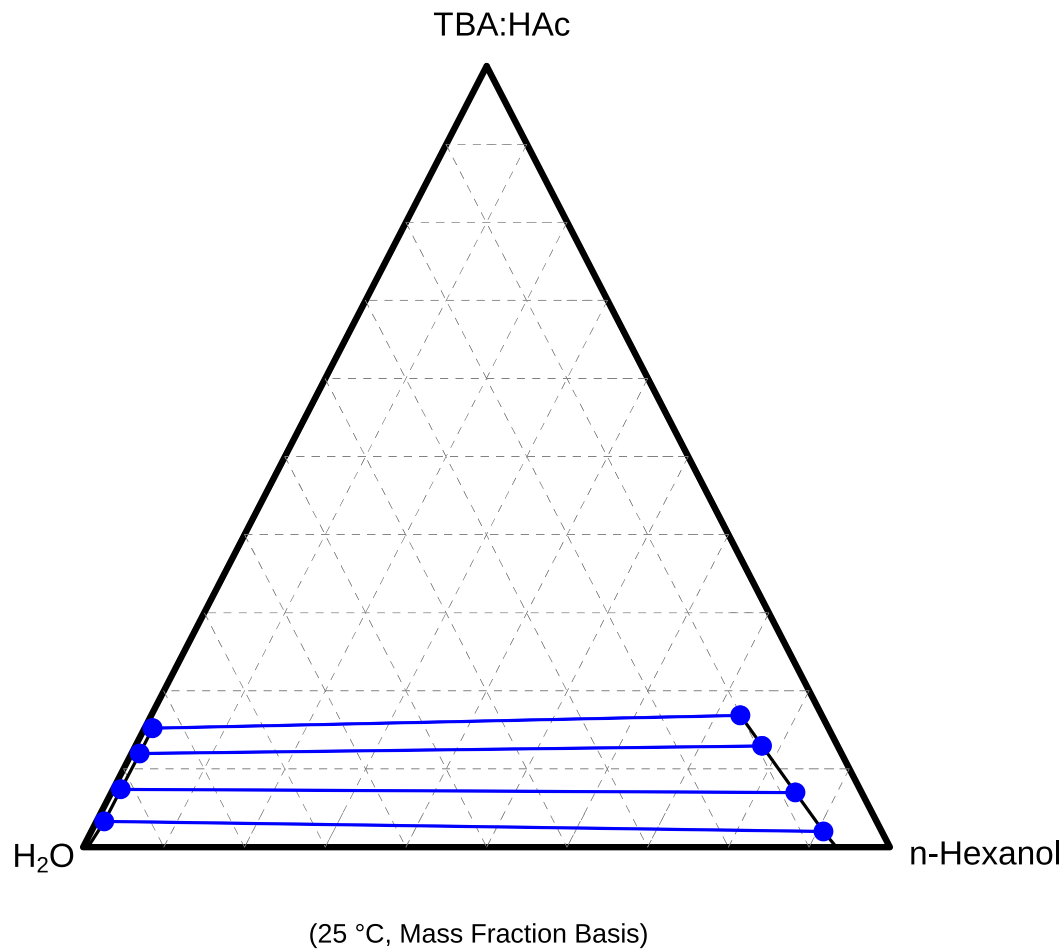
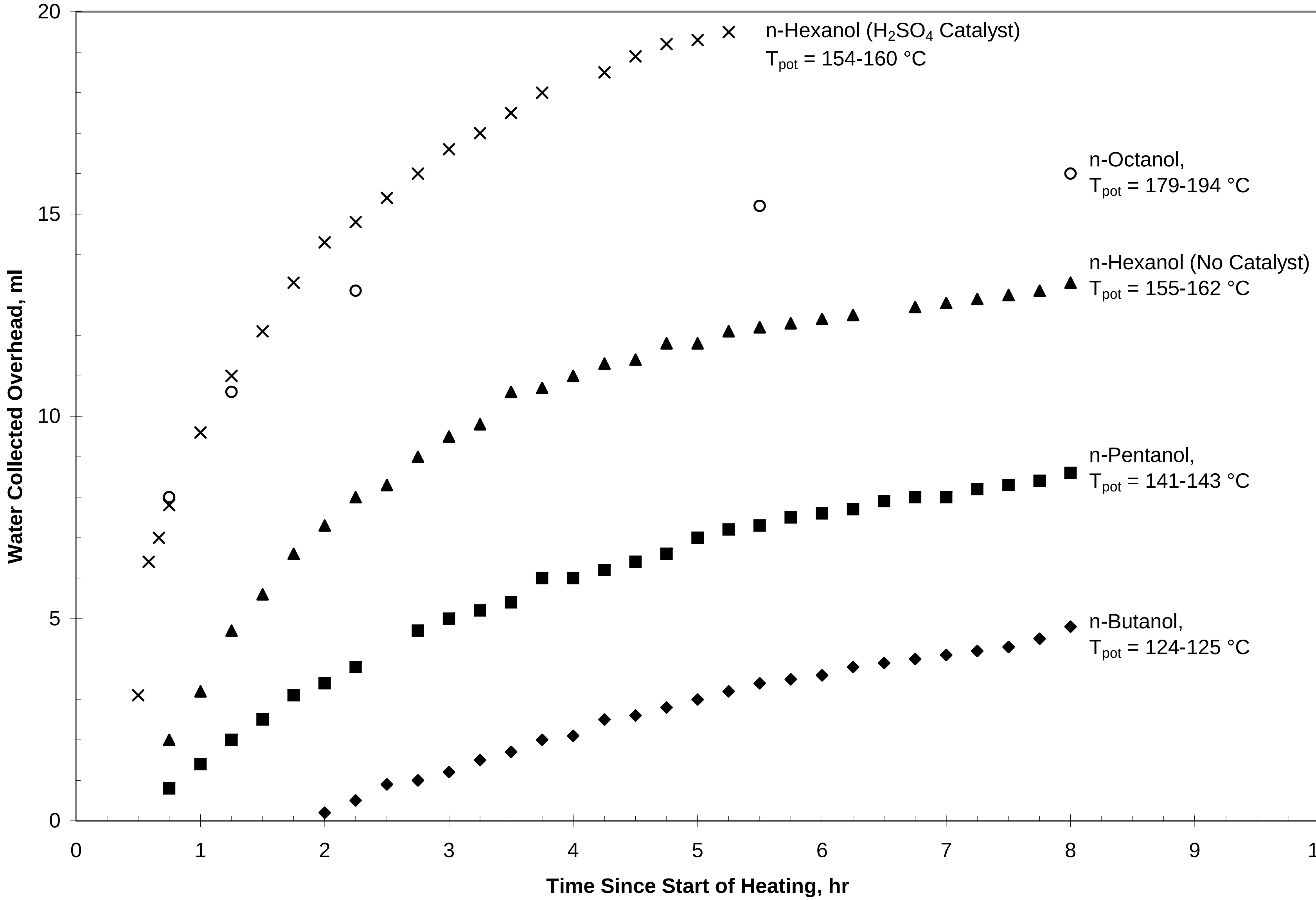


Figure 2.3 – Experimental Phase Diagram for the Water + TBA:HAc + n-Hexanol System

Figure 2.4 – Comparison of Esterification Experimental Results



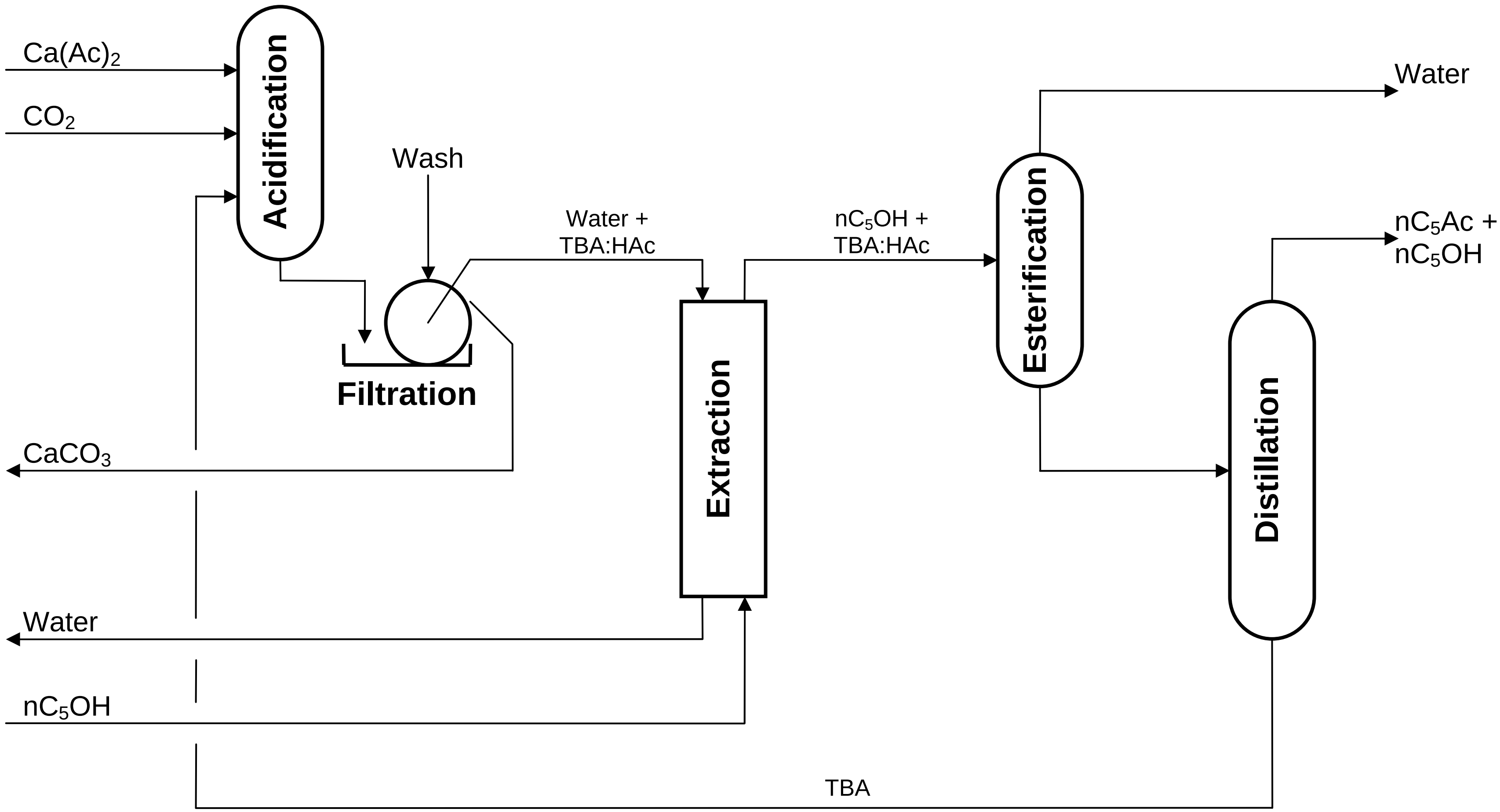


Figure 2.5 – Simplified Sketch of Recovery Process Using n-Pentanol as the Esterifying Alcohol

Table 2.1 – Extraction Solvent Screening Results For the TBA:HAc Complex

Solvent	Distribution Coefficient	Selectivity
Ethyl Acetate	0.105	
Butyl Acetate	0.082	
Toluene	0.0392	
2-Octanone	0.087	
Chloroform	0.987	
Ethyl Acetate/Ethanol (2/1)	0.293	
Ethyl Propionate/Ethanol (1/1)	0.249	
n-Butanol	2.40	8.79
n-Pentanol	1.45	14.77
n-Hexanol	1.13	19.26
n-Octanol	0.75	21.91

Table 2.2 Comparison of Alcohols in the Extraction Solvent Screening and Esterification Experiments

Solvent	Distribution Coefficient	Selectivity	Esterification Yield at 4 hr, % Theoretical
n-Butanol	2.40	8.79	12.6
n-Pentanol	1.45	14.77	38.1
n-Hexanol	1.13	19.26	82.7 / 93.6 (No Catalyst / H_2SO_4 Catalyst)
n-Octanol	0.75	21.91	88.8

Task 3 – Modeling

Process Model

The design basis for the model is a grassroots facility that produces 100 MMgal/yr (denatured) ethanol using the indirect process route. Carbohydrate and nutrients are supplied to the plant by an across-the-fence corn wet mill. HYSYS v3.2 (Build 5029), a commercial process simulator licensed from Aspen Technologies Inc., was use to perform the detailed material and energy balance calculations for the process model. Process performance assumptions are based on P90 assumptions for critical process parameters (i.e. the assumptions do not represent observed laboratory performance, but are in-line with what should be achievable with a modest amount of R&D effort. In this case, the estimated probability for success of the required R&D program is 90%). The design and economics are based upon nth plant assumptions.

Figure 3.1 is a simplified block flow diagram for the base case. A portion of the starch hydrolyzate and light steep water streams from an existing corn wet mill are used as carbohydrate and nutrient sources for the fermentation step. The acetate is recovered from the broth and an acetate ester is produced by esterification with the recycle alcohol. This ester then undergoes hydrogenolysis to produce the desired ethanol product plus the recycle alcohol. Hydrogen is provided by gasification of corn stover. A portion of the syngas produced by the gasifier is diverted to the combined cycle unit. The combined cycle unit produces steam and power using a gas turbine topping cycle and a non-condensing steam turbine bottoming cycle.

The corn wet mill was not explicitly modeled. Starch hydrolyzate, light steep water, and steep water return streams are transferred to/from the ethanol plant at a negotiated transfer price. Utility and infrastructure systems for steam, power, cooling water, raw material storage and final product storage were explicitly modeled in the simulations. Other utility and infrastructure systems were accounted in the economics by appropriate allocations for capital and operating costs. Appendix E contains a detailed process description. Major design assumptions, as well as detailed process flow diagrams with material and energy balance information, are presented in this appendix.

Several variations on the base process model were considered. The Balanced Case, summarized in Figure 3.2, assumes the combined cycle block is replaced with a simple boiler+non-condensing steam turbine to provide steam and power for the plant. The Minimum Capital Case, summarized in Figure 3.3, assumes that hydrogen is purchased at $2.50 per 1000 SCF and eliminates the gasification section of the plant. The Defined Media Case, summarized in Figure 3.4, improves integration with the wet mill by replacing the light steep water medium with a defined media; the cell mass and residual fermentables are no longer returned to the mill but are digested to produce a methane rich biogas used as a fuel trim for the gasifier.

Economic Model

An economic model was assembled using the process model as the basis. The economic analysis consists of a factored capital cost estimate, an operating cost estimate, a revenue summary, discounted cash flow calculations, plus single parameter and Monte Carlo sensitivity analyses for each case. Appendix F provides a detailed discussion of the economic model for the Base Case.

Table 3.1 summarizes the economic analyses. The Base Case is projected to have a fixed capital cost of $2.97 per annual gallon of capacity. A typical corn dry mill of equivalent capacity would require $1.00-1.50 of fixed capital per annual capacity based on our survey of recent plant announcements in (1). Projected fixed capital requirements for direct fermentation ethanol plants using lignocellulosic feedstocks are much higher, for example, the goal case considered in (2) estimates fixed capital at $2.85 per annual gallon of capacity. The projected capital costs for the Base Case appear to be reasonable given that both a conventional feedstock (e.g. starch hydrolyzate) and a lignocellulosic feed (e.g. corn stover) are handled in the facility.

Operating costs are projected to be $1.58 per gal (denatured) without credits for electricity or steep water return sales. Cash costs are $1.28 per gal (denatured) on the same basis. Revenues from electricity sales and steep water return sales are $0.44 per gal (denatured), so net cash costs are $0.84 per gal (denatured). Our internal estimate of the net cash cost for a comparable size corn dry mill are $0.99 per gal (denatured), so the indirect route appears to have a net cash cost advantage over conventional dry mill technology.

Discounted cash flow calculations use the time value of money concept to combine capital costs, operating costs, and revenues into one or more performance measures. The calculations can be done on either a rational pricing or market pricing basis, the choice of which depends on the objectives of the analysis. The rational ethanol price, defined as the ethanol price required for an internal rate of return (IRR) of 10% nominal after-tax for the project, is typically used in research environments to compare emerging technologies without complications caused by the consideration of market forces. The market price of ethanol depends upon many factors. A primary factor is its value in use, which in turn, is strongly influenced by the price of crude oil. In Appendix F we discuss historical rack prices for denatured fuel grade ethanol, Midwest basis, over the time period 1990-2004. Based on this preliminary market analysis, we selected a market ethanol price of $1.24 per gal (denatured) for the internal rate of return calculations reported in Table 3.1. At the time of this writing, crude oil prices are at historic nominal highs, current ethanol prices are much higher than $1.24, so the reported internal rates of return are much lower than those that would result from using current market conditions.

The Base Case is projected to have a rational ethanol price of $1.29 per gal (denatured) or an IRR of 8.7% (nominal, after-tax). Thus, while the indirect route has a cash cost advantage over conventional dry mill technology, the higher capital cost of the indirect route results in comparable discounted cash flow measures between the Base Case and conventional dry mill technology.

Single parameter and Monte Carlo sensitivity analyses of the Base Case economic models were done to find the drivers of economic performance and refine the focus of future R&D efforts. The price of starch hydrolyzate was found to be a major driver of the economics. In actual practice, the price of starch hydrolyzate would be set by contractual agreement with the host corn wet mill. This agreement would most likely transfer commodity risk from the wet mill to the ethanol facility via a formula that takes into account fluctuations in corn and related wet mill co-product prices. The formula would also include a fixed margin to account for other processing costs and provide a financial return to the mill.

The Base Case model assumed starch hydrolyzate would be purchased from the mill at \$0.05 per lb (dry). As shown in Appendix F, this roughly corresponds to a corn price of \$2.50 per bushel. At the time of this writing, corn prices are on the order of \$2.00 per bushel. Using this lower corn price, the IRR for the project is projected to be on the order of 15% (nominal, after-tax). Thus, the economic performance is quite sensitive to the price of fermentable carbohydrate.

The Balanced Case presented in Figure 3.2 and Table 3.1 replaces the gas turbine cogeneration system with a simple boiler+non-condensing steam turbine. The amount of corn stover fed to the gasifier is reduced since the design is required to be in steam balance and is very close to being in power balance. Capital costs, operating costs, and revenues are all reduced compared to the Base Case. As shown by the discounted cash flow performance measures, the reduction in revenue more than offsets the reduction in capital and operating costs, resulting in poorer economic performance.

The Minimum Capital Case presented in Figure 3.3 and Table 3.1 assumes that hydrogen can be purchased from a pipeline at \$2.50 per SCF. Pipeline hydrogen prices are often based on a formula that takes into account the price of natural gas (i.e. the primary feedstock used for hydrogen production via steam methane reforming). A hydrogen price of \$2.50 per SCF would roughly correspond to a natural gas price in the range of \$4.00-5.00 per MMBtu. As shown in Table 3.1, the reduction in capital cost for the Minimum Capital Case is offset by higher operating costs and lower revenues, resulting in poorer economic performance when compared to the Base Case.

The Defined Medium Case presented in Figure 3.4 and Table 3.1 replaces the light steep water nutrient source with a defined medium. The residual solubles and cell mass produced in the fermentation are digested to produce a methane rich biogas that is used as a fuel trim for the gasifier. When compared to the Base Case, the Defined Medium Case has slightly higher capital costs, comparable operating costs, and lower revenues. The lower revenues are a result of the fact that there is no longer a steep water return stream. Although this case does show poorer economic performance when compared to the Base Case, integration with the mill would be easier and performance of the fermentation recovery system would probably be better since the broth would be cleaner.

As discussed earlier, the sensitivity analysis showed that the cost of the fermentable carbohydrate strongly influences the projected economic performance. While starch hydrolyzate does have the advantage of being a relatively clean source of carbohydrate, it is relatively expensive. The acetogens used in our indirect process are capable of processing a mixed sugar stream such as those commonly encountered with biomass hydrolyzates. The gasifier and much of the other infrastructure needed to handle a biomass feedstock are already present in the Base Case. Converting the Base Case to a biomass feed would only require the addition of a pretreatment step, an enzymatic hydrolysis step, and some solids separation/dewatering equipment to prepare the solid residuals from fermentation for gasification. As mentioned in the

Project Description section of this report, a biomass feedstock is efficiently handled by the indirect process since all of the chemical energy stored in the feedstock is potentially available for conversion into ethanol.

Rigorous modeling of a biomass feedstock is outside the scope of work for this grant. However, we have included a block flow diagram in Figure 3.5 and some order-of-magnitude economic projections in Table 3.1. We expect that a rational ethanol price on the order of $1.00-1.10 per gal (denatured) could be attained given the recent improvements in pretreatment technology and recent breakthroughs in lowering prices for cellulase and hemicellulase enzymes. Future R&D efforts for the indirect process should focus on processing of biomass hydrolyzates.

Energy Savings Metrics

One purpose of detailed process modeling is to formulate quantitative answers to policy level questions such as the energy savings metrics considered in this grant. However, great care must be taken to define the system to ensure that results of these calculations are meaningful. Fortunately, USDA has spent quite a bit of effort in analyzing the net energy value of corn derived ethanol. For the conventional technology case of Table 3.2, we repeat the results given in (3) which report energy usage per gallon (neat) of ethanol produced on a higher heating value basis. Their analysis includes energy usage for corn production including the energy content of fertilizers, corn transportation, ethanol conversion, and ethanol distribution. Their value for ethanol conversion is an industry weighted average of energy usage for both wet mill and dry mill technologies. Co-product credits are estimated using the replacement value method. Under their assumptions, the energy ratio (defined as the ratio of the green energy produced divided by the fossil energy consumed) for the convention technology case is 1.34.

The second column of values in Table 3.2 shows a breakdown of energy usage for the Base Case assuming the wet mill utilities are provided by fossil energy resources, which is widely practiced in the industry today. Values for corn production and transportation were directly ratioed from the USDA model. Values for stover production and transport were taken from a recent life cycle analysis from the National Renewable Energy Laboratory (4). The ethanol conversion entry refers to the fossil energy consumed in the front end corn wet mill. The back-end ethanol plant in the Base Case derives its steam and power from corn stover, so these are not counted in the ethanol conversion entry for this analysis. In fact, a credit is taken later since the ethanol plant is a net exporter of green electricity. Ethanol distribution and feed co-product credits from the wet mill are ratioed directly from the USDA model. The resulting energy ratio for the Base Case is 3.11, much higher than the energy ratio of 1.34 for the conventional technology case.

The third column of values in Table 3.2 shows a breakdown of energy usage for the Base Case assuming the wet mill utilities are provided by green resources. The resulting energy ratio is 5.73, showing that the source of the energy used to process the feedstock into a fermentable substrate can have a dramatic impact on the environmental performance of the overall process. Green utilities could be provided to the wet mill by expanding the gasifier/cogeneration section of the ethanol plant or by other means such as combustion of landfill gas in the existing wet mill boilers.

We expect that the environmental performance for the Biomass Feed Case considered previously in Figure 3.5 would also be much better than the Base Case. The fossil energy input required for growing most lignocellulosic feedstocks is much less than that required for corn. This, plus the fact that all of the utilities in the Biomass Feed case are derived from renewables, suggests that very high energy ratios could result. The last column of values in Table 3.2 were derived from the data in (5) for fossil inputs required for lignocellulosic crops and an assumed chemical energy efficiency in ethanol conversion of 65% with the balance of feedstock energy used for utility production with no export/import of steam or power. An energy ratio of 12.32 is projected. Further improvements in energy ratio would result if the restriction on export power is relaxed. These findings strengthen the previous recommendation for future R&D efforts in processing biomass hydrolyzates with the indirect process.

The forecast for 2010 assumes the indirect process is responsible for 100 MMgal/yr (neat) of ethanol production. This is a small percentage of market projections, which typically predict 2010 ethanol production at about 5 billion gallons/yr. The projected energy savings for adopting the indirect route is 7.48 trillion Btu/yr if the wet mill front-end derives its utilities from fossil resources, or 9.56 trillion Btu/yr if the wet mill front-end derives its utilities from green resources. Slightly lower energy savings is projected for the Biomass Feed case (5.60 trillion Btu/yr) since this case assumes no credit for power export.

Sub-Task Review

The description of the sub-tasks, taken from Appendix B Statement of Work in the original proposal, is repeated below:

<u>Task 3.1 Process Modeling</u> – An integrated process model of the fermentation and esterification steps will be created and used to guide the experimental program. Rigorous material and energy balances will be generated using HYSYS.Process, a commercial process simulation package currently licensed by ZeaChem. The kinetic models developed in the experimental program will be used to generate several reactor designs that are potentially suitable for use at the semi-works facility. All auxiliary processing steps, such as broth clarification prior to esterification, will also be rigorously modeled. The outcome of this task will be a high quality process model that can be used to support the design of a semi-works commercial facility.

<u>Task 3.2 Economic Modeling</u> – The process models developed in Task 3.1 will be used as the basis for economic evaluation. Discounted cash flow calculations will be done in Excel and will be used as the basis for evaluation of process alternatives. Capital and operating costs will be estimated using standard factored estimation methods. The outcome of this task will be a high quality economic model that can be used to guide the experimental program and support our future commercialization efforts.

The following discussion compares the work actually accomplished against the original proposal subtasks:

<u>Task 3.1 Process Modeling</u> – Complete.

Task 3.2 Economic Modeling – Complete.

References

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2) Aden, A., Ruth, M., Ibsen, K., Jechura, J., Neeves, K., Sheehan, J., Wallace, B., Montague, L., Slayton, A., Lukas, J., "Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover", National Renewable Energy Laboratory, NREL/TP-510-32438, June, 2002.

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5) Lynd, L., Wang, M., "A Product-Nonspecific Framework for Evaluating the Potential of Biomass-Based Products to Displace Fossil Fuels", Journal of Industrial Ecology, Vol. 7, No. 3-4, p. 17-32, 2004.

Figure 3.1 – Base Case Block Flow Diagram

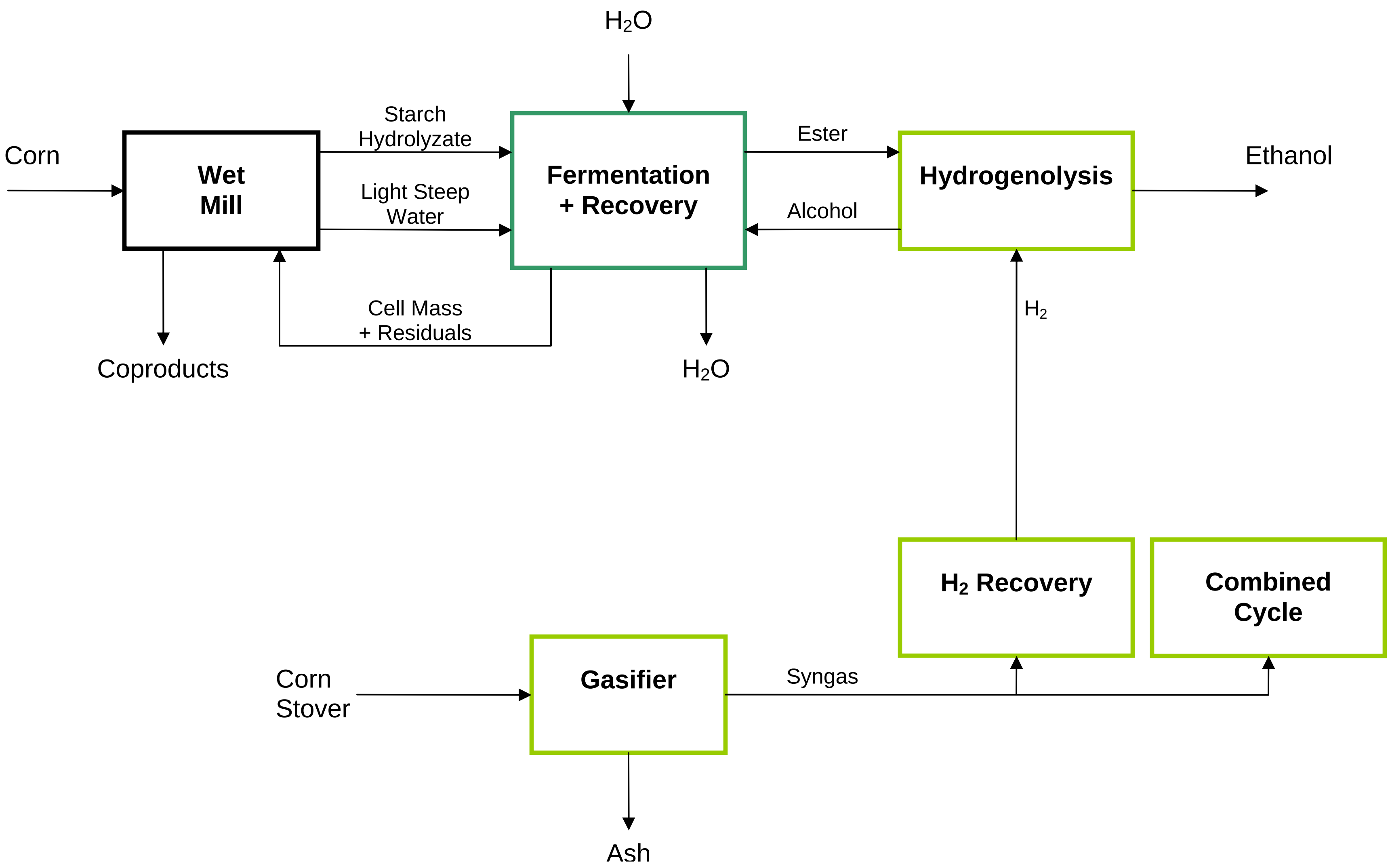

Figure 3.2 – Block Flow Diagram for Balanced Case

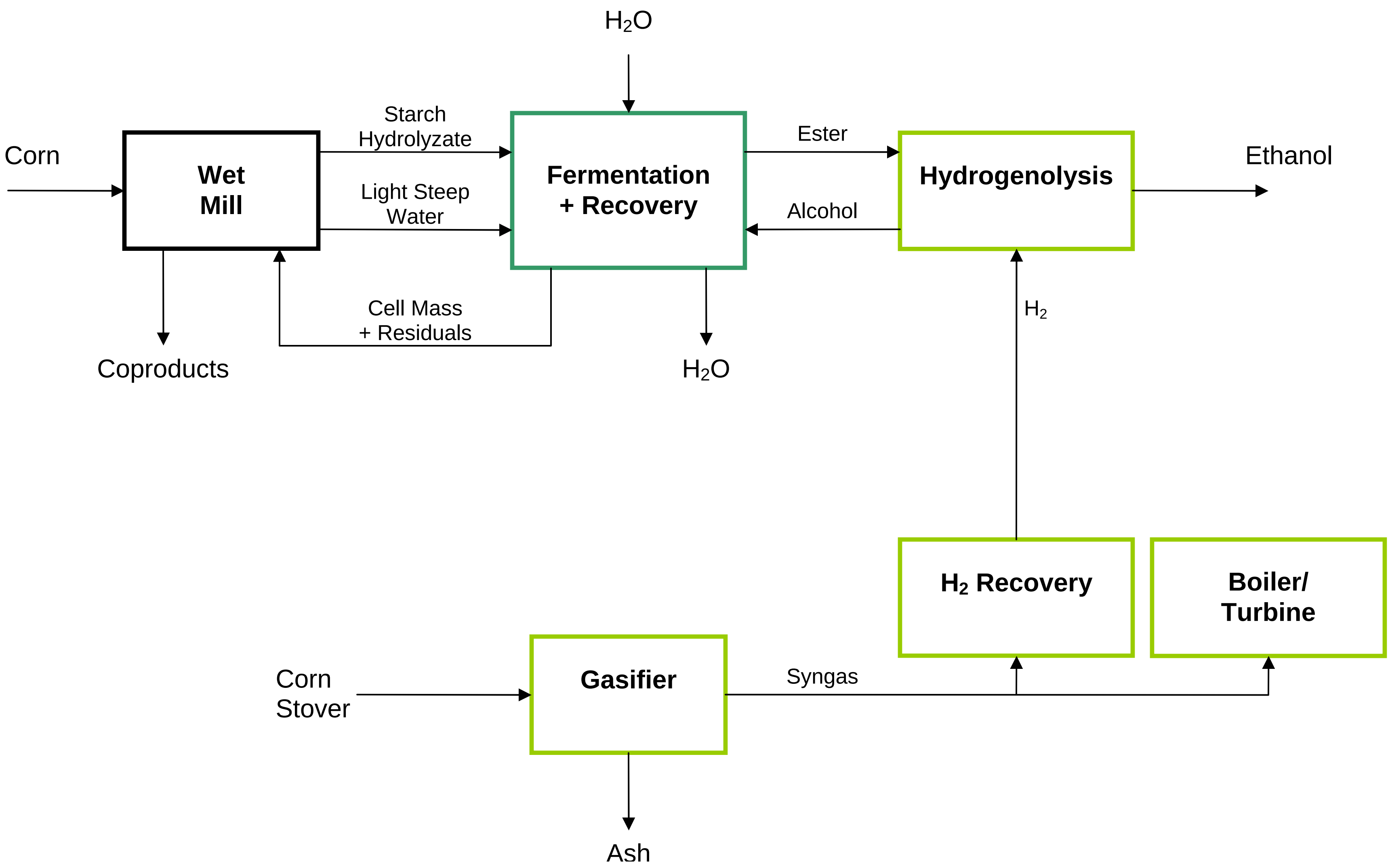

Figure 3.3 – Block Flow Diagram for Minimum Capital Case

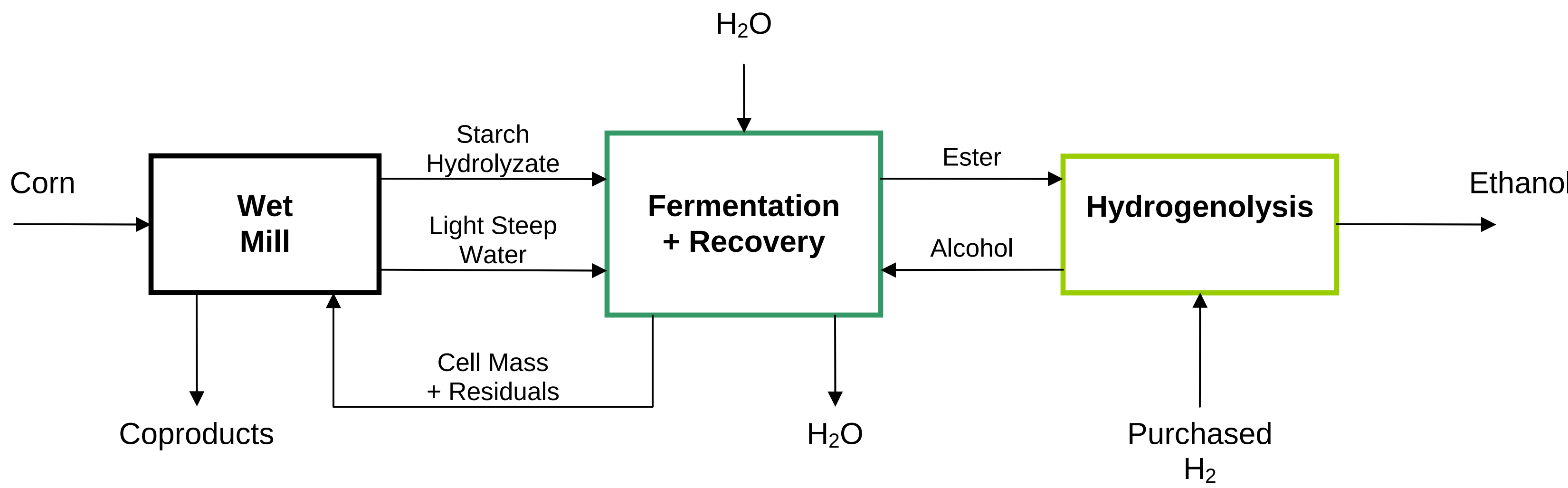

Figure 3.4 – Block Flow Diagram for Defined Medium Case

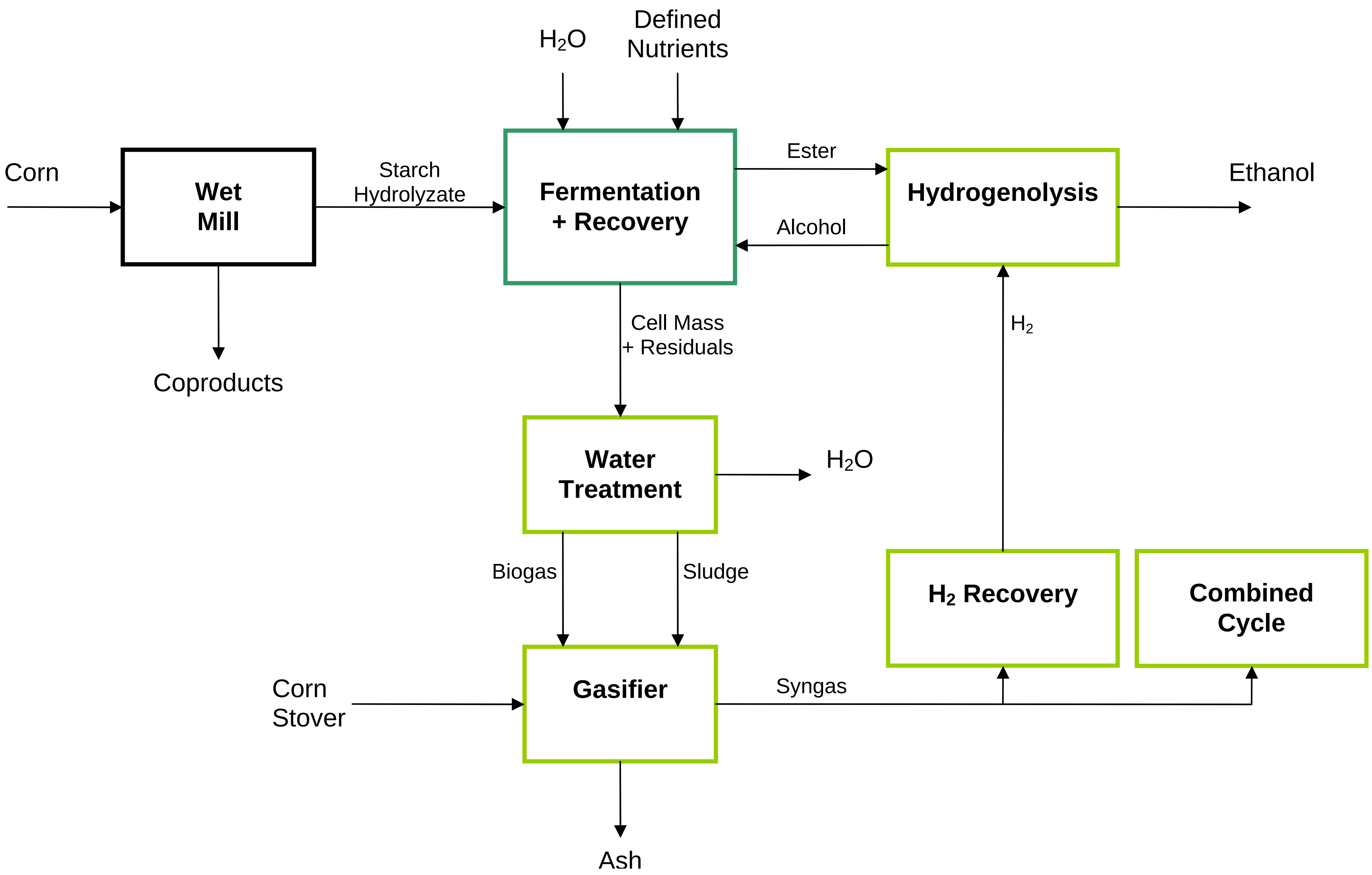

Figure 3.5 – Block Flow Diagram for Biomass Feed Case

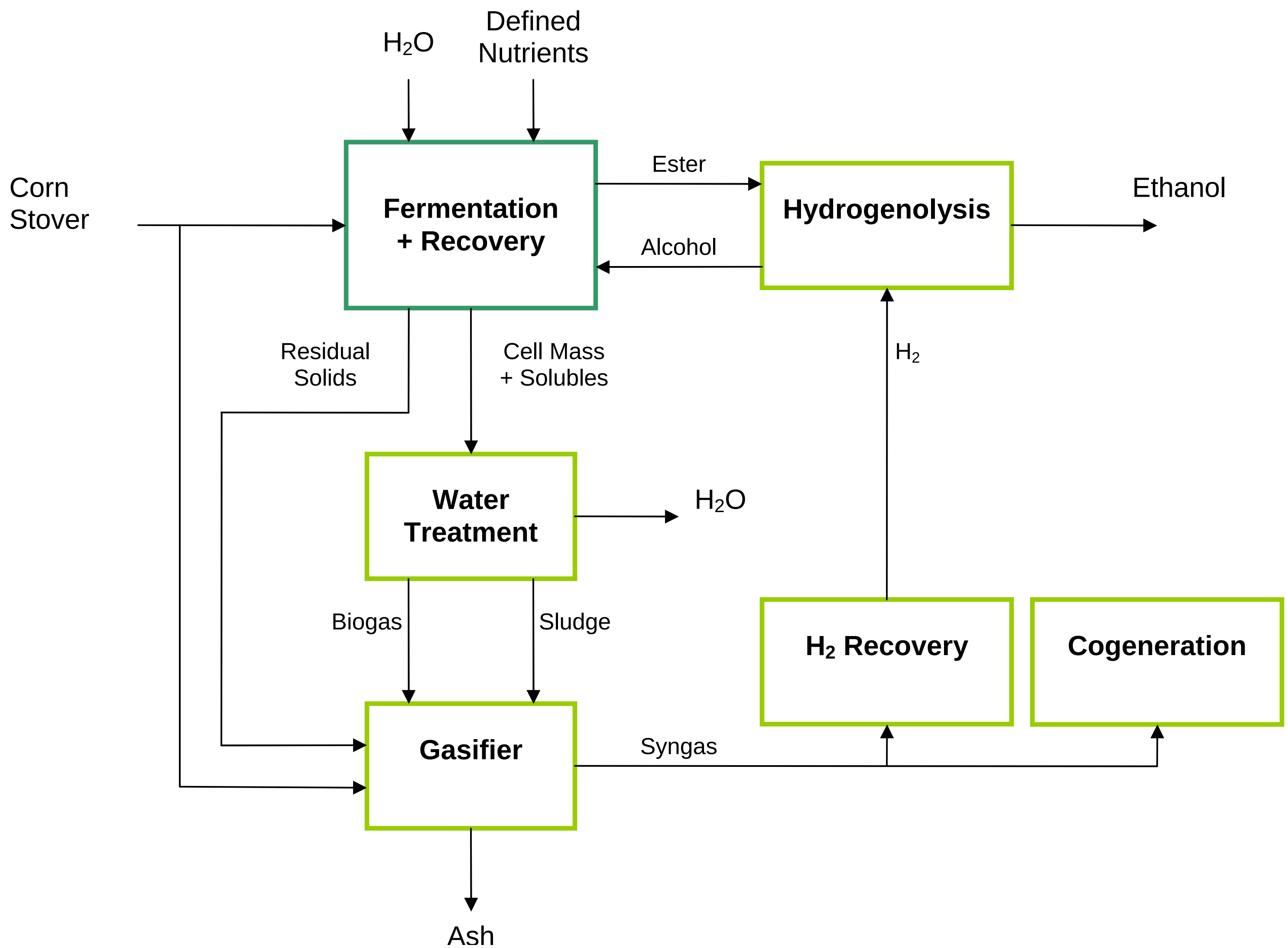

Table 3.1 Economic Summary

100 MM Gal/yr (Denatured) EtOH Facility

	Base	Balanced	Minimum Capital	Defined Medium	Biomass Feed*
Capital, $MM					
Fixed	297.3	248.7	138.2	307.3	356.6
Working + Start-up	34.6	29.3	23.5	33.5	33.3
Total	331.9	278.0	161.7	340.8	389.9
Operating Costs, $/gal (denatured)					
Variable	1.07	0.98	1.24	1.06	0.83
Fixed	0.51	0.43	0.24	0.52	0.61
Total	1.58	1.41	1.48	1.58	1.44
Cash	1.28	1.16	1.34	1.28	1.08
Revenues, $MM/yr (Market)					
	167.6	143.4	141.6	154.5	208.2
Profitability					
Rational EtOH Price, $/gal (Denatured)	1.29	1.35	1.41	1.44	1.06
IRR, Nominal After-Tax	8.7%	6.8%	-0.3%	5.0%	13.2%

* Order-of-Magnitude Results. Biomass Feed Case was not modeled to the same level of detail as the other cases.

Table 3.2 Summary of Energy Metrics

Energy Metrics per Gallon of Ethanol	Conventional Technology, Btu (HHV) / gal EtOH (neat)	ZeaChem Base Case, Btu (HHV) / gal EtOH (neat)	ZeaChem Base Case w/ Green Wet Mill, Btu (HHV) / gal EtOH (neat)	ZeaChem w/ Biomass Feed, Btu (HHV) / gal EtOH (neat)
Fossil Energy Use				
Crop Production	21,598	15,566	15,566	2,339
Crop Transport	2,263	1,631	1,631	2,886
Stover Production & Transport	0	16,573	16,573	0
Ethanol Conversion	51,779	20,833	0	0
Ethanol Distribution	1,588	1,588	1,588	1,588
Subtotal	77,228	56,192	35,359	6,813
Coproduct Credits				
Mill Coproducts	14,372	10,670	10,670	0
Net Electricity Export (Thermal Equivalent)	0	57,425	57,425	0
Subtotal	14,372	68,095	68,095	0
Fossil Energy w/ Coproduct Credits	62,856	-11,903	-32,736	6,813
Ethanol Higher Heating Value	83,961	83,961	83,961	83,961
Net Green Energy	21,105	95,864	116,697	77,148
Energy Savings vs. Conventional Technology	-	74,759	95,592	56,043
Energy Ratio	1.34	3.11	5.73	12.32

Energy Metrics Forecast for 2010	Conventional Technology	ZeaChem Technology	ZeaChem Technology	ZeaChem Technology
Estimated Capacity in US by 2010, MMgal EtOH/yr (neat)	5,000	100	100	100
Estimated Fossil Energy Savings by 2010, Trillion Btu/yr	-	7.48	9.56	5.60

Task 4 – Reporting

Sub-Task Review

The description of the sub-tasks, taken from Appendix B Statement of Work in the original proposal, is repeated below:

Task 4.1 Progress Reports – Two semi-annual progress reports will be submitted to DOE.

Task 4.2 Final Report – One final report will be submitted to DOE within 3 months of completion of the experimental portion of the work. At the discretion of ZeaChem Inc., this report could be used as a basis for future technical presentations and publications. The Annual Symposium on Biotechnology for Fuels and Chemicals meeting in May 2004, The American Institute of Chemical Engineers (AIChE) annual national meeting in November 2004, and the Corn Utilization Conference sponsored by the National Corn Growers Association are potential presentation forums.

The following discussion compares the work actually accomplished against the original proposal subtasks:

Task 4.1 Progress Reports – The reporting frequency was changed by US DOE from semi-annual in the Solicitation to quarterly in the final contract. Eight quarterly reports were submitted on-time per the revised reporting requirements.

Task 4.2 Final Report – This document constitutes the final technical report and was submitted prior to the June 2005 deadline given in the final contract.

Two oral presentations on portions of this work were given in public forums:

1) "Recovery of Organic Acids From Fermentation Broths". Southern Bio-Products Conference, Beau Rivage Resort, Biloxi, MS, March 4-6, 2004

2) "Recovery of Organic Acids From Fermentation Broths", Oral Presentation 3-05, 26th Symposium on Biotechnology for Fuels and Chemicals, Chattanooga, TN, May 11, 2004

One paper based on a portion of this work was authored, peer reviewed and submitted for publication in Applied Biochemistry and Biotechnology. Final publication of this paper, entitled "Recovery of Organic Acids from Fermentation Broths", is scheduled for Spring 2005.

One provisional patent application, based on a portion of this work, was submitted to the US Patent and Trademark Office. US DOE has certain rights to this intellectual property as specified in the contract for this grant. US DOE was notified of our filing; US DOE responded with an acknowledgement letter and provided a case number for future correspondence (S-104,376 "Direct Esterification of Acetic Acid Amine Complexes").

We have submitted an abstract for an oral presentation, entitled “The Importance of Utility Systems in Today’s and Tomorrow’s Biorefineries”, to the 27th Symposium on Biotechnology for Fuels and Chemicals to be held May 1-4, 2005 in Denver, CO. We have been notified that our presentation has been accepted. We currently plan to author a paper based on this presentation and submit the paper for publication in Applied Biochemistry and Biotechnology.

Conclusions

1) All tasks of the original proposal were successfully accomplished:

a) The laboratory program for the acetogenic fermentation step showed that the selected could be adapted to a corn steep liquor medium and still produce acetate with industrially relevant yield, concentration and kinetics.

b) An industrially viable recovery scheme to produce acetate esters from near pH fermentation broths without the production of stoichiometric amounts of a salt co-product was successfully developed.

c) Process and economic models for the indirect route were developed and used to guide the development effort.

2) The projected economics of the Base Case developed in this work are comparable to today's corn based ethanol technology. Sensitivity analysis shows that significant improvements in economics for the indirect route would result if a biomass feedstock rather that starch hydrolyzate were used as the carbohydrate source.

3) The energy ratio, defined as the ratio of green energy produced divided by the amount of fossil energy consumed, is projected to be 3.11 to 12.32 for the indirect route depending upon the details of implementation. Conventional technology has an energy ratio of 1.34, thus the indirect route will have a significant environmental advantage over today's technology. Energy savings of 7.48 trillion Btu/yr will result when 100 MMgal/yr (neat) of ethanol capacity via the indirect route is placed on-line by the year 2010.

Appendix A

Final Task Schedule

Final Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	Fermentation Step	6/30/03	06/15/05	09/30/04	100%	Completed.
2	Esterification Step	12/31/03	06/15/05	09/30/04	100%	Completed.
3	Modeling	12/31/03	06/15/05	03/31/05	100%	Completed.
4	Reporting	3/31/04	06/15/05	04/29/05	100%	Completed.

Notes:

1) Original plan assumed a January 1, 2003 start date for Period of Performance. Actual start was delayed to end of June 2003.

Appendix B

Final Spending Schedule

Final Spending Schedule **Project Period:** 06/15/03 to 06/15/05

Task	Approved Budget	Final Project Expenditures
Task 1 Fermentation Step	110,000	114,443
Task 2 Esterification Step	115,000	119,635
Task 3 Modeling	60,000	91,022
Task 4 Reporting	15,000	22,755
Total	300,000	347,855
DOE Share	200,000	200,000
Cost Share	100,000	147,855

Appendix C

Final Cost Share Contributions

Final Cost Share Contributions

Funding Source	Approved Cost Share		Final Contributions	
	Cash	In-Kind	Cash	In-Kind
ZeaChem Inc.		100,000		147,855
Total		100,000		147,855
Cumulative Cost Share Contributions				147,855

Appendix D

Energy Savings Metrics

One Unit of Proposed Technology:

The process model developed for this grant is based on a grassroots indirect ethanol plant with a 100 MMgal/yr (denatured) capacity. The plant is provided corn starch hydrolyzate from an across-the-fence corn wet mill. Utilities for the wet-mill are assumed to be provided from fossil resources. All values reported in the Energy Savings Metrics are on a Btu/yr per gal (neat) higher heating value basis. The reported values take into account energy usage for corn production, corn transport, stover production and transport, ethanol conversion, and ethanol distribution.

One Unit of Current Technology:

The current technology case is reproduced from: Shapouri, H., Duffield, J.A., Wang, M., "The Energy Balance of Corn Ethanol: An Update", United States Department of Agriculture, Agricultural Economic Report Number 814, July, 2002. All values reported in the Energy Savings Metrics are on a Btu/yr per gal (neat) higher heating value basis. The reported values take into account energy usage for corn production, corn transport, stover production and transport, ethanol conversion, and ethanol distribution.

Energy Savings Metrics

Type of Energy Used	A Current Technology (Btu / yr / unit)	B Proposed Technology (Btu / yr / unit)	C=A-B Energy Savings (Btu / yr / unit)	D Estimated Number of Units in U.S. by 2010 (units)	E=CxD Energy Savings by 2010 (Btu / yr)
Fossil Energy	77,228	56,192			
Mill Coproducts Credit	-14,372	-10,670			
Net Electricity Export (Thermal Equivalent)	0	-57,425			
Total Per Unit	62,856	-11,903	74,759	100×10^6	7.48×10^{12}

Discussion of Energy Savings:

See discussion in Task 3 – Modeling for more detail.

Appendix E
Detailed Base Model Description

This appendix contains a detailed description of the process and utility systems assumed in the base model. Process performance assumptions are based on P90 assumptions for critical process parameters (i.e. the assumptions do not represent observed performance in the laboratory, but are in-line with what should be achieved with a reasonable amount of R&D effort. In this case, the estimated probability for success of the required R&D program is 90%). The design and economics are based upon nth plant assumptions.

HYSYS v3.2 (Build 5029), a commercial process simulator licensed from Aspen Technologies Inc., was used to perform most of the detailed material and energy balance calculations. A significant portion of the modeling effort was devoted to ensuring that the thermodynamic basis for the model was reasonable. When available, library components were used to represent components in the simulation. A number of components were not available in the library. Table 1 is a list of these components plus the references used to develop the heat of formation and heat capacity data needed the simulator. Table 2 lists the various equilibrium models used in the simulation and provides the basis for the interaction parameters.

Table 3 shows the overall material and energy balance for the simulation, excluding heat cross-exchange for the steam generation system. The non-closure in the overall material balance is 20 lb/hr out of 56,944,763 lb/hr total (i.e. 0.000036% non-closure); the non-closure in the overall energy balance is 23,979 Btu/hr out of 38,152,215,275 Btu/hr total (i.e. 0.000063% non-closure). Most of the non-closure in the material balance can be attributed to round-off errors in reactor operations caused by the level of precision that HYSYS carries in the component molecular weights. Most of the non-closure in the energy balance can be attributed to non-closure of the recycle operation RCY-4 @FREC. The non-closure in both the material and energy balances is acceptably small on a percentage basis.

The philosophy behind the utility system design in the base case is to maximize power production, with the limitation that the steam system only uses a non-condensing turbine to provide the process steam requirements. In other words, the stover rate to the gasifier was allowed to vary, along with gas turbine size, until the system came into steam balance. At design conditions, slightly over 50% of the stover is being gasified to provide heat and power. Power in excess of process needs is assumed to be sold to the grid.

Detailed cross-exchanges for the steam generation system were not installed in the simulation because it would increase difficulties with model convergence and decrease the flexibility needed for future process studies. However, it is important to ensure that the model does not lead situations that violate fundamental thermodynamic principles, such as the fact that energy must balance and there needs to be a temperature driving force for heat transfer to occur. Fortunately pinch analysis provides the tools needed for analysis of the steam generation system.

Below is a list of the exchangers that do not have an explicit cross exchange in the simulation:

Hot Sides	Cold Sides
E-2101 Combustor Offgas Heat Recovery	E-3100 Degasifier Preheater
E-2200 Conditioned Gas Heat Recovery	E-3101 Degasifier Preheater
E-2204 Regen Offgas Heat Recovery	E-3102 BFW Preheater
E-2501 Heat Recovery	E-3101 Steam Generation
E-2502 Heat Recovery	E-3104 Superheater
E-3000 HRSG	
E-3105 Blowdown Cross Exchanger	
E-3107 Desuperheater	
E-3108 Desuperheater	

Most of the hot side exchangers are located in either the Gasification and H2 Recovery or Cogeneration sections of the plant, areas where significant amounts of heat are released. This heat is to be used by the cold side exchangers, all of which are located in the Steam System, to generate steam for the non-condensing turbine and process needs.

Figure 1, derived from the pinch analysis, is plot of the composition curves showing the amount of heat available/required versus temperature. Because the two composite curves do not cross and the right hand boundaries of the two composite curves match, the required amount of steam can be generated through cross exchanges. In fact, Figure 1 shows that there is an excess of roughly 111,000,000 Btu/hr of heat available at temperatures below 360 °F. To completely close the energy balance for the plant, one would need to adjust the flue gas exit temperatures slightly upward from their assumed values of 250 °F to eliminate the 111,000,000 Btu/hr excess.

Another interesting conclusion drawn from Figure 1 is that there is no reason to include any process exchangers in the pinch analysis that liberate heat at temperatures below 360 °F. For example, the duties for the overhead condensers E-1506, E-1507, E-1603, and E-1604 in the Esterification and Fractionation and Water Management sections are quite large, however the heat is liberated at too low of a temperature to be useful for the steam system. The base case assumes these exchangers use the atmosphere as their heat sink, either directly as air cooled exchangers, or indirectly through the cooling water system.

The rest of this appendix provides a more detailed description process and utility systems. The simulation uses HYSYS's subflowsheet architecture to divide the simulation into logical pieces. Process flow diagrams and material and energy box scores for each of the subflowsheets are provided at the back of this appendix.

Fermentation and Recovery

The overall responsibility of this area is to convert fermentable carbohydrates into an ester suitable for downstream hydrogenolysis. The tasks performed are further subdivided into: Feed Prep, Fermentation, Pre-Concentration, Acidification, Extraction, Esterification + Fractionation, and Water Management.

Feed Prep – The various feed materials are mixed in the proper proportions, sterilized and temperature is adjusted prior to sending the media to downstream fermentation. For purposes modeling, the media formulation targets were assumed to be:

Fermentable Sugars	58.26 g/l
Protein	5.0 g/l
Reductant	0.09 g/l
Mineral Supplement	0.5 g/l

The level of fermentable sugars was set so that the broth would contain 50 g/l of acetate (measured as HAc) after fermentation. The primary sugar source is starch hydrolyzate, assumed to be supplied by an "across-the-fence" corn wet mill. The assumed composition for the starch hydrolyzate is shown in Table 4. This is representative of an enzymatic derived hydrolyzate after filtration to remove insoluble protein and fat, essentially an unrefined 95^+ DE syrup at 30 wt% dry solids (10). Dextrose, maltose and isomaltose are considered as fermentable sugars; the higher oligomers are not considered fermentable.

The light steep water is the primary nutrient source for the fermentation. Like the starch hydrolyzate, light steep water is assumed to be supplied by an "across-the-fence" corn wet mill. Light steep water is a complex mixture. The assumed composition for light steep water is also given in Table 4, arrived at by simplification of the composition profiles given in the literature (11, 12).

It is not clear which component in steep water is the limiting nutrient. For purposes of modeling, we assumed the media formulation would be based on 5 g/l of protein. In the lab, we have demonstrated good fermentation performance with yeast extract formulated to a solubles solids content of 10 g/l, which equivalent to about 5g/l on a protein basis since yeast extract is approximately 50% protein on a dry basis (11). We have also demonstrated good fermentation performance with corn steep liquor solubles at 30 g/l, which is equivalent to about 11 g/l on a protein basis. We argue that light steep water should be a more active nutrient source compared to corn steep liquor solubles, and good fermentation performance at a protein content of 5 g/l should be achievable with a reasonable R&D effort (i.e. a P50 target).

The fermentation organism is a strict anaerobe. Water typically contains 8-9 ppm dissolved oxygen. While the organism is capable of lowering the redox potential of the media on its own, it is standard practice to provide a reduced media. This can be done using a combination of degassing and the introduction of a reductant to scavenge for dissolved oxygen. In our laboratory work, we use degassing and ~ 0.75 g/l of sodium thioglycolide as the reductant. For purposes of cost modeling, we assumed no degassing and a 10% excess of sodium sulfite as the reductant. The stoichiometry for this scavenging reaction is:

$$O_2 + 2Na_2SO_3 \rightarrow 2Na_2SO_4$$

A similar need to remove a trace quantity of dissolved oxygen from a large amount of water is faced in boiler feed water systems. Without pretreatment to remove dissolved oxygen, the generating tubes in the boilers for power plants and other industrial facilities would quickly corrode and fail. A number of low-cost reductants have been developed for this application that could potentially be adapted for fermentation media formulation.

Acetogens also require a number of minerals in the media. While we expect that light steep water would provide most of these minerals, additional mineral supplements may become necessary as the concentration of steep water is reduced through R&D efforts. For cost purposes, we assumed that a mineral supplement of 0.5 g/l of KH_2PO_4 is required.

Two sterilization methods are used. Filter sterilization is used for liquid materials that have a low bioload. These include the dilution water and backset, starch hydrolyzate, reductant and mineral supplements. Heat sterilization is used for feed materials with a high bio-load (e.g. light steep water) and solids content (e.g. Wet Cake and Fresh $CaCO_3$). For heat sterilization, the media is heated to 121 °C and passed through a trombone pipe reactor (i.e. X-1000 Sterilizer) to complete the sterilization.

Fermentation – The fermentation is modeled with a conversion reactor. Table 5 details the stoichiometry assumed for the various reactions. The model assumes a homoacetogen capable of simultaneously converting a variety of fermentables into either acetate or cell mass. The assumed conversion and selectivities are:

Fermentables Conversion	95%
Selectivity to Acetate	90%
Selectivity to Cell Mass	10%

These are defined using the incoming fermentables as the basis. Fermentables include dextrose, fructose, galactose, arabinose, xylose, maltose, isomaltose, and lactate. Higher oligomers from the starch hydrolyzate and ethanol recycled with the backset were not considered to be fermentable.

Our elemental nitrogen balance around the fermentation step is based on a few simplifying assumptions:

1) Overall composition of cell mass can be represented by the formula $CH_{1.8}O_{0.5}N_{0.2}$ on a dry basis. This is a typical "generic" composition assumed in fermentor design and bio-energetic models (13, 1).
2) Ammonia present in the media is preferentially converted to cell mass. Light steep water is a significant source of ammonia.
3) Once ammonia from the feed is exhausted, the cells will then catabolize proteins, peptides, and amino acids in the feed to produce intracellular ammonia and various carbon skeletal fragments. The intracellular ammonia can then participate in the cell synthesis reactions. For purposes of the model, this protein source was assumed to have the formula $C_6H_{13}O_2N$ (i.e. leucine, a dominant amino acid in light steep water).
4) The carbon skeletal fragments produced by amino acid catabolism will be reformed by the cell into intracellular glucose, which can then participate in cell synthesis and acetate production.

Under the assumptions of the model, the light steep water does not provide enough ammonia to complete cell production. 26.5% of the incoming proteins, peptides, and amino acids in the feed are catabolized for cell synthesis.

The model assumes adiabatic operation with the fermentor outlet temperature set at 58 °C. The fermentation reactions are net exothermic, demonstrated by the fact that the fermentor inlet stream (Stream 1101) has to be adjusted to 49.6 °C to maintain the required outlet temperature.

A near neutral pH is maintained by a stoichiometric addition of calcium carbonate to fermentor. Carbon dioxide is liberated when the fermentation is neutralized with calcium carbonate. The carbon dioxide can be present in the form of a separate gas phase, a dissolved gas, or as bicarbonate or carbonate ions in the broth. Stripping the fermentor with an inert gas removes both gaseous and dissolved carbon dioxide and also shifts the aqueous electrolyte equilibrium to reduce the concentration of bicarbonate and carbonate ions in the broth, thereby improving the efficacy of calcium carbonate as a neutralization agent.

The cell mass produced in the fermentation step is removed and concentrated in X-1100 Clarifier. This cell mass is homogenized and then exported back to the host corn wet mill as part of the steep water return stream.

It is too early in the development program to provide a detailed process design for the fermentation and clarification steps. Batch, fed-batch, continuous chemostats, and various cell recycle configurations could potentially be used, but more detailed design information using the truly representative media and organism is needed. For purposes of sizing, a fermentor productivity of 0.5 g acetate (as HAc) per liter per hour requires 6.2 million gallons of fermentation capacity at 100 MMgal/yr of denatured ethanol production. Additional volume is needed for gas disengagement, cycles for batch configurations, seed trains, etc., so the model assumes that 10 one million gallon tanks are required. As a point of reference, a one million gallon tank is roughly 60 feet in diameter and 48 feet tall. Tanks at a petroleum refinery tank farm typically range in capacity from 100,000-400,000 barrels, equivalent to 4.2-16.8 million gallons each, so the fermentor volumes assumed in the model are constructible.

<u>Pre-Concentration</u> – The clarified broth from fermentation is concentrated by reverse osmosis from 50 to 80 g/l (as HAc). Preconcentrating the broth reduces downstream energy requirements. For purposes of sizing, we assumed a flux of 0.360 $m^3/(m^2$ day) and a specific power requirement of 5 kWe/m^3 of permeate.

The amount of concentration that can be provided by reverse osmosis is limited either by the osmotic pressure of the retentate or by precipitation/fouling of the membranes. Osmotic pressures are limited to about 600-700 psia, with operating pressures limited to 800-1,000 psia to provide a driving force for separation (14). An electrolyte model of an aqueous calcium acetate solution would show the acetate ion and $Ca(Ac)^+$ complex as the dominant ionic species in the solution. Back of the envelope calculations, using the assumption that these are the only ions, results in the conclusion that a 15-20 wt% calcium acetate solution (as HAc) would have an osmotic pressure of 600-700 psia. We limited the preconcentration of the broth to 80 g/l (as

HAc) since precipitation is likely to be the limiting factor in RO design and operation. Further study is needed to understand the amount of preconcentration that can be achieved by reverse osmosis. This, in turn, is closely tied to the amount of light steep water nutrient required by the fermentation step, so it is not possible to completely decouple future RO process development work from future fermentation media development efforts.

Acidification – The concentrated broth is then cooled to 110 °F, mixed with a stoichiometric amount of tributyl amine (TBA) and fed to V-1302 Acidifier where it is converted to the TBA:HAc complex using carbon dioxide from the fermentation stripping gas plus a small amount of make-up CO_2 as the acidification agent. The acidifier is a trayed vessel that conducts the following reaction:

$$Ca(Ac)_2 + 2TBA + H_2O + CO_2 \rightarrow CaCO_3 + 2TBA:HAc$$

The model assumes calcium acetate is the limiting reactant, and assumes 100% conversion of calcium acetate to the amine complex.

Our laboratory work to date has only used a single stage reactor with a large excess of CO_2 blown through the solution. A multi-staged contactor will allow high conversion of the calcium acetate at low excess partial pressures of CO_2. Since the inert carrier that accompanies the rich stripping gas from the fermentor is recycled back as the lean stripping gas for fermentation, using a multi-stage contactor to reduce the amount of excess CO_2 required for acidification has the effect of reducing the power requirements required for stripping gas circulation. While not the largest power users in the plant, the combined power requirements for stripping gas circulation (C-1300 and C-1301) are responsible for about 11% of the total power demand for the facility.

Tray design for V-1302 Acidifier requires balancing contacting efficiency with the ability to handle solids. The calcium carbonate produced in the acidification reaction will precipitate as a fine powder in solution. Doughnut trays, shelf trays, or other tray designs capable of handling solids are required.

The bottoms product of the acidifier is filtered to remove the calcium carbonate precipitated. The cake is wash with hot water to displace residual TBA:HAc complex. Wash liquors are combined with the filtrate and sent to downstream extraction. The washed cake is recycled for use as pH control in fermentation.

The model assumes the acidifier will be capable of reducing the CO_2 content of the gaseous product to 1000 ppm mol. The gas is fed to a lime scrubber where the reaction:

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$$

lowers the residual CO_2 content of the lean stripping gas to 50 ppm mol. As with the acidifier, the trays for the lime scrubber need to be able to handle solids. The spent lime from the scrubber, containing calcium carbonate, is combined with the wet cake from filtration and recycled back to the fermentor for pH control. While lime scrubbers are not as common as caustic scrubbers in industry, a lime scrubber is preferred in this application because there is a use for the spent lime.

Extraction – The aqueous TBA:HAc complex produced by the acidification step is next extracted with a n-pentanol rich organic phase. The TBA:HAc complex is transferred to the organic phase.

Figure 2 plots the equilibrium curve, operating line, and stages for V-1400. Nine theoretical stages at a solvent to feed mass ratio of 0.65 gives a recovery of 98.9%, based on the amount of TBA:HAc present in the aqueous feed. This solvent rate is about 1.3 times the minimum rate. A rotating disk contactor would be a good type of extractor to use for this application.

Esterification + Fractionation – The extract is fed to a reactive distillation unit to produce n-pentyl acetate according to the reaction:

$$TBA : HAc + nC_5OH \leftrightarrow nC_5Ac + H_2O + TBA$$

This reversible reaction is conducted in the liquid phase at ~170 °C and 35.5 psia. The reaction does not proceed appreciably to the right unless water concentration is quite low.

The simulation uses a combination of an ordinary distillation with a recycle conversion reactor to model the esterification unit. Overall conversion is 95% of theoretical. Figures 3 and 4 plot the equilibrium curve, operating lines, stages and feed qualities for V-1500 Esterifier Column using a pseudo binary analysis on either linear or log axes. The single design specification for the column is the water content of the bottoms product is set at 500 ppm mass. The figures show no excessive pinching and reasonable feed locations.

The esterification unit requires the largest steam load in the base case. The combined duties of Q.E-1503 and Q.V-1501 account for ~63% of the overall steam production for the plant, thus it is important to make sure the esterification unit duties are reasonable. Nearly 88% of the water that is distilled in V-1500 is free water that was co-extracted with the n-pentanol solvent, with the remaining 12% balance coming from the water generated by the esterification reaction. The total heating duty is 1556 Btu/lb of water distilled. This seems to be a reasonable number considering the facts that the heat of vaporization for water is roughly 1000 Btu/lb, some solvent is distilled overhead, there is a heat load for the endothermic heat of reaction, and there is a heat load associated with the work of separation.

The above analysis suggests several ways to lower steam requirements: 1) Switch to a different extraction solvent that does not co-extract as much water, 2) Optimize the Pre-Concentration and Extraction steps to lower the amount of solvent needed for extraction.

Upon cooing and condensing, the overhead product from the esterification unit phase splits. The organic phase is recycled as solvent for extraction. The aqueous phase is sent downstream to water management where the residual solvent is stripped.

The bottoms product from the esterification unit is cooled and undergoes a vacuum distillation in V-1503. The column operates at 50 mm Hg with a bottoms temperature of 233 °F and an overhead temperature of 161 °F. Reboiler duty is supplied by cross-exchange with the overhead condenser for V-1500; condenser duty is supplied by cooling water.

Figures 5 and 6 show the equilibrium curve, operating line, stages, and feed quality for V-1503 using a pseudo binary analysis on both linear and reverse log axes. The two design specifications for the column are: 1) The mole fraction of n-pentyl acetate in the bottoms product is 0.04, and 2) the TBA content of the overhead product is set at 100 ppm mole. The figures show no excessive pinching, reasonable feed location, and that the majority of stages are used to meet the TBA specification for the overhead product.

The bottoms product from V-1503 is cooled and recycled for use as TBA in the acidification step. The overhead product is a mixture of n-pentyl acetate along with the excess n-pentanol. The mole fraction of n-pentyl acetate in the overhead product is only 0.1956. While one could, in principle, add another column to separate n-pentyl acetate and n-pentanol, this separation is difficult and it is more efficient to just feed the downstream hydrogenolysis step with a dilute feed.

Water Management – The aqueous raffinate and esterification water streams are mixed with a small amount of lime to decompose any residual TBA:HAc complex according to the equation:

$$TBA : HAc + 0.5Ca(OH)_2 \rightarrow TBA + 0.5Ca(Ac)_2 + H_2O$$

The aqueous stream, which contains dissolved n-pentyl acetate, n-pentanol, and TBA, is fed to V-1600 Water Stripper to remove these contaminants. Figure 7 shows the equilibrium line, operating line, stages, and feed quality for V-1600 using a pseudo binary analysis. The single design specification for the column is the n-pentanol content of the bottoms product is set at 50 ppm mass.

Upon cooling and condensation, the overhead product from V-1600 phase splits. The organic phase is recycled for use as solvent in the extraction step. A portion of the aqueous phase is recycled back to the feed tank, and the rest is taken as a water stream that exported from the plant. It is unrealistic to expect all of the overhead water could be recycled back to the feed tank since light water soluble components such as ammonia and ethanol would build-up to excessive levels.

The stripped water bottoms product from V-1600 is stored and then either used as backset, wash water for the filter cake in the acidification step, or feed for a second reverse osmosis step. This second reverse osmosis step concentrates the solubles to ~42 g/l, so that when combined with the cell mass the total solids content of the steep water return stream is 6 wt% (i.e. the same as the solids content of the light steep water feed stream). The permeate water is fairly clean and could be used either as fermentation water, make-up water for the steam or cooling water system, or discharged from the plant.

Hydrogenolysis

In the hydrogenolysis unit, the ester is mixed with a large excess of hydrogen, vaporized and superheated, then fed to a packed bed reactor to carry out the reaction:

$$nC_5Ac + 2H_2 \leftrightarrow nC_5OH + EtOH$$

Our analysis of the results cited in (15) suggests that this reaction can be adequately modeled as an equilibrium reaction when a reduced CuO/ZnO catalyst is used. At 20:1 molar ratio of hydrogen to n-pentyl acetate, 200 °C, and 190 psia, a conversion of over 98% of theoretical will occur with a space velocity of 0.43 hr^{-1} based on liquid n-pentyl acetate feed. The reaction is exothermic. Some of the heat recovered from the reactor effluent is used to drive the reboiler of the downstream fractionation column; the rest is used to preheat the reactor feed.

The excess hydrogen is disengaged from the crude reaction product in V-1701 HP KO Drum. It is the compressed with a centrifugal compressor (C-1700) and recycled. It is unusual to use a centrifugal compressor in a service with a hydrogen rich stream, however in this case the head requirement is low enough (~50,000 ft lb_f/lb_m) that a single case centrifugal can be used. From a maintenance point of view, a centrifugal is usually preferred since they have much lower vibration than a reciprocating compressor, and thus have longer periods of operation between scheduled maintenance shutdowns.

The liquid from V-1701 HP KO Drum is then flashed to near ambient pressure across VLV-101 and fed to V-1702 LP KO Drum. The additional vapor formed is cooled in E-1705 LP KO Drum Knockback Condenser to recover additional ethanol from the vapor. Both E-1705 and E-1708 (discussed later) are cooled against a closed loop propane refrigerant cycle.

The liquid from V-1702 LP KO Drum is then flashed an fed to V-1703 Ethanol Splitter. V-1703 operates at 175 mm Hg abs with an overhead temperature of 110 °F and a bottoms temperature of 220 °F. Figures 8 and 9 show the equilibrium curve, operating lines, stages, and feed quality for V-1703 using a pseudo binary analysis on both linear and log axes. The three design specifications for V-1703 are: 1) the mole fraction of ethanol in the overhead liquid product is set at 0.98, 2) the mole fraction of n-pentanol in the bottoms product is set at 0.96, and 3) the temperature of the reflux drum is set at 110 °F. The overhead condenser is actually a partial condenser since there is a small amount of dissolved hydrogen in the column feed. The overhead vapor is cooled further in the knockback condenser E-1708 to recover additional ethanol.

The overhead liquid product from V-1703 is ready for denaturing without further treatment. Notice that the water content of the stream is actually set way back at the esterification step. The bottoms production from V-1703 is recycled for use as solvent in the extraction step.

Denaturing

The blending recipe is taken from (16) and is typical for a fuel grade ethanol product. 100 parts by volume of neat ethanol are blended with 5 parts by volume natural gasoline to denature the product. 20 pounds of corrosion inhibitors per thousand barrels of ethanol (PTBE) are also added, and the denatured product is filtered (F-1800) before load out.

Gasification and H_2 Recovery

An indirectly heated biomass gasifier with char combustor and tar reforming capabilities was selected for the base case. Corn stover, with the properties listed in Table 6, was assumed as the feed. The design of the Gasification and H2 Recovery section is similar to that given in the goal case of reference (17). This type of indirectly heated gasifier is currently being licensed by Future Energy Resources Corporation. Capital costs for the Feed Handling, Gasification, and Conditioning areas were scaled from reference (17), so the simulation in these areas is only detailed enough to estimate operating costs and conditioned gas flow rate and composition.

Feed Handling – Minimal handling was assumed since the feedstock is already dry. Tramp metal is removed by magnets, the material is shredded, and then feed downstream to the gasifier. No washing or other processing is assumed

Gasification – The stover is fed to V-2100 Gasifier along with some low pressure steam for fluidization and moderation, plus hot sand recycled from V-2101 Combustor to heat the stover and steam feeds. The gasifier is an entrained bed operating at 23 psia and 1444 °F. The raw gas is disengaged from the circulating sand and char by a series of cyclones (X-2100, X-2101). The circulating sand and char, along with make-up sand and magnesium oxide (used to sequester potassium in the feed) are fed to the combustor (V-2101) where the char is burned in a bubbling bed and the sand temperature is raised to 1849 °F. The circulating sand is disengaged from the combustion offgas and fly ash in X-2103 Combustor Primary Cyclone and returned to V-2100 Gasifier.

Fly ash is disengaged from the combustor offgas by V-2104 Combustor Secondary Cyclone and X-2105 Electrostatic Precipitator. It is cooled, conditioned with small amount of water to control dustiness, and then disposed.

The cleaned combustor offgas is then expanded to near ambient pressure to recover power, and then heat is recovered in E-2101 by raising steam.

Conditioning – The raw gas contains quite a bit of methane and other light hydrocarbons plus heavier tars. These are converted into additional syngas in V-2200 Tar Reformer. Heat for the endothermic reforming reactions is supplied by burning tail gas from the downstream PSA unit plus a small amount of cleaned syngas. Additional power and heat are recovered from the regenerator offgas.

The reformed syngas is cooled to near ambient temperature, the water condensed and knocked out, and then the conditioned gas is sent downstream for compression. The water knockout contains some solids and low levels of dissolved species such as ammonia, tars, etc. The solids are removed from the water by sedimentation in X-2200 Clarifier and pumped out for disposal. Likewise, the water overflow from X-2200 is exported.

Compression – The conditioned gas is fed to a multi-case compressor with four interstage cooling circuits plus aftercoolers where it is compressed to an outlet pressure of 285 psia. Most of the heat of compression is ejected directly to the atmosphere by air fin coolers. Interstage temperatures are limited to 300 °F to prevent thermal degradation of the lubricating oils and maintain high compressor efficiency. Polytropic efficiency was assumed to be 85%, consistent with the improvements in machine efficiency cited in (18) over the past two decades. Water knocked out during compression is exported.

Bulk Desulfurization – Most of the sulfur in the incoming stover is converted to H_2S in the gasifier, and then passes through conditioning and compression with the syngas. A LO-CAT II (19,20) skid unit is used to remove the bulk of the H_2S and convert it to elemental sulfur. This unit uses a proprietary aqueous chelated iron solution to remove H2S from the gas stream and then uses air to produce an elemental sulfur product plus a regenerated iron solution. For purposes of the economic analysis, the elemental sulfur product is assumed to be stockpiled (i.e. neither a disposal cost nor revenue stream is associated with the material).

H2 Recovery – Some of the syngas is used for fuel (either for the tar reformer regenerator or the gas turbine); the rest is used for hydrogen production and recovery to supply hydrogen for the hydrogenolysis step. Syngas sent to H2 recovery is preheated to 375 °C, passed over zinc oxide bed to remove the trace levels of H2S that remain after bulk desulfurization, the steam is added and the gas undergoes high temperature and low temperature shift to produce more hydrogen from the carbon monoxide in the syngas according to the equation:

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

After shift, the gas is cooled to 110 F, the water knocked out, and high purity (99.999 %) hydrogen is recovered by pressure swing adsorption (PSA). The low pressure PSA Offgas is used as fuel in the regenerator for the tar reformer. The high pressure hydrogen product is sent downstream as make-up hydrogen for the hydrogenolysis step.

Cogeneration

The cogeneration unit consists of a gas turbine topping cycle with heat recovery, plus a non-condensing bottoming cycle steam system that produces both power and process steam requirements.

Gas Turbine - High pressure, low sulfur syngas is combusted in a gas turbine to produce power. The gas turbine is assumed to operate at a pressure ratio of 15, and the turbine inlet air rate is set to limit the gas temperature at the inlet expander to 2420 °F. The exhaust leaves the turbine at 1172 °F. The philosophy behind the utility system design is to maximize power production with the limitation being that non-condensing turbine is used in the steam system with all of the extracted steam being used to meet process needs. Since the utility system design is limited by the amount of steam needed by the process, an unfired heat recovery steam generator (HRSG) is used for the gas turbine.

Steam System – A high pressure steam bottoming cycle is used to produce additional power and meet the process steam needs. Make-up boiler feed water is de-ionized by ion exchange, preheated, combined with condensate returns and then degasified. Boiler feedwater chemicals (e.g. hydrazine for oxygen scavenging, filming amines for acid gas induced corrosion protection, etc.) are added to the degasifier, then the boiler feed water is pump to pressure and converted to steam. A 2% blowdown from V-3101 HP Steam Drum is assumed. The saturated steam is superheated so that the turbine inlet conditions are 1250 psig at 1000 °F, the highest values proposed by a joint ASME-IEEE committee charged with standardizing steam turbine design conditions (8).

X-3100 is a non-condensing turbine with extraction at 300 psig to provide medium pressure steam for process needs. The turbine exhausts at 50 psig; the exhaust steam is used for low pressure process steam needs. The shift steam and gasifier steam are both exported without desuperheating; the medium pressure and low pressure steam for all other process steam needs are desuperheated before process use. Some low pressure process steam is also generated by let-down of the medium pressure condensate.

Cooling Water

A standard cooling water system consisting of a tower, circulation pumps, make-up and blowdown systems, and chemical injection for biological growth and corrosion control is used. Table 7 displays the design conditions for the system. The air properties in Table 1 were also used for all fired heater and air cooled exchanger applications in the model.

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Table 1
Data Sources for Non-Library Components

Component	Heat of Formation or Heating of Combustion	Heat Capacity
Dextrose	Ref. (1), Table 3.7	Ref. (2), p. 114
Fructose	Ref. (1), Table 3.7	Ref. (2), p. 114
Galactose	Ref. (1), Table 3.7	Ref. (2), p. 114
Arabinose	Ref. (2), p. 163	From structure
Xylose	Ref. (2), p. 163	From structure
Maltose	Ref. (3), p. 114	Ref. (3), p. 114
Isomaltose	Ref. (3), p. 114	Ref. (3), p. 114
Gluc_Olig	Ref. (2), p. 250	From structure
N-Soluble	Ref. (1), Table 3.7	From structure
Cell_Mass	Ref. (1), Table 3.7	From structure
Phytate	From structure	From structure
TBA:HAc	Ref. (4), Table III	From structure
Ca(Ac)2	Ref. (5)	From structure
CaCO3	Ref. (6), Appendix B	Ref. (7), p. 20
Ca(OH)2	Ref. (6), Appendix B	Ref. (7), p. 207
Ash_Soluble (as CaO)	Ref. (6), Appendix B	Ref. (7), p. 119
Sand	Ref. (6), Appendix B	Ref. (8)., p. 2-186
Stover	Ref. (9), Boie Correlation	Ref. (9), IA.30.6 p. 3
Char-C	Ref. (9), Boie Correlation	Ref. (9), IA.30.6 p. 3
Char-H	Ref. (9), Boie Correlation	Ref. (9), IA.30.6 p. 3
Char-N	Ref. (9), Boie Correlation	Ref. (9), IA.30.6 p. 3
Char-S	Ref. (9), Boie Correlation	Ref. (9), IA.30.6 p. 3
Char-O	Ref. (9), Boie Correlation	Ref. (9), IA.30.6 p. 3
Char-Ash	Ref. (9), Boie Correlation	Ref. (7), p. 119

Table 2
Equilibrium Model Summary

Equilibrium Model	Subflowsheet Areas	Basis for Interaction Parameters
UNIQUAC Activity Coefficients w/ Ideal Gas	Main, Fermentation+Recovery, Feed Prep, Fermentation, Pre-Concentration, Acidification, Lime Scrubber, Filtration, Esterification+Fractionation (non-LLE areas), Water Management (non-LLE areas), Reverse Osmosis	HYSYS defaults or estimated from structure. Cross checked HYSYS predicted VLE against published data for following binaries: H2O-nC5OH, nC5OH-nC5Ac. Checked HYSYS predicted VLE “reasonableness” for following binaries: H2O-nC5Ac, H2O-TBA,nC5Ac-TBA, nC5OH-TBA
NRTL Activity Coefficients w/ Ideal Gas	Extraction, Esterification+Fractionation (LLE areas), Water Management (LLE areas)	Fitted experimental data for: H2O-TBA:HAc-nC5OH ternary, H2O-nC5OH binary; Otherwise used HYSYS defaults or estimated from structure. Check HYSYS predicted LLE “reasonableness” for following binaries: H2O-nC5Ac, H2O-TBA
Peng-Robinson	Refrigeration, Cogeneration, Gas Turbine, Cooling Water	HYSYS Defaults
Sour Peng-Robinson (Uses Wilson’s API Sour Water method to account for aqueous phase ionization of H2S, CO2, and NH3)	Gasification+H2 Recovery, Feed Handling, Gasification, Conditioning, Compression, Bulk Desulfurization, H2 Recovery, ZnO Beds, PSA	HYSYS Defaults
Peng-Robison Stryjek-Vera	Hydrogenolysis, Denaturing	HYSYS Defaults
ASME Steam Tables	Steam System	Not Applicable

Table 3 - Overall Material and Energy Balance
(Excludes Steam Generation Cross Exchanges)
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11/5/04 7:34 PM

In

Stream	Mass Flow, lb/hr	Enthalpy, Btu/hr
BFW Chemicals @STEM	5	-35,930
CO2 @FREC	634	-2,440,216
Combustor Air @GH2R	548,631	-61,228,508
CW Chemicals @CW	5	-33,604
Desulfurization Air @GH2R	529	-59,037
Dry Air @CW	24,605,243	539,722,117
Ester @HYDR	829,522	-1,420,113,394
Fermentation Water @FREC	964,129	-6,571,709,473
Fresh CaCO3 @FREC	-129	669,442
Fresh Solvent @FREC	162	-280,743
Fresh TBA @FREC	33	-21,772
Fresh Water @Main	1,128,875	-7,690,780,515
Gasifier Steam @GH2R	103,782	-584,453,358
Humidity @CW	491,420	-3,340,567,546
Hydrogen @HYDR	6,767	752,999
Inert Gas @FREC	24	-103
Inhibitors @DENA	5	-14,239
Light Steep Water @FREC	349,708	-2,272,679,400
Lime @FREC	2,130	-12,229,756
Make-Up BFW @COGN	164,746	-1,125,002,385
Make-Up CW @CW	607,900	-4,103,710,629
Make-Up Sand @GH2R	2,995	-18,244,264
MgO @GH2R	197	-1,198,991
Minerals @FREC	1,032	-1,635,191
Natural Gasoline @DENA	3,209	-3,180,099
Neat EtOH @DENA	76,065	-198,519,039
Recycle Pentanol @FREC	760,146	-1,298,000,546
Reductant @FREC	187	-296,533
Regen Air @GH2R	205,477	-22,931,697
Regen Offgas @GH2R	331,755	-718,575,948
Shift Steam @GH2R	45,915	-252,614,543
Starch Hydrolyzate @FREC	368,335	-2,060,504,984
Steam Blowdown @COGN	15,055	-101,980,088
Stover @GH2R	306,774	-1,009,794,101
Syngas to Turbine @COGN	114,546	-295,038,244
Turbine Air @COGN	1,333,583	-148,830,966
1340 @ACID	2,132,875	-237,567,797
1542 @ESTR	6,053,787	-674,294,120
1641 @WATR	3,179,678	-354,164,843
2205 @COND	312,242	-1,062,686,329
2329 @COMP	7,826,432	-873,453,663
2507 @H2RE	128,840	-473,563,578
2510 @H2RE	128,840	-489,091,783
2519 @H2RE	2,184,742	-243,823,873
3016 @GAST	1,448,130	-1,047,570,176
3100 @STEM	164,746	-1,123,365,012
3117 @STEM	15,055	-100,505,531
HP.C-1300 @ACID	-	13,679,870
HP.C-1301 @ACID	-	4,935,472
HP.C-1700 @HYDR	-	5,789,675
HP.C-1701 @HYDR	-	11,414
HP.C-1702 @REFR	-	886,736
HP.C-2100 @GASI	-	11,883,843
HP.C-2200 @COND	-	3,492,301
HP.C-2300a @COMP	-	13,736,182
HP.C-2300b @COMP	-	13,736,182
HP.C-2300c @COMP	-	13,736,182
HP.C-2300d @COMP	-	13,736,182
HP.C-2300e @COMP	-	13,736,182
HP.C-3000 @GAST	-	230,516,350
HP.P-1000 @FEED	-	47,578
HP.P-1001 @FEED	-	1,131
HP.P-1002 @FEED	-	205
HP.P-1003 @FEED	-	111,411
HP.P-1004 @FEED	-	79,822
HP.P-1005 @FEED	-	26,809
HP.P-1100 @FERM	-	16,220
HP.P-1201 @PREC	-	30,766
HP.P-1300 @ACID	-	36,743
HP.P-1400 @EXTR	-	66,617
HP.P-1401 @EXTR	-	51,537
HP.P-1500 @ESTR	-	318,049
HP.P-1501 @ESTR	-	5,408
HP.P-1502 @ESTR	-	98,319
HP.P-1503 @ESTR	-	66,608
HP.P-1600 @WATR	-	174,132
HP.P-1601 @WATR	-	142,825
HP.P-1602 @RO2	-	11,456
HP.P-1603 @WATR	-	665
HP.P-1700 @HYDR	-	809,229
HP.P-1701 @HYDR	-	8,284
HP.P-1702 @HYDR	-	122,874
HP.P-1800 @DENA	-	3,886
HP.P-1801 @DENA	-	188
HP.P-1802 @DENA	-	0
HP.P-1803 @DENA	-	6,107
HP.P-2200 @COND	-	1,800
HP.P-2201 @COND	-	47
HP.P-2300 @COMP	-	1,321
HP.P-3100 @STEM	-	45,631
HP.P-3101 @STEM	-	15,336
HP.P-3102 @STEM	-	4,112,546
HP.P-4000 @CW	-	5,823,092
HP.X-2100 @GASI	-	9,902
HP.X-4000 @CW	-	6,713,448
Q.E-3100 @STEM	-	39,374,189
Q.E-3101 @STEM	-	2,082,965
Q.E-3102 @STEM	-	233,466,068
Q.E-3103 @STEM	-	441,523,837
Q.E-3104 @STEM	-	233,326,567
Q.T-1100a @FERM	-	3,575,006
Q.T-1100b @FERM	-	-3,575,005
Q.V-1302 @ACID	-	79
Q.V-1303 @SCRB	-	0
Q.V-1700 @HYDR	-	-16
Q.V-2100 @GASI	-	0
Q.V-2101a @GASI	-	47
Q.V-2101b @GASI	-	0
Q.V-2202 @COND	-	-5,541,971
Q.V-2500 @ZNO	-	-49
Q.V-2501 @H2RE	-	-6
Q.V-2502 @H2RE	-	2
Q.X-1300 @FILT	-	0
Q.X-2103 @GASI	-	0
Q.X-2105 @GASI	-	-1,245
Q.X-2200 @COND	-	0
Q.X-2400a @DESU	-	10,409
Q.X-2400b @DESU	-	55,360
Q.X-2400c @DESU	-	1,194
Q.X-2500 @PSA	-	243,210
Q.X-3100 @COGN	-	0
QC.X-2400 @CW	-	55,055
Q.NonClosure @CW	-	449
Total	56,944,762	-38,152,215,275

Out

Stream	Mass Flow, lb/hr	Enthalpy, Btu/hr
Adsorbed Sulfur @GH2R	2	-165
Ash @GH2R	20,883	-109,117,724
Bulk Sulfur @GH2R	219	814,148
Compression KO Water @GH2	46,895	-314,844,327
CW Blowdown @CW	111,739	-759,588,163
Degasifier Vent @COGN	0	0
Denatured EtOH @DENA	79,280	-201,703,195
Desulfurization Offgas @GH2	434	-140,421
Ester @FREC	829,522	-1,416,470,805
Ferm+Rec Vents @FREC	26	-8,220
Fermentation Water @Main	964,129	-6,568,399,572
Gasifier Steam @STEM	103,782	-584,944,420
Hydrogen @GH2R	6,767	751,908
Hydrogenolysis Vents @HYDI	81	-20,397
Make-Up BFW @Main	164,746	-1,122,380,943
Neat EtOH @HYDR	76,065	-198,519,039
Net Conditioning Water @GH2	36,070	-243,856,009
Recycle Pentanol-rec @HYDI	760,146	-1,307,950,414
Regen Offgas @GH2R	331,755	-718,575,948
RO Permeates @FREC	1,049,252	-7,071,526,335
Shift KO Water @GH2R	24,749	-167,334,688
Shift Steam @STEM	45,915	-252,688,206
Solids @GH2R	628	-3,977,845
Stack Gas @COGN	1,448,130	-1,047,570,176
Steam Blowdown @COGN	15,055	-101,980,088
Steam Blowdown @STEM	15,055	-101,856,080
Steep Water Return @FREC	563,547	-3,650,299,339
Stripper OVHD Water @FRE	4,031	-26,625,345
Syngas to Turbine @GH2R	114,546	-295,038,244
Tower Exhaust @CW	25,592,830	-5,625,656,064
1341 @ACID	2,132,875	-206,207,859
1547 @ESTR	6,053,787	-585,284,490
1646 @WATR	3,179,678	-307,413,610
2130 @GASI	631,339	-612,866,948
2204 @COND	312,242	-867,310,848
2221 @COND	331,755	-593,349,800
2340 @COMP	7,826,432	-758,139,866
2506 @H2RE	128,840	-466,212,588
2508 @H2RE	128,840	-473,563,576
2520 @H2RE	2,184,742	-211,634,121
3015 @GAST	1,448,130	-681,106,407
3100 @COGN	164,746	-1,125,002,385
3116 @STEM	15,055	-94,302,885
HP.X-2108 @GASI	-	29,022,194
HP.X-2202 @COND	-	11,447,724
HP.X-3000a @GAST	-	400,239,752
HP.X-3000b @GAST	-	67,514,624
HP.X-3100a @STEM	-	113,856,707
HP.X-3100b @STEM	-	19,704,000
Q.E-3107 @STEM	-	76,151,419
Q.E-3108 @STEM	-	1,773,783
Total	56,944,741	-38,152,191,295

Closure

Balance	Absolute Difference	Difference
Mass	-20.64	-0.000036%
Enthalpy	23,979.34	-0.000063%

Table 4
Model Composition for
Starch Hydrolyzate and Light Steep Water

Starch Hydrolyzate

Dry Solids, wt% 30

Component	Wt% (Dry Basis)
Dextrose	96.0
Maltose	1.0
Isomaltose	1.2
Higher Oligomers	1.8
Total	100

Light Steep Water

Dry Solids, wt% 6

Component	Wt% (Dry Basis)
N-Soluble	37.8
Lactate (as Acid)	26.0
Ammonia	4.2
Phytate	7.8
Dextrose	4.9
Fructose	3.64
Galactose	3.5
Arabinose	1.68
Xylose	0.28
Ash	10.2
Total	100

Table 5
Amino Acid Catabolism, Cell Synthesis and Acetate Production Reactions

Amino Acid Catabolism:

$$C_6H_{13}O_2N + 1.5CO_2 + 2.5H_2O \rightarrow NH_3 + 1.25C_6H_{12}O_6$$

Cell Synthesis:

Six Carbon Sugars

$$C_6H_{12}O_6 + \tfrac{0.2}{0.175}NH_3 \rightarrow \tfrac{1}{0.175}CH_{1.8}O_{0.5}N_{0.2} + \tfrac{0.05}{0.175}CO_2 + \tfrac{0.45}{0.175}H_2O$$

Five Carbon Sugars

$$C_5H_{10}O_5 + \tfrac{0.2}{0.21}NH_3 \rightarrow \tfrac{1}{0.21}CH_{1.8}O_{0.5}N_{0.2} + \tfrac{0.05}{0.21}CO_2 + \tfrac{0.45}{0.21}H_2O$$

Dimer Sugars

$$C_{12}H_{22}O_{11} + \tfrac{0.2}{0.0875}NH_3 \rightarrow \tfrac{1}{0.0875}CH_{1.8}O_{0.5}N_{0.2} + \tfrac{0.05}{0.0875}CO_2 + \tfrac{0.3625}{0.0875}H_2O$$

Lactate (as Acid)

$$C_3H_6O_3 + \tfrac{0.2}{0.35}NH_3 \rightarrow \tfrac{1}{0.35}CH_{1.8}O_{0.5}N_{0.2} + \tfrac{0.05}{0.35}CO_2 + \tfrac{0.45}{0.35}H_2O$$

Acetate Production:

Six Carbon Sugars

$$C_6H_{12}O_6 + 1.5CaCO_3 \rightarrow 1.5Ca(Ac)_2 + 1.5CO_2 + 1.5H_2O$$

Five Carbon Sugars

$$C_5H_{10}O_5 + 1.25CaCO_3 \rightarrow 1.25Ca(Ac)_2 + 1.25CO_2 + 1.25H_2O$$

Dimer Sugars

$$C_{12}H_{22}O_{11} + 3CaCO_3 \rightarrow 3Ca(Ac)_2 + 3CO_2 + 2H_2O$$

Lactate (as Acid)

$$C_3H_6O_3 + 0.75CaCO_3 \rightarrow 0.75Ca(Ac)_2 + 0.75CO_2 + 0.75H_2O$$

Table 6
Model Composition for Stover

Ultimate Analysis:

		Wt %, (dry basis)
Carbon		44.00
Hydrogen		5.61
Nitrogen		0.62
Sulfur		0.09
Oxygen		43.58
Ash		6.10
	Total	100.00

Proximate Analysis:

		Wt %
Moisture		15.00
Fixed Carbon		21.55
Volatile Carbon		58.26
Ash		5.19
	Total	100.00

Table 7
Cooling Water System Design Basis

Cooling Water Specifications:		
	Supply Conditions	90 °F at 50 psig
	Return Conditions	110 °F at 45 psig
Ambient Air Conditions:		
	Pressure	1 Atm
	Dry Bulb Temperature	90 °F
	Wet Bulb Temperature	80 °F
	Composition	Mole Fraction
	Nitrogen	0.756556
	Oxygen	0.202943
	Argon	0.009049
	Carbon Dioxide	0.000339
	Water	0.031113
	Total	1.000000
Other:		
	Drift	0.2% of Water In
	Cycles of Concentration	5
	Chemical Usage	2.0E-07 lb/lb circulation
	Tower L/G	1.0

Figure 1 - Composite Curves for Steam Generation System

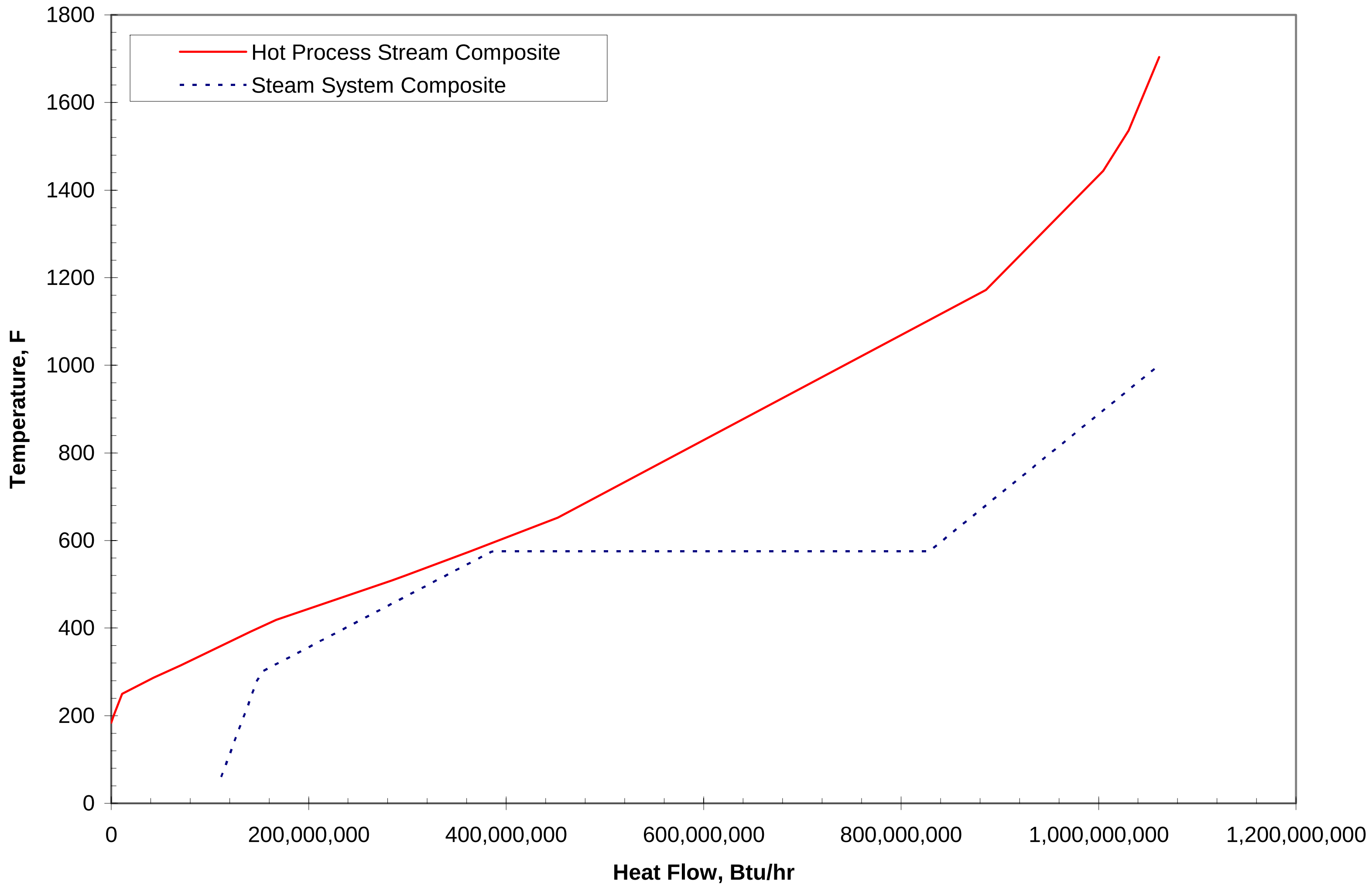


Figure 2 - Process Design for V-1400 Extractor

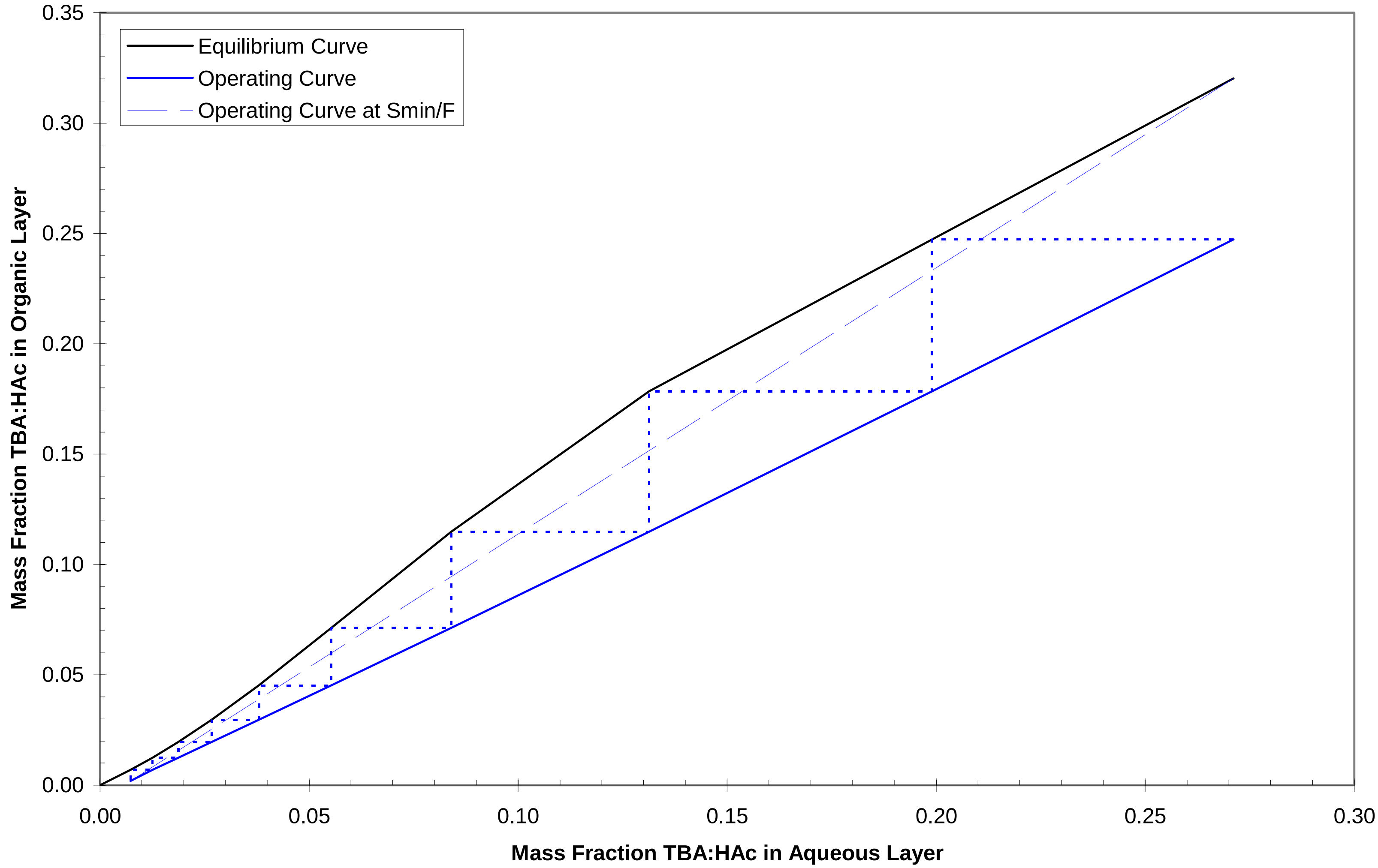


Figure 3 - Process Design for V-1500 Esterifier Column
(Pseudo Binary Analysis, Light Keys = H_2O and Lighter)

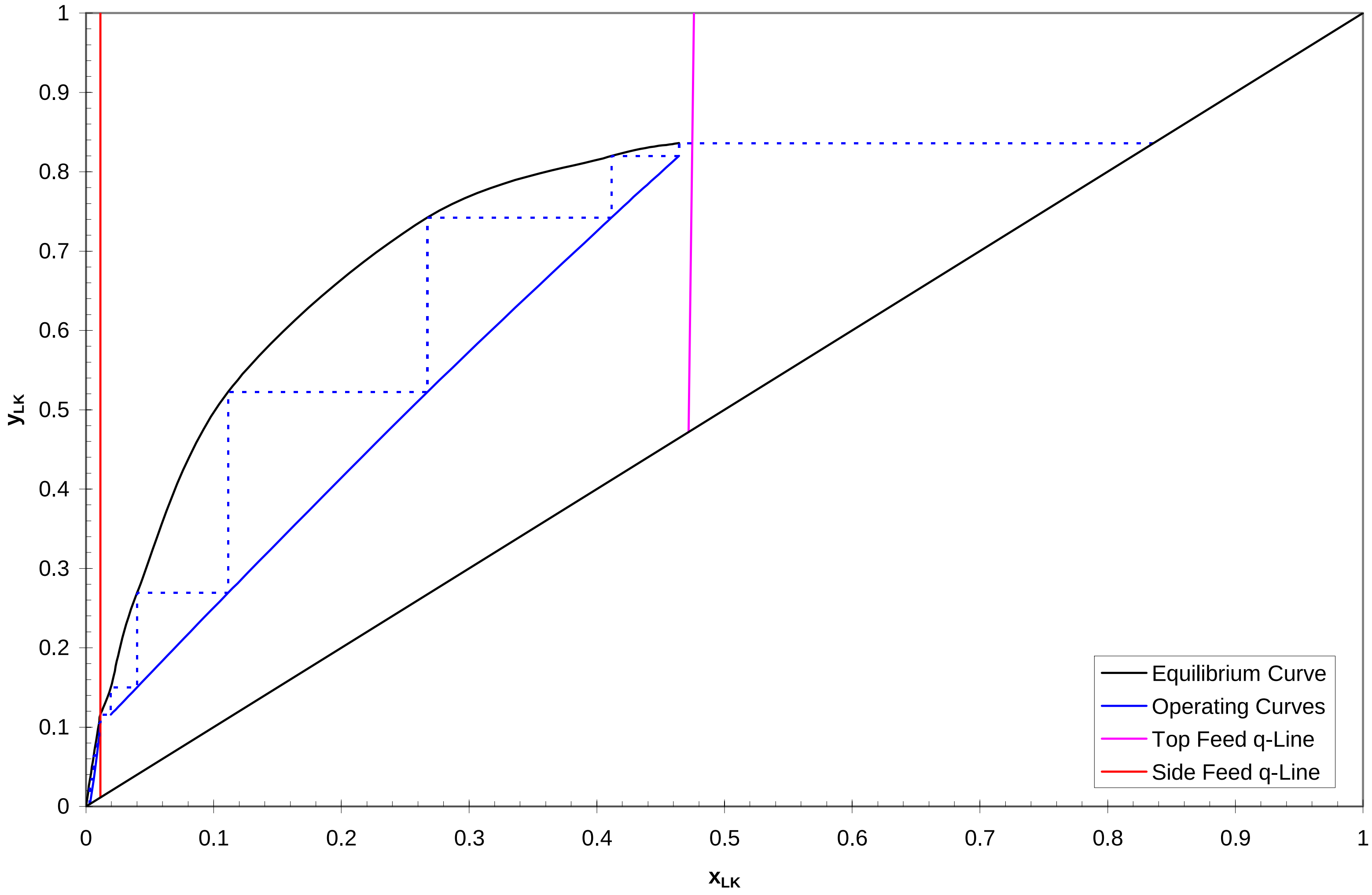


Figure 4 - Process Design for V-1500 Esterifier Column
(Pseudo Binary Analysis, Light Keys = H_2O and Lighter)

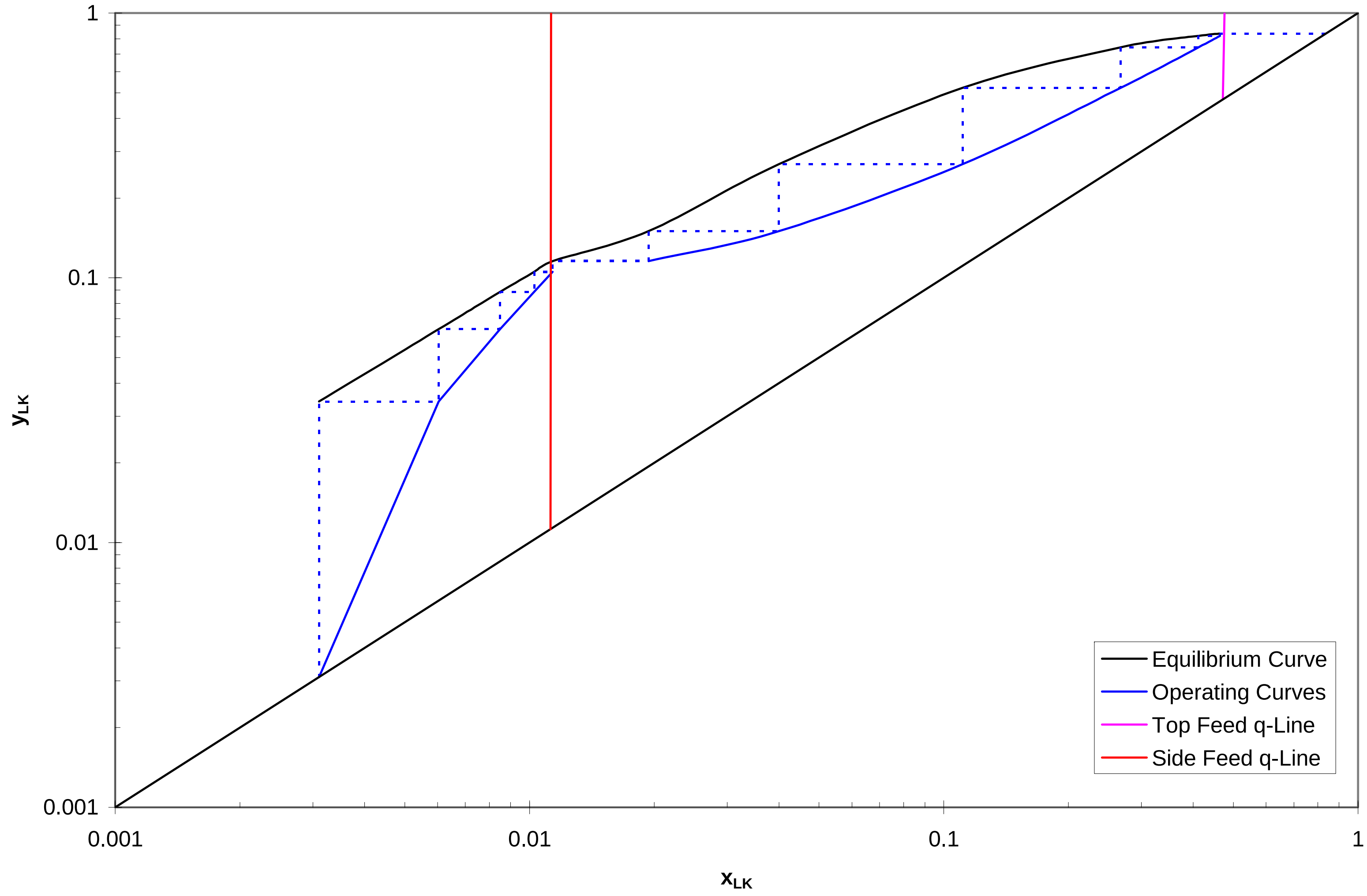


Figure 5 - Process Design for V-1503 TBA Splitter
(Pseudo Binary Analysis, Light Keys = nC_5Ac and lighter)

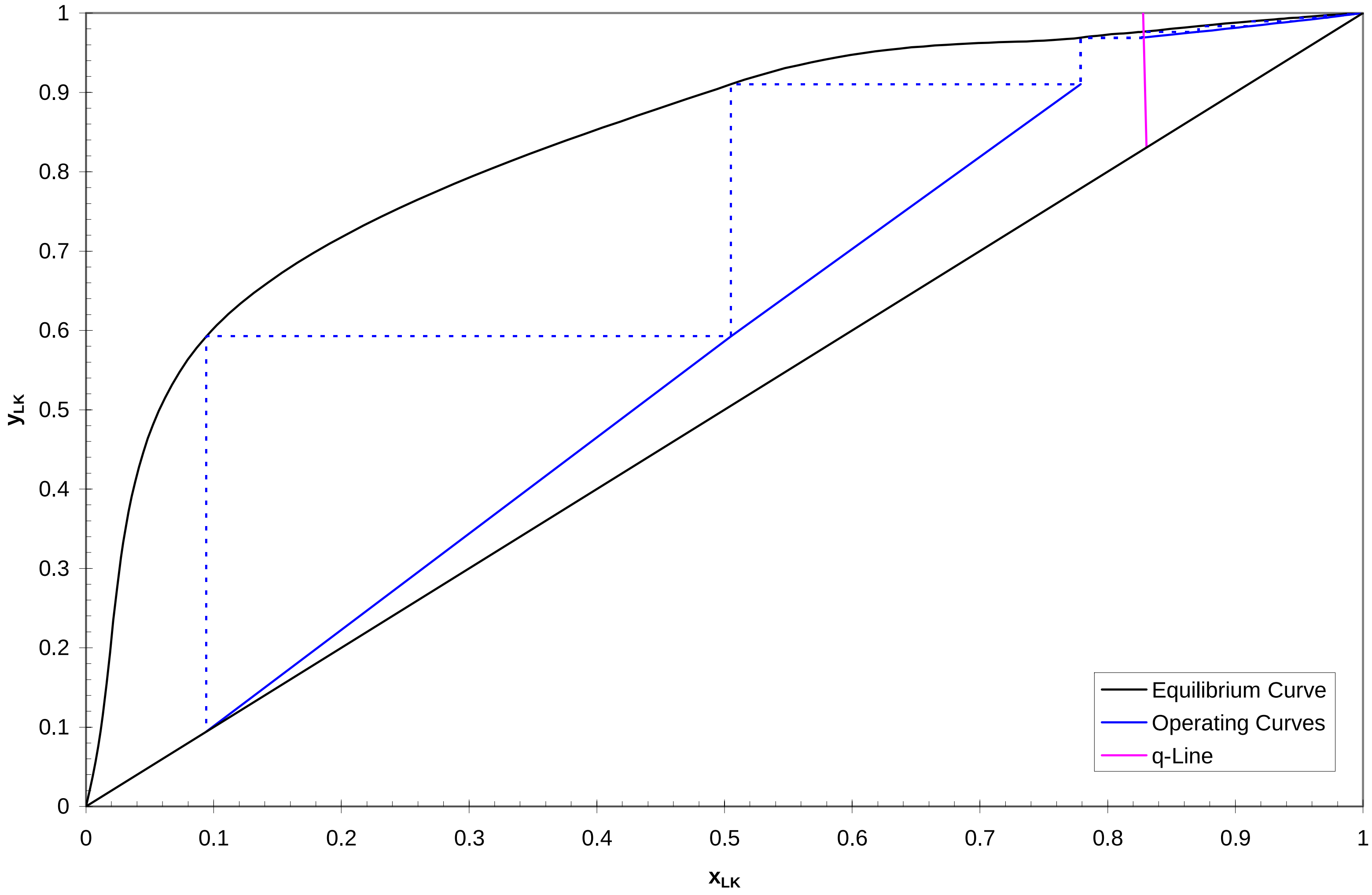


Figure 6 - Process Design for V-1503 TBA Splitter
(Pseudo Binary Analysis, Heavy Keys = TBA and heavier)

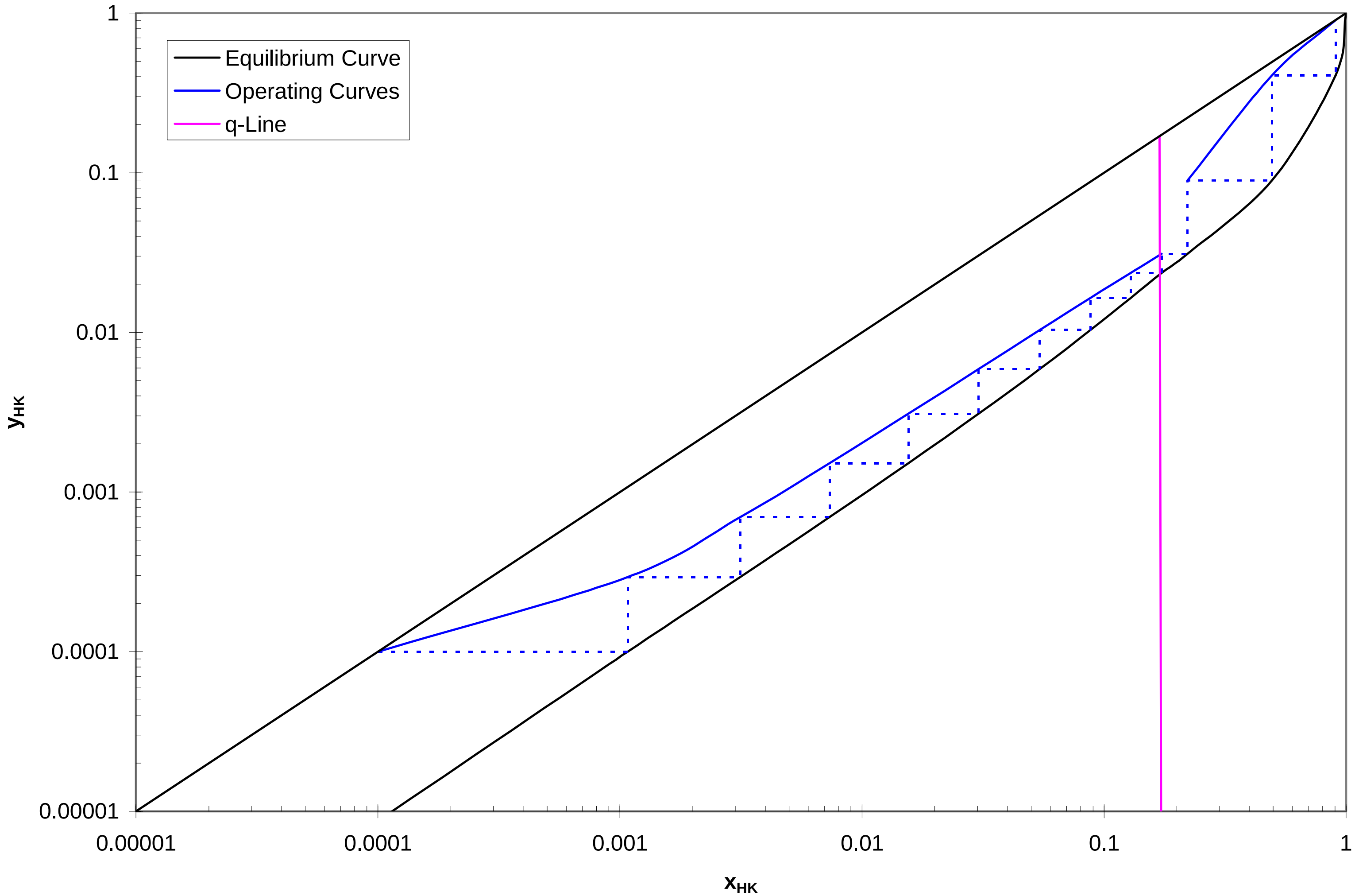


Figure 7 - Process Design for V-1600 Water Stripper
(Pseudo Binary Analysis, Light Keys = EtOH + nC_5AC + nC_5OH + TBA + Light Gases)

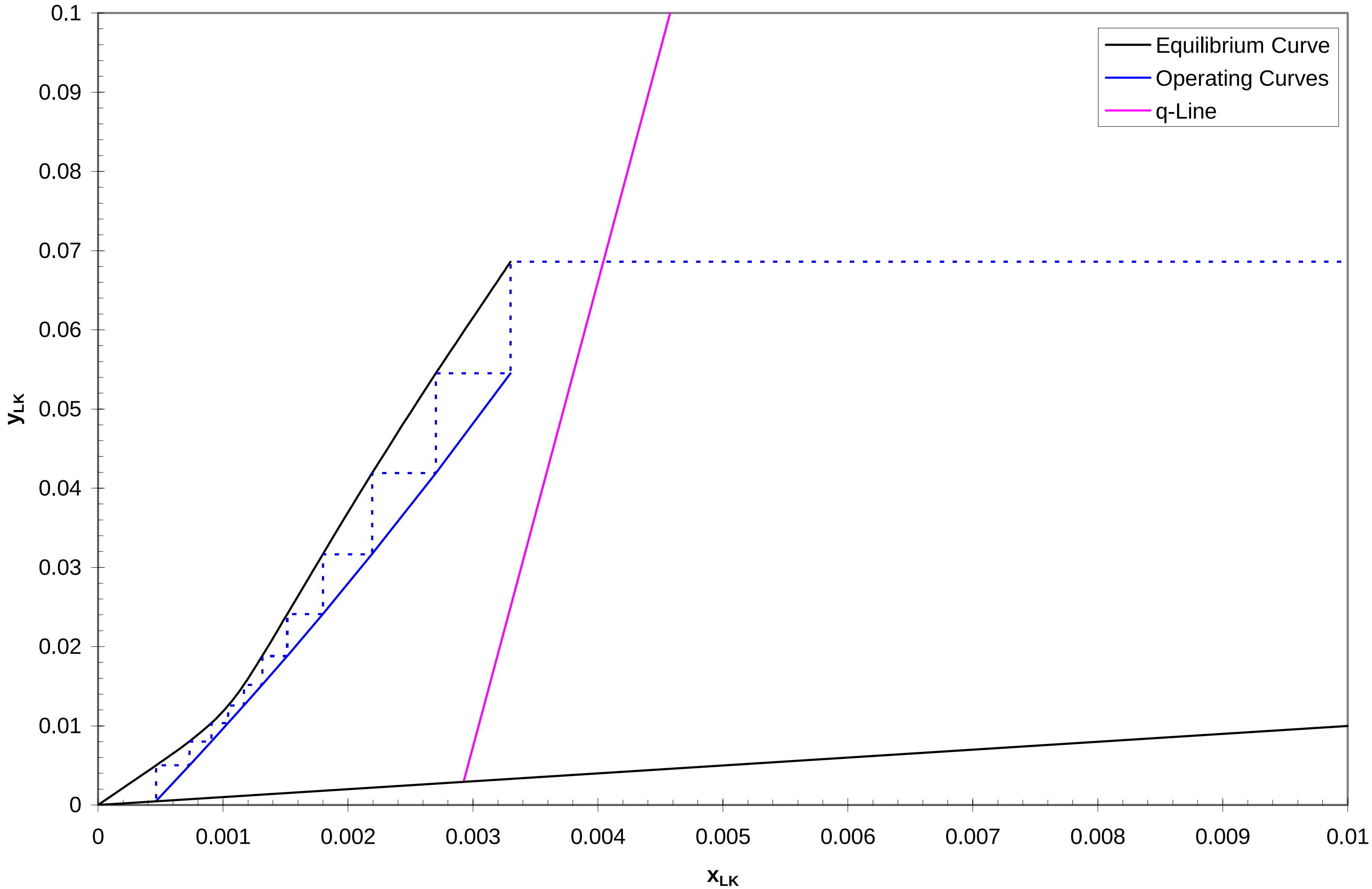


Figure 8 - Process Design for V-1703 Ethanol Splitter
(Pseudo Binary Analysis, Light Keys = H_2 + CO + H_2O + EtOH)

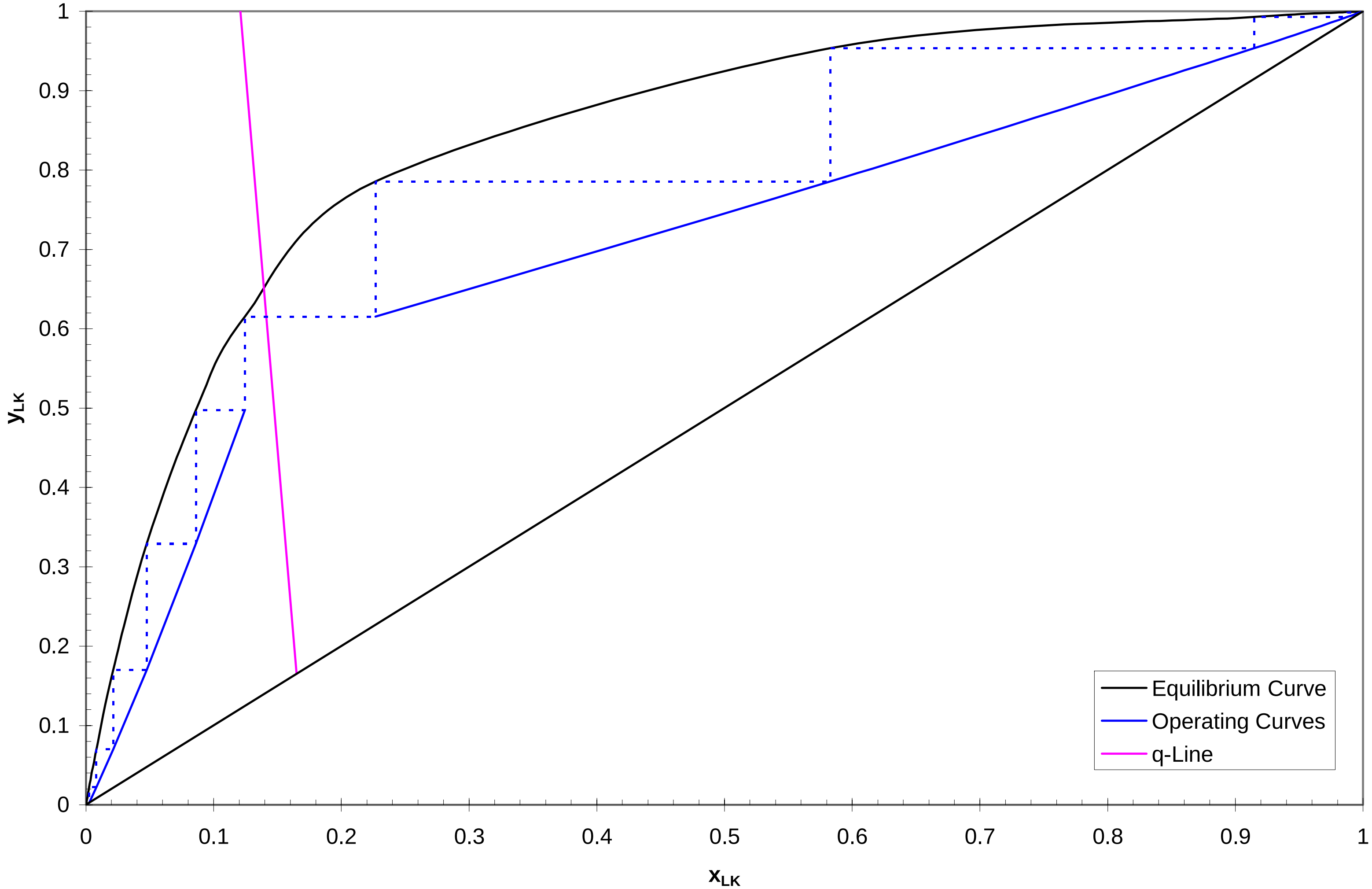
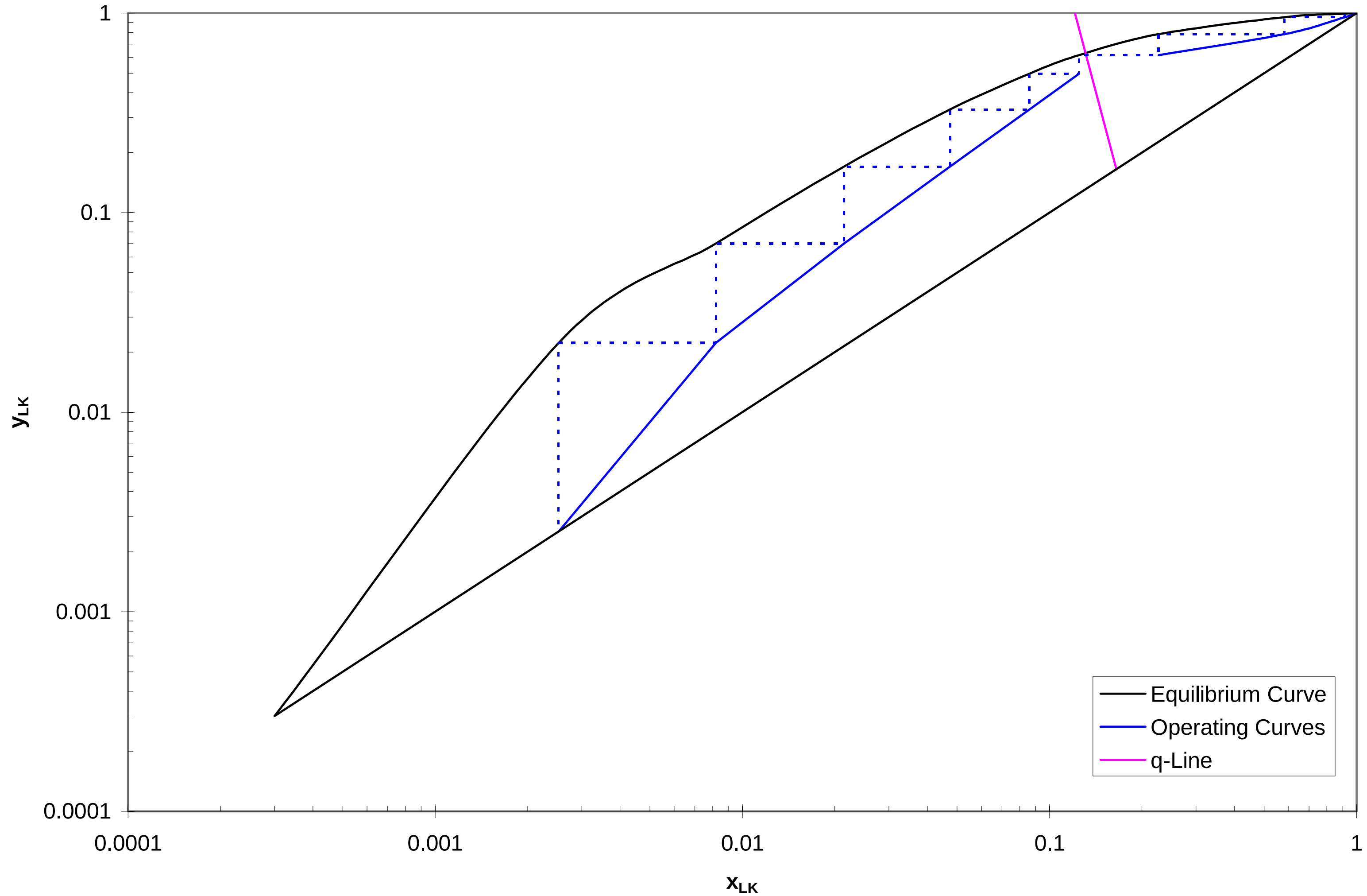
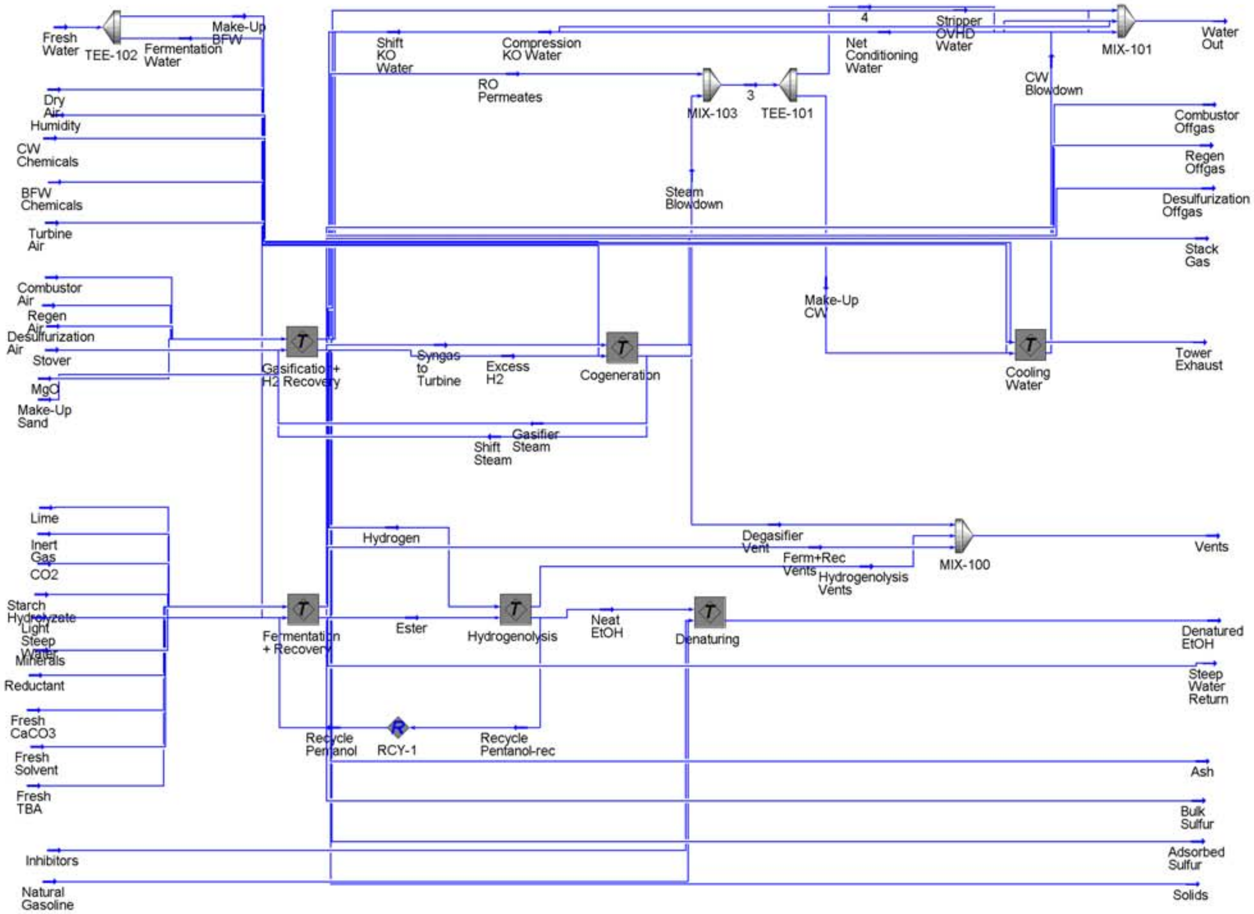


Figure 9 - Process Design for V-1703 Ethanol Splitter

(Pseudo Binary Analysis, Light Keys = H_2 + CO + H_2O + EtOH)





Power Balance	
Generation, kWe	118166
Consumption, kWe	55642
Net Export, kWe	62524

Power Balance

Efficiency Calcs	
Chem Energy Efficiency, %	66.85
EtOH Yield, % of Theoretical	84.01

Efficiency Calcs

Summary	
Starch Hydrolyzate, lb/hr (dry)	110500
Starch Hydrolyzate, bu/d Grind Equiv.	74286
Light Steep Water Import, lb/hr (dry)	20982
Light Steep Water Import, bu/d Grind Equiv.	162760
Light Steep Water Export, lb/hr (dry)	33813
Net Light Steep Water Production, lb/hr (dry)	12830
Stover, metric ton/d (dry)	2839
Stover, bu/d Grind Equivalent	224106
Denatured EtOH, MMgal/yr	100.0
Yield, gal(Neat)/bu Starch Hydrolyzate Grind Equiv	3.693

Summary

Flowsheet: Case (Main)

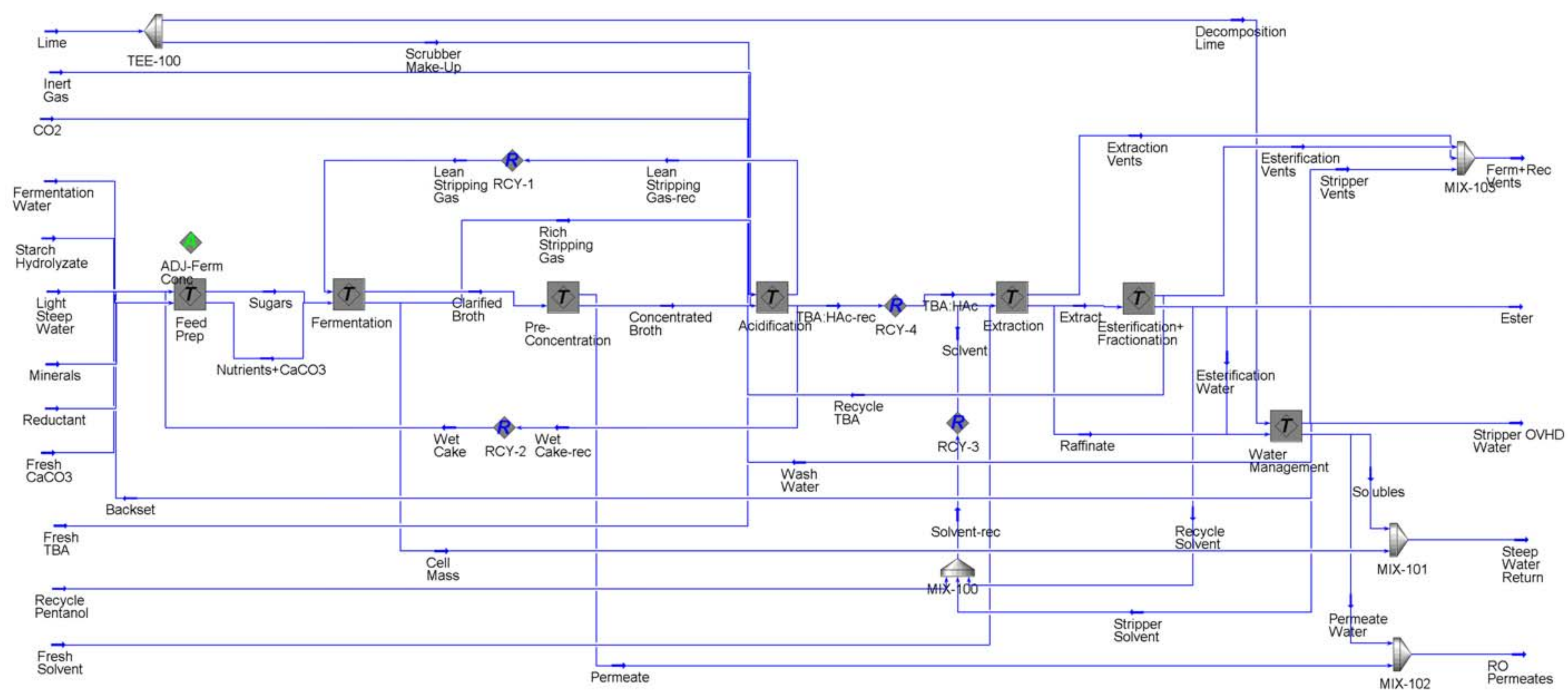
Stream	3	4	Adsorbed Sulfur	Ash	BFW Chemicals	Bulk Sulfur	CO2	CW Blowdown	CW Chemicals	Combustor Air	Combustor Offgas	Compression KO Water	Degasifier Vent	Denatured EtOH	Desulfurization Air
Pressure, psia	14.69594446	14.69594446	265.0009644	14.69594446	14.69594446	14.69594446	24.696	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	135.7095251	135.7095251	707	110.0010345	60	110.0000238	60	89.90452349	60	90	249.9999999	137.8959756	60	104.8122639	90
Components, lb/hr															
Hydrogen	0	0	0	0.000381818	0	0	0	0	0	0	0	0.036365039	0	0.014127578	0
CO	0	0	0	0.002696501	0	0	0	0	0	0	0	0.261864759	0	0.000417118	0
Nitrogen	0	0	0	0.000104972	0	0	0	0	0	406202.9434	406308.781	0.011469187	0	0	391.661554
Oxygen	0	0	0	0	0	0	0	0	0	124470.6336	11315.51214	0	0	0	120.014792
Argon	0	0	0	0	0	0	0	0	0	6928.795767	6928.795767	0	0	0	6.680756408
CO2	0	0	0	6.97362997	0	0	633.7537259	0	0	286.0436313	147462.9206	342.3073654	0	0	0.275803745
H2O	1064307.169	456407.2489	0	2078.414929	5.269273437	0	0	111738.8711	4.921048619	10742.80151	59282.60829	46423.14927	0	593.5168899	10.35822709
H2S	0	0	1.73115767	0.02388774	0	0	0	0	0	0	0	1.071695845	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	40.5970779	0	0	0	0
Ammonia	0	0	0	2.915905296	0	0	0	0	0	0	0	128.5252214	0	0	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	6.15941E-06	0	0	0	0	0	0	0	0.000163812	0	0	0
Ethane	0	0	0	1.28493E-06	0	0	0	0	0	0	0	4.84818E-05	0	0	0
Ethylene	0	0	0	8.62693E-06	0	0	0	0	0	0	0	0.000104412	0	0	0
Acetylene	0	0	0	1.62824E-05	0	0	0	0	0	0	0	7.88529E-05	0	0	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	327.9458009	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	1024.451014	0
n-Heptane	0	0	0	0	0	0	0	0	0	0	0	0	0	1856.870563	0
Benzene	0	0	0	8.87514E-08	0	0	0	0	0	0	0	2.29368E-05	0	0	0
Naphthalene	0	0	0	7.40374E-10	0	0	0	0	0	0	0	1.02179E-05	0	0	0
S_Rhombic	0	0	0	0	0	218.6587811	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	2901.527609	0	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	15893.40472	0	0	0	0	0	0	0	0	0	0	0
Dextrose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fructose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Galactose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arabinose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Xylose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maltose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isomaltose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gluc_Olig*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LacticAcid	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	75426.0049	0
1-Pentanol	0	0	0	0	0	0	0	0	0	0	0	0	0	17.06369979	0
nPentylAceta	0	0	0	0	0	0	0	0	0	0	0	0	0	34.26996007	0
triButylamin	0	0	0	0	0	0	0	0	0	0	0	0	0	0.06144299	0
TBA:HAc*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(Ac)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	1064307.169	456407.2489	1.73115767	20883.2639	5.269273437	218.6587811	633.7537259	111738.8711	4.921048619	548631.2179	631339.2149	46895.36368	0	79280.19882	528.9911332
Heat Flow, Btu/hr	-7173099249	-3076042884	-164.7686711	-109090930.4	-35898.40799	814147.8772	-2440667.107	-758024612.7	-33526.02844	-61224616.06	-880128932	-314305564.8	0	-201703195.2	-59032.87669

Stream	Desulfurization Offgas	Dry Air	Ester	Excess H2	Ferm+Rec Vents	Fermentation Water	Fresh CaCO3	Fresh Solvent	Fresh TBA	Fresh Water	Gasifier Steam	Humidity	Hydrogen	Hydrogenolysis Vents	Inert Gas
Pressure, psia	14.69594446	14.69594446	14.69594446	225.0009644	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	54.696	14.69594446	225.0009644	14.69594446	30
Temperature, F	110	176.7746739	161.2181489	110.0000002	112.9256147	60	60	60	60	60	352.4429737	90	110.0000002	23.66262013	60
Components, lb/hr															
Hydrogen	0	0	2.0806E-27	7.458052767	1.34077E-10	0	0	0	0	0	0	0	6766.499674	77.55934288	0
CO	0	0	2.89248E-26	0.001036234	2.39295E-10	0	0	0	0	0	0	0	0.940148069	0.756793603	0
Nitrogen	391.6600659	18581404.37	1.87204E-24	0	23.80740397	0	0	0	0	0	0	0	0	0	24.44081797
Oxygen	10.9104167	5693802.104	3.30506E-26	0	4.7724E-09	0	0	0	0	0	0	0	0	0	0
Argon	6.68075611	316951.8045	4.12593E-26	0	4.83837E-09	0	0	0	0	0	0	0	0	0	0
CO2	0.275753186	13084.81995	4.54538E-26	0	1.11575E-15	0	0	0	0	0	0	0	0	0	0
H2O	24.85654549	0	593.6307834	0	1.060854576	964128.9216	0	0	0	1128875.283	103781.6441	491420.2177	0	0.075556494	0
H2S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetylene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dextrose*	0	0	1.55486E-24	0	1.61788E-17	0	0	0	0	0	0	0	0	0	0
Fructose*	0	0	1.55486E-24	0	6.15152E-20	0	0	0	0	0	0	0	0	0	0
Galactose*	0	0	1.55486E-24	0	5.91492E-20	0	0	0	0	0	0	0	0	0	0
Arabinose*	0	0	1.2938E-24	0	3.01681E-16	0	0	0	0	0	0	0	0	0	0
Xylose*	0	0	1.26928E-24	0	5.02802E-17	0	0	0	0	0	0	0	0	0	0
Maltose*	0	0	2.95423E-24	0	1.52956E-18	0	0	0	0	0	0	0	0	0	0
Isomaltose*	0	0	2.95423E-24	0	1.83547E-18	0	0	0	0	0	0	0	0	0	0
Gluc_Olig*	0	0	1.39938E-24	0	3.0326E-11	0	0	0	0	0	0	0	0	0	0
LacticAcid	0	0	5.89242E-14	0	4.2019E-08	0	0	0	0	0	0	0	0	0	0
N_Soluble*	0	0	2.75602E-19	0	7.99621E-07	0	0	0	0	0	0	0	0	0	0
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	0	1.55486E-24	0	1.0474E-20	0	0	0	0	0	0	0	0	0	0
Ethanol	0	0	0.083114192	0	0.044522683	0	0	0	0	0	0	0	0	2.13909229	0
1-Pentanol	0	0	608987.0178	0	0.285420817	0	0	161.661996	0	0	0	0	0	0.005873119	0
nPentylAceta	0	0	219781.1953	0	1.097013409	0	0	0	0	0	0	0	0	0.004862542	0
triButylamin	0	0	159.9708869	0	0.00021364	0	0	0	32.53251004	0	0	0	0	0.000385597	0
TBA:HAc*	0	0	1.98753E-24	0	5.98428E-09	0	0	0	0	0	0	0	0	0	0
Ca(Ac)2*	0	0	1.63115E-15	0	1.43147E-08	0	0	0	0	0	0	0	0	0	0
CaCO3*	0	0	0	0	0	0	-128.7079172	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	0	1.64342E-63	0	1.65069E-13	0	0	0	0	0	0	0	0	0	0
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	434.3835374	24605243.1	829521.8979	7.459089	26.29542996	964128.9216	-128.7079172	161.661996	32.53251004	1128875.283	103781.6441	491420.2177	6767.439822	80.54190652	24.44081797
Heat Flow, Btu/hr	-140412.7623	539727043.6	-1420113394	829.9575301	-8204.080134	-6568399572	669441.6227	-283447.3475	-21288.86929	-7690780515	-584454709.6	-3333697195	752999.145	-20396.5125	-109.481036

Stream	Inhibitors	Light Steep Water	Lime	Make-Up BFW	Make-Up CW	Make-Up Sand	MgO	Minerals	Natural Gasoline	Neat EtOH	Net Conditioning Water	RO Permeates	Recycle Pentanol	Recycle Pentanol-rec	Reductant
Pressure, psia	14.69594446	14.69594446	19.69594446	14.69594446	14.69594446	23	23	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	60	122	60	60	135.7095251	60.00317594	60.00317594	60	60	110.1052426	109.9999992	136.0313574	110	110	60
Components, lb/hr															
Hydrogen	0	0	0	0	0	0	0	0	0	0.014127578	0.006594814	0	1.69877E-19	1.6992E-19	0
CO	0	0	0	0	0	0	0	0	0	0.000417118	0.046574323	0	4.04305E-20	4.04406E-20	0
Nitrogen	0	0	0	0	0	0	0	0	0	0	0.001813089	0	0	0	0
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0	0	0	120.4494294	0	0	0	0
H2O	0	328725.7005	0	164746.3611	607899.9205	0	0	0	0	593.5168899	35898.65474	1049252.102	0.039814795	0.039818494	0
H2S	0	0	0	0	0	0	0	0	0	0	0.412592156	0	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	0	881.2646439	0	0	0	0	0	0	0	0	50.36389249	0	0	0	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0.000106386	0	0	0	0
Ethane	0	0	0	0	0	0	0	0	0	0	2.21935E-05	0	0	0	0
Ethylene	0	0	0	0	0	0	0	0	0	0	0.000149006	0	0	0	0
Acetylene	0	0	0	0	0	0	0	0	0	0	0.000281232	0	0	0	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	327.9458009	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	1024.451014	0	0	0	0	0	0
n-Heptane	0	0	0	0	0	0	0	0	1856.870563	0	0	0	0	0	0
Benzene	0	0	0	0	0	0	0	0	0	0	1.53293E-06	0	0	0	0
Naphthalene	0	0	0	0	0	0	0	0	0	0	1.27878E-08	0	0	0	0
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	0	2994.589401	196.8008162	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dextrose*	0	1028.142085	0	0	0	0	0	0	0	0	0	0	0	0	0
Fructose*	0	763.7626914	0	0	0	0	0	0	0	0	0	0	0	0	0
Galactose*	0	734.3872032	0	0	0	0	0	0	0	0	0	0	0	0	0
Arabinose*	0	352.5058576	0	0	0	0	0	0	0	0	0	0	0	0	0
Xylose*	0	58.75097626	0	0	0	0	0	0	0	0	0	0	0	0	0
Maltose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isomaltose*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gluc_Olig*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LacticAcid	0	5455.447795	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	0	7931.381795	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	1636.634339	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethanol	5.443914015	0	0	0	0	0	0	0	0	75420.56099	0	0	1002.36596	1002.306325	0
1-Pentanol	0	0	0	0	0	0	0	0	0	17.06369979	0	0	755201.1956	755201.1615	0
nPentylAceta	0	0	0	0	0	0	0	0	0	34.26996007	0	0	3782.514787	3782.496977	0
triButylamin	0	0	0	0	0	0	0	0	0	0.06144299	0	0	159.9085973	159.9086541	0
TBA:HAc*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(Ac)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	2129.980672	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	2140.214135	0	0	0	0	0	1032.24585	0	0	0	0	0	0	187.1921598
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	5.443914015	349708.192	2129.980672	164746.3611	607899.9205	2994.589401	196.8008162	1032.24585	3209.267378	76065.48753	36069.9362	1049252.102	760146.0248	760145.9132	187.1921598
Heat Flow, Btu/hr	-14238.63991	-2272305055	-12229755.75	-1122380943	-4097056365	-18244264.43	-1198991.13	-1109109.958	-3180098.881	-198519039.4	-243393133.5	-7071306538	-1307950658	-1307950414	-201131.047

Stream	Regen Air	Regen Offgas	Shift KO Water	Shift Steam	Solids	Stack Gas	Starch Hydrolyzate	Steam Blowdown	Steep Water Return	Stover	Stripper OVHD Water	Syngas to Turbine	Tower Exhaust	Turbine Air	Vents
Pressure, psia	14.69594446	14.69594446	14.69594446	304.696	34.696	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	275.0009644	14.69594446	14.69594446	14.69594446
Temperature, F	90	249.9999998	110.3166349	651.9141016	140.0840697	249.9999999	158	113.2617414	134.9848757	60	110.0254341	118.9434276	97.34600798	90	25.93385786
Components, lb/hr															
Hydrogen	0	0	0.052881953	0	0	0	0	0	1.38471E-12	0	1.86422E-12	7741.805901	0	0	77.55934288
CO	0	0	0.025096296	0	0	0	0	0	7.53515E-12	0	1.76267E-10	49785.06193	0	0	0.756793604
Nitrogen	152133.7521	152799.9208	0.017313529	0	0	988058.3758	0	0	0.257247473	0	0.063124768	681.9568745	18581404.37	987376.2855	23.80740397
Oxygen	46617.54628	4237.900932	1.2439E-06	0	0	204071.4637	0	0	4.82273E-11	0	1.55279E-10	9.57957E-06	5693802.104	302556.527	4.7724E-09
Argon	2595.017379	2595.01738	1.95657E-08	0	0	16842.1444	0	0	5.52689E-11	0	1.35856E-10	1.50679E-07	316951.8045	16842.1444	4.83837E-09
CO2	107.1309098	134771.0275	128.5043149	0	0	138687.263	0	0	1.396825689	0	0	53504.81392	13084.81995	695.2994869	1.11575E-15
H2O	4023.463465	37349.69699	24619.82758	45914.91934	314.0297355	100466.5237	257834.3456	15055.06696	529733.9821	46016.10021	3888.267747	616.906247	987586.1882	26113.02459	1.13641107
H2S	0	0	0	0	0	0	0	0	0	0	0	2.391208471	0	0	0
SO2	0	1.136712744	0	0	0	4.495480566	0	0	0	0	0	0	0	0	0
Ammonia	0	0	0.117466249	0	0	0	0	0	3.94035E-16	0	0	0.162254351	0	0	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0.000214867	0	0	0	0	0	0	0	0	1731.469749	0	0	0
Ethane	0	0	3.23653E-06	0	0	0	0	0	0	0	0	6.54901471	0	0	0
Ethylene	0	0	0.000240656	0	0	0	0	0	0	0	0	436.9437634	0	0	0
Acetylene	0	0	1.61147E-05	0	0	0	0	0	0	0	0	26.18595607	0	0	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	0	6.22024E-11	0	0	0	0	0	0	0	0	8.664496771	0	0	0
Naphthalene	0	0	2.58697E-14	0	0	0	0	0	0	0	0	2.599347583	0	0	0
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	289.8626081	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	244848.6001	0	0	0	0	0
Char - C*	0	0	0	0	4.017110388	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0.543212134	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0.010584999	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0.002032243	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	3.699193333	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	15.89499422	0	0	0	0	15909.29971	0	0	0	0	0
Dextrose*	0	0	0	0	0	0	106080.4165	0	6987.443228	0	6.94936E-12	0	0	0	1.61788E-17
Fructose*	0	0	0	0	0	0	0	0	26.5693118	0	2.64226E-14	0	0	0	6.15152E-20
Galactose*	0	0	0	0	0	0	0	0	25.54741519	0	2.54064E-14	0	0	0	5.91492E-20
Arabinose*	0	0	0	0	0	0	0	0	12.26211708	0	4.30422E-11	0	0	0	3.01681E-16
Xylose*	0	0	0	0	0	0	0	0	2.043686181	0	7.17369E-12	0	0	0	5.02802E-17
Maltose*	0	0	0	0	0	0	1105.004338	0	38.44213573	0	3.42801E-16	0	0	0	1.52956E-18
Isomaltose*	0	0	0	0	0	0	1326.005206	0	46.13056284	0	4.11362E-16	0	0	0	1.83547E-18
Gluc_Olig*	0	0	0	0	0	0	1989.007809	0	1988.99046	0	3.83896E-05	0	0	0	3.0326E-11
LacticAcid	0	0	0	0	0	0	0	0	189.8242323	0	0.031170353	0	0	0	4.2019E-08
N_Soluble*	0	0	0	0	0	0	0	0	5200.384421	0	0.452979578	0	0	0	7.99621E-07
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	8934.834519	0	0	0	0	0	0
Phytate*	0	0	0	0	0	0	0	0	1636.618142	0	4.43031E-14	0	0	0	1.0474E-20
Ethanol	0	0	0	0	0	0	0	0	917.7369458	0	85.0892031	0	0	0	2.183614973
1-Pentanol	0	0	0	0	0	0	0	0	47.51088458	0	57.47865572	0	0	0	0.291293935
nPentylAceta	0	0	0	0	0	0	0	0	13.8706277	0	0.001082155	0	0	0	1.10187595
triButylamin	0	0	0	0	0	0	0	0	1.12419E-13	0	0.001978817	0	0	0	0.000599236
TBA:HAc*	0	0	0	0	0	0	0	0	39.88755363	0	0	0	0	0	5.98428E-09
Ca(Ac)2*	0	0	0	0	0	0	0	0	4343.41496	0	0.097024551	0	0	0	1.43147E-08
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	0	0	0	0	0	0	0	3359.642092	0	1.95049E-07	0	0	0	1.65069E-13
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	205476.9102	331754.7004	24748.54513	45914.91934	628.0594709	1448130.266	368334.7794	15055.06696	563546.7895	306774	4031.483005	114545.5107	25592829.28	1333583.281	106.8373365
Heat Flow, Btu/hr	-22930238.97	-718574305.7	-167021769.4	-252622387.6	-3974502.179	-1047568227	-2076824238	-101792710.5	-3649597829	-1009061893	-26617556.5	-295033948.9	-5605456323	-148821506.5	-28600.59263

Stream	Water Out
Pressure, psia	14.69594446
Temperature, F	125.8968628
Components, lb/hr	
Hydrogen	0.095841806
CO	0.333535378
Nitrogen	0.093720572
Oxygen	1.24406E-06
Argon	1.97015E-08
CO2	591.2611098
H2O	678976.0193
H2S	1.484288001
SO2	0
Ammonia	179.0065801
NO2	0
Methane	0.000485065
Ethane	7.39117E-05
Ethylene	0.000494073
Acetylene	0.000376199
Propane	0
i-Butane	0
n-Butane	0
i-Pentane	0
n-Pentane	0
n-Hexane	0
n-Heptane	0
Benzene	2.44698E-05
Naphthalene	1.02307E-05
S_Rhombic	0
Sand*	0
Stover*	0
Char - C*	0
Char - H*	0
Char - N*	0
Char - S*	0
Char - O*	0
Char - Ash*	0
Dextrose*	6.94936E-12
Fructose*	2.64226E-14
Galactose*	2.54064E-14
Arabinose*	4.30422E-11
Xylose*	7.17369E-12
Maltose*	3.42801E-16
Isomaltose*	4.11362E-16
Gluc_Olig*	3.83896E-05
LacticAcid	0.031170353
N_Soluble*	0.452979578
N_Insoluble*	0
Cell_Mass*	0
Phytate*	4.43031E-14
Ethanol	85.0892031
1-Pentanol	57.47865572
nPentylAceta	0.001082155
triButylamin	0.001978817
TBA:HAc*	0
Ca(Ac)2*	0.097024551
CaCO3*	0
Ca(OH)2*	0
Ash_Soluble*	1.95049E-07
Ash_Insolub*	0
Total, lb/hr	679891.448
Heat Flow, Btu/hr	-4585405520


Lime
TEE-100
Scrubber Make-Up
Inert Gas
CO2
Decomposition Lime
Extraction Vents
Esterification Vents
Stripper Vents
MIX-103
Ferm+Rec Vents
Fermentation Water
Starch Hydrolyzate
Light Steep Water
Minerals
Reductant
Fresh CaCO3
ADJ-Ferm Conc
Feed Prep
Sugars
Nutrients+CaCO3
Fermentation
Lean Stripping Gas
RCY-1
Lean Stripping Gas-rec
Rich Stripping Gas
Clarified Broth
Pre-Concentration
Concentrated Broth
Acidification
TBA:HAc-rec
RCY-4
TBA:HAc
Extraction
Solvent
Extract
Esterification+ Fractionation
Ester
Esterification Water
Recycle TBA
RCY-3
Raffinate
Water Management
Stripper OVHD Water
Wet Cake
RCY-2
Wet Cake-rec
Wash Water
Solubles
Backset
Fresh TBA
Solvent-rec
Recycle Solvent
MIX-101
Steep Water Return
Cell Mass
MIX-100
Recycle Pentanol
Stripper Solvent
Permeate Water
Fresh Solvent
Permeate
MIX-102
RO Permeates

Flowsheet: Fermentation + Recovery (FREC)

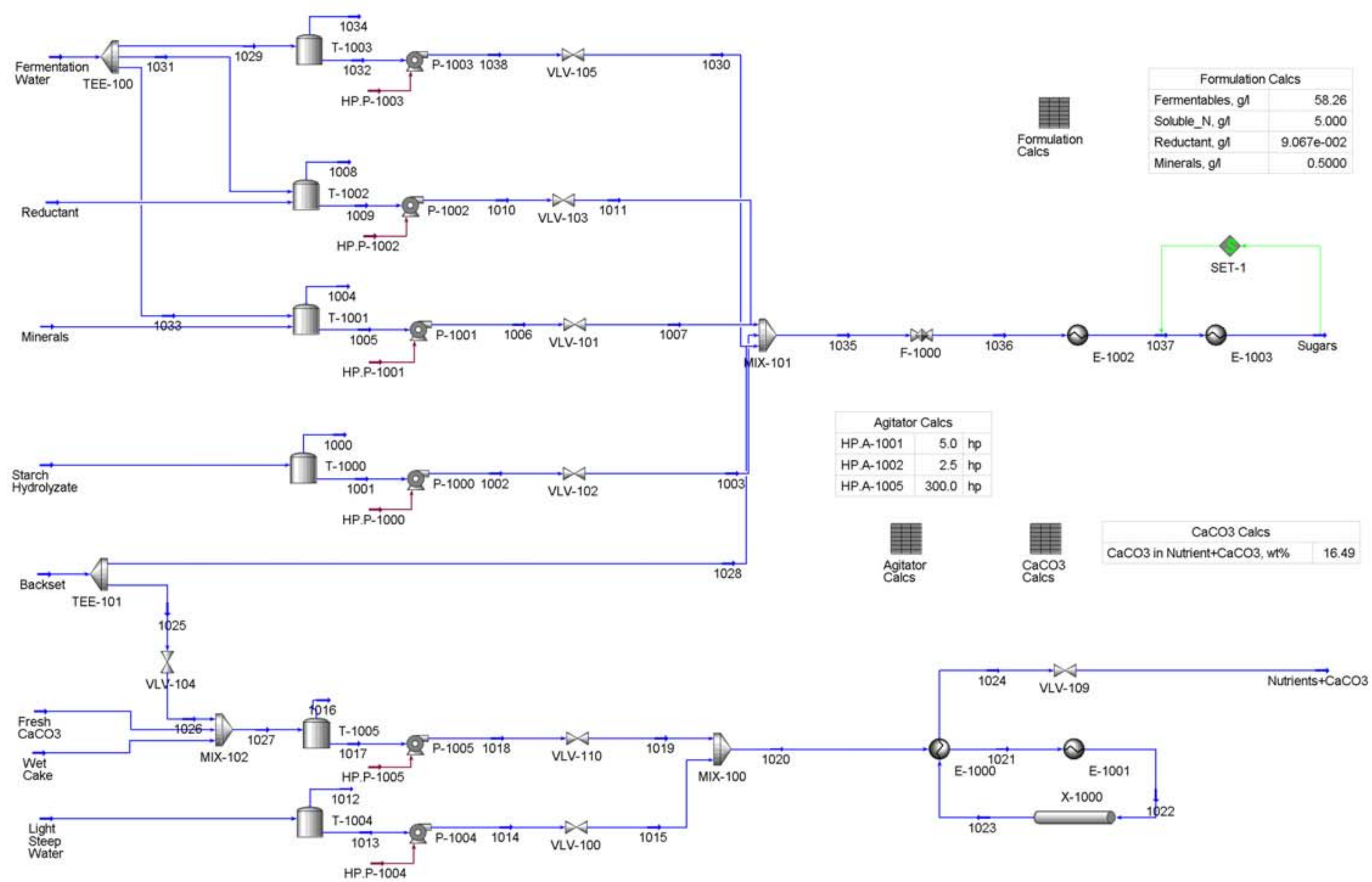
Stream	Backset	CO2	Cell Mass	Clarified Broth	Concentrated Broth	Decomposition Lime	Ester	Esterification Vents	Esterification Water	Extract	Extraction Vents	Ferm+Rec Vents	Fermentation Water	Fresh CaCO3	Fresh Solvent
Pressure, psia	34.69594446	24.696	14.69594446	14.69594446	24.696	19.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	134.8197707	60	136.7695924	136.4255512	136.4127328	60	161.2181489	108.9952216	109.219099	105.4953106	131.521685	112.9256147	60	60	60
Components, lb/hr															
Hydrogen	0	0	1.38471E-12	7.89419E-11	7.89418E-11	0	2.0806E-27	6.84691E-11	3.64239E-11	1.85461E-10	2.26005E-11	1.34077E-10	0	0	0
CO	0	0	7.53515E-12	4.29577E-10	4.29577E-10	0	2.89248E-26	1.61207E-11	1.6498E-10	2.19826E-10	6.5722E-12	2.39295E-10	0	0	0
Nitrogen	0	0	0.257247473	14.66567609	14.66564025	0	1.87204E-24	13.89665466	3.322085414	35.60724675	6.87105847	23.80740397	0	0	0
Oxygen	0	0	4.82273E-11	2.74943E-09	2.74943E-09	0	3.30506E-26	2.12564E-09	1.92234E-09	7.53699E-09	5.50648E-10	4.7724E-09	0	0	0
Argon	0	0	5.52689E-11	3.15087E-09	3.15087E-09	0	4.12593E-26	2.28812E-09	1.89671E-09	7.65553E-09	6.69845E-10	4.83837E-09	0	0	0
CO2	0	633.7537259	1.396825689	79.63272566	79.63272097	0	4.54538E-26	9.22134E-16	1.40358E-14	5.43509E-14	1.9362E-16	1.11575E-15	0	0	0
H2O	288108.3427	0	32826.57312	1871435.551	1107024.394	0	593.6307834	0.595246974	293927.9775	293779.4817	0.360455042	1.060854576	964128.9216	0	0
Dextrose*	2510.351107	0	175.8985528	10027.93694	10027.93694	0	1.55486E-24	7.17413E-18	866.6870688	1965.757989	9.00467E-18	1.61788E-17	0	0	0
Fructose*	9.545450511	0	0.668846157	38.130769	38.130769	0	1.55486E-24	2.72792E-20	3.295621893	7.474115092	3.4236E-20	6.15152E-20	0	0	0
Galactose*	9.178317799	0	0.643121305	36.66420096	36.66420096	0	1.55486E-24	2.623E-20	3.168867219	7.186649048	3.29192E-20	5.91492E-20	0	0	0
Arabinose*	4.405355638	0	0.308698835	17.59885118	17.59885118	0	1.2938E-24	9.95692E-17	1.040244234	3.137094565	2.02112E-16	3.01681E-16	0	0	0
Xylose*	0.73422594	0	0.051449806	2.933141863	2.933141863	0	1.26928E-24	1.65949E-17	0.173374035	0.522849031	3.36853E-17	5.02802E-17	0	0	0
Maltose*	13.81097122	0	0.967677614	55.16708316	55.16708316	0	2.95423E-24	1.2306E-18	20.07628945	28.36192934	2.98958E-19	1.52956E-18	0	0	0
Isomaltose*	16.57316545	0	1.161213137	66.20049979	66.20049979	0	2.95423E-24	1.47672E-18	24.09154291	34.03432051	3.5875E-19	1.83547E-18	0	0	0
Gluc_Olig*	714.577016	0	50.06914631	2854.430771	2854.430771	0	1.39938E-24	5.30634E-13	6.954641862	306.8185984	2.97953E-11	3.0326E-11	0	0	0
LacticAcid	68.19796482	0	4.777016099	272.3366135	272.3366135	0	5.89242E-14	2.82654E-10	0.298299625	10.82664003	4.13455E-08	4.2019E-08	0	0	0
Ammonia	0	0	3.94035E-16	2.24639E-14	2.24639E-14	0	0	0	0	0	0	0	0	0	0
N_Soluble*	1868.339333	0	130.8637477	7460.512824	7460.512824	0	2.75602E-19	8.46807E-10	1.343826108	297.0980589	7.95093E-07	7.99621E-07	0	0	0
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	8934.834519	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	587.9845587	0	41.19068241	2348.271541	2348.271541	0	1.55486E-24	3.72241E-21	140.8683899	299.7740519	6.75158E-21	1.0474E-20	0	0	0
Ethanol	335.9170023	0	6.265374481	357.1875902	357.1875902	0	0.083114192	0.006415634	190.9140691	244.0434874	0.002206489	0.044522683	0	0	0
1-Pentanol	14.81016936	0	7.325218937	417.6090842	417.6090842	0	608987.0178	0.223233362	4429.205792	996471.3063	0.02223405	0.285420817	0	0	161.661996
nPentylAceta	1.71821E-08	0	13.87062766	790.7613638	790.7613636	0	219781.1953	0.006915831	4.784552148	16961.95626	1.090079792	1.097013409	0	0	0
triButylamin	4.14315E-14	0	0	0	0	0	159.9708869	0.000131178	0.031282878	7427.767183	5.6155E-15	0.00021364	0	0	0
TBA:HAc*	0	0	39.88755363	2273.980462	2273.980462	0	1.98753E-24	1.36524E-10	2427.845602	432965.5098	5.84776E-09	5.98428E-09	0	0	0
Ca(Ac)2*	733.6952248	0	2352.618618	134122.2583	134122.2583	0	1.63115E-15	3.91854E-10	0.136441886	18.15337534	1.03036E-08	1.43147E-08	0	0	0
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	-128.7079172	0
Ca(OH)2*	0	0	0	0	0	1373.40037	0	0	0	0	0	0	0	0	0
Ash_Soluble*	1207.016642	0	84.54333848	4819.796714	4819.796714	0	1.64342E-63	1.49869E-15	6.998948314	191.5272141	1.6357E-13	1.65069E-13	0	0	0
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	296203.4792	633.7537259	44674.17259	2037491.626	1273080.469	1373.40037	829521.8979	14.72859764	302059.2145	1751056.345	8.346034695	26.29542996	964128.9216	-128.7079172	161.661996
Heat Flow, Btu/hr	-1962399436	-2440216.153	-245603559.6	-13234892953	-8083370400	-7885682.388	-1416470805	-3650.552596	-2003421613	-4315096496	-3855.267029	-8220.011422	-6571709473	669441.6227	-280742.9036

Stream	Fresh TBA	Inert Gas	Lean Stripping Gas	Lean Stripping Gas-rec	Light Steep Water	Lime	Minerals	Nutrients+CaCO3	Permeate	Permeate Water	RO Permeates	Raffinate	Recycle Pentanol	Recycle Solvent	Recycle TBA
Pressure, psia	14.69594446	30	14.69594446	14.69594446	14.69594446	19.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	60	60	172.0250768	172.0252577	122	60	60	160.4260343	136.4527309	134.9006685	136.0313574	108.3517867	110	109.2062421	110
Components, lb/hr															
Hydrogen	0	0	7.9471E-07	7.94573E-07	0	0	0	7.18628E-13	0	0	0	2.73517E-11	1.69877E-19	8.05679E-11	4.78634E-28
CO	0	0	1.97661E-07	1.97238E-07	0	0	0	2.19739E-12	0	0	0	3.91639E-10	4.04305E-20	3.87253E-11	6.65404E-27
Nitrogen	0	24.44081797	283591.691	283592.004	0	0	0	0.126185832	0	0	0	1.865850735	0	18.38850952	1.0394E-28
Oxygen	0	0	1.81344E-05	1.81295E-05	0	0	0	2.60496E-11	0	0	0	1.53786E-09	0	3.48901E-09	7.60314E-27
Argon	0	0	2.26792E-05	2.26741E-05	0	0	0	2.62956E-11	0	0	0	1.17716E-09	0	3.4707E-09	9.49153E-27
CO2	0	0	23.62865649	23.62870548	0	0	0	0	0	0	0	6.94906E-15	0	3.9393E-14	1.04565E-26
H2O	0	0	10754.02876	10753.99462	328725.7005	0	0	408955.3539	764411.1569	284840.9455	1049252.102	864046.5266	0.039814795	29148.23041	0.003380807
Dextrose*	0	0	0	0	1028.142085	0	0	1734.04799	0	0	0	9182.222552	0	31.03817124	1068.032045
Fructose*	0	0	0	0	763.7626914	0	0	766.4468526	0	0	0	34.91471402	0	0.118021246	4.060469274
Galactose*	0	0	0	0	734.3872032	0	0	736.9681275	0	0	0	33.57184039	0	0.113481968	3.904297286
Arabinose*	0	0	0	0	352.5058576	0	0	353.7456446	0	0	0	16.60184029	0	0.031798871	2.065050402
Xylose*	0	0	0	0	58.75097626	0	0	58.95760743	0	0	0	2.766973386	0	0.005299812	0.344175008
Maltose*	0	0	0	0	0	0	0	3.879906065	0	0	0	35.17877057	0	3.11321795	5.172409956
Isomaltose*	0	0	0	0	0	0	0	4.655887328	0	0	0	42.21452906	0	3.735861113	6.206902106
Gluc_Olig*	0	0	2.27136E-09	2.27133E-09	0	0	0	200.915093	0	0	0	2940.619651	0	0.107174683	299.756696
LacticAcid	0	0	0.002352667	0.002352697	5455.447795	0	0	5474.527362	0	0	0	277.6708207	0	0.001117087	10.52722031
Ammonia	0	0	0	0	881.2646439	0	0	881.2646439	0	0	0	0	0	0	0
N_Soluble*	0	0	0.063296921	0.063297928	7931.381795	0	0	8454.119165	0	0	0	8429.834168	0	0.00503544	295.7491163
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	0	0	0	1636.634339	0	0	1801.477665	0	0	0	2212.814633	0	2.724654964	156.1808986
Ethanol	0	0	31.39807879	31.33446532	0	0	0	88.85255422	0	0	0	1367.822146	1002.36596	53.03987565	2.69409E-06
1-Pentanol	0	0	559.7512603	559.7484906	0	0	0	54.15310084	0	0	0	12484.04051	755201.1956	227284.6112	9510.020228
nPentylAceta	0	0	2726.234448	2726.18022	0	0	0	54.58200112	0	0	0	7.261448046	3782.514787	2844.067607	10338.97649
triButylamin	32.53251004	0	0	0	0	0	0	1.06875E-14	0	0	0	0.464948088	159.9085973	397.521365	314412.7984
TBA:HAc*	0	0	0.006552077	0.006552057	0	0	0	2313.861885	0	0	0	6669.906593	0	1927.8493	21430.49241
Ca(Ac)2*	0	0	0	0	0	0	0	189.2604335	0	0	0	122.0606538	0	0.067676313	17.94925201
CaCO3*	0	0	0	0	0	0	0	85790.19858	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	2129.980672	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	0	8.9717E-09	8.97162E-09	2140.214135	0	1032.24585	2477.8854	0	0	0	4883.130246	0	0.026210004	184.5020024
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	32.53251004	24.44081797	297686.8045	297686.9627	349708.192	2129.980672	1032.24585	520395.28	764411.1569	284840.9455	1049252.102	912791.4895	760146.0248	261714.796	357746.7415
Heat Flow, Btu/hr	-21771.70188	-103.139474	-60043809.72	-60043363.79	-2272679400	-12229755.75	-1635191.323	-3239499561	-5151491787	-1920034548	-7071526335	-5951266354	-1298000546	-593371190.8	-271377637.7

Stream	Reductant	Rich Stripping Gas	Scrubber Make-Up	Solubles	Solvent	Solvent-rec	Starch Hydrolyzate	Steep Water Return
Pressure, psia	14.69594446	14.69594446	19.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	60	136.4255512	60	134.8607011	109.7855463	109.7855001	158	134.9848757
Components, lb/hr								
Hydrogen	0	7.94631E-07	0	0	9.9472E-11	9.94702E-11	0	1.38471E-12
CO	0	1.97226E-07	0	0	2.02361E-10	2.02345E-10	0	7.53515E-12
Nitrogen	0	283576.8943	0	0	20.47385602	20.47362646	0	0.257247473
Oxygen	0	1.81317E-05	0	0	4.69776E-09	4.69765E-09	0	4.82273E-11
Argon	0	2.2676E-05	0	0	4.52827E-09	4.5282E-09	0	5.52689E-11
CO2	0	37089.94725	0	0	3.93915E-14	3.9393E-14	0	1.396825689
H2O	0	42840.89663	0	496907.409	31469.82368	31468.68253	257834.3456	529733.9821
Dextrose*	0	3.91961E-14	0	6811.544675	38.54107372	38.54336241	106080.4165	6987.443228
Fructose*	0	1.49029E-16	0	25.90046564	0.146546413	0.146555119	0	26.5693118
Galactose*	0	1.43297E-16	0	24.90429388	0.140910012	0.140918383	0	25.54741519
Arabinose*	0	1.14637E-12	0	11.95341825	0.052458629	0.052460845	0	12.26211708
Xylose*	0	1.91062E-13	0	1.992236375	0.008743104	0.008743473	0	2.043686181
Maltose*	0	1.2647E-17	0	37.47445812	3.124017058	3.124393099	1105.004338	38.44213573
Isomaltose*	0	1.51764E-17	0	44.96934971	3.748820048	3.749271296	1326.005206	46.13056284
Gluc_Olig*	0	5.51534E-07	0	1938.921314	89.37730056	89.37336515	1989.007809	1988.99046
LacticAcid	0	0.022754378	0	185.0472162	5.147297724	5.147200104	0	189.8242323
Ammonia	0	1.16355E-13	0	0	0	0	0	3.94035E-16
N_Soluble*	0	0.678837581	0	5069.520673	957.325565	957.3721965	0	5200.384421
N_Insoluble*	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	8934.834519
Phytate*	0	1.01842E-16	0	1595.427459	4.469264578	4.46944338	0	1636.618142
Ethanol	0	92.71467068	0	911.4715713	1185.865745	1185.32068	0	917.7369458
1-Pentanol	0	203.7802273	0	40.18566565	999272.0239	999282.2908	0	47.51088458
nPentylAceta	0	1976.184458	0	4.66216E-08	6645.15143	6638.627294	0	13.8706277
triButylamin	0	0	0	1.12419E-13	7428.232131	7429.458505	0	1.12419E-13
TBA:HAc*	0	0.000421096	0	0	1927.998476	1927.8493	0	39.88755363
Ca(Ac)2*	0	21.82379007	0	1990.796342	119.1985361	119.2127127	0	4343.41496
CaCO3*	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	756.5803021	0	0	0	0	0
Ash_Soluble*	187.1921598	8.34297E-08	0	3275.098754	62.08964536	62.08883418	0	3359.642092
Ash_Insolub*	0	0	0	0	0	0	0	0
Total, lb/hr	187.1921598	365802.9434	756.5803021	518872.6169	1049232.939	1049236.132	368334.7794	563546.7895
Heat Flow, Btu/hr	-296533.0357	-386995871	-4344073.363	-3404695778	-1943331992	-1943329323	-2060504984	-3650299339

Stream	Stripper OVHD Water	Stripper Solvent	Stripper Vents	Sugars	TBA:HAc	TBA:HAc-rec	Wash Water
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	14.696	14.696	14.696
Temperature, F	110.0254341	109.7014753	109.8070734	112.3828485	105.3860813	105.3861267	134.860701
Components, lb/hr							
Hydrogen	1.86422E-12	1.89024E-11	4.30074E-11	0	1.35941E-10	1.35941E-10	0
CO	1.76267E-10	1.6362E-10	2.16602E-10	0	4.15676E-10	4.15677E-10	0
Nitrogen	0.063124768	2.085116943	3.039690842	0	23.87029995	23.8703186	0
Oxygen	1.55279E-10	1.20864E-09	2.09612E-09	0	4.92774E-09	4.92775E-09	0
Argon	1.35856E-10	1.05749E-09	1.88041E-09	0	4.97427E-09	4.97428E-09	0
CO2	0	0	0	0	2.21021E-14	1.87547E-14	0
H2O	3888.267747	2320.4123	0.10515256	1510071.61	1126356.545	1126361.357	82576.67356
Dextrose*	6.94936E-12	7.505191164	7.49995E-31	108590.7676	11109.43947	11109.57165	719.5086473
Fructose*	2.64226E-14	0.028533872	2.85161E-33	9.545450511	42.2422827	42.24296407	2.735885894
Galactose*	2.54064E-14	0.027436415	2.74193E-33	9.178317799	40.61757943	40.61823459	2.630659514
Arabinose*	4.30422E-11	0.020661974	5.32609E-26	4.405355638	19.68647623	19.68676374	1.262648666
Xylose*	7.17369E-12	0.003443662	8.87682E-27	0.73422594	3.281079313	3.281127232	0.210441444
Maltose*	3.42801E-16	0.01117515	2.52066E-34	1118.815309	60.41668285	60.41804321	3.958455527
Isomaltose*	4.11362E-16	0.013410184	3.02479E-34	1342.578371	72.50002952	72.50166196	4.750146629
Gluc_Olig*	3.83896E-05	89.26619046	3.80412E-17	2703.584825	3158.060949	3158.082134	204.8097338
LacticAcid	0.031170353	5.146083017	3.90793E-10	68.19796482	283.3501631	283.3513555	19.54667826
Ammonia	0	0	0	0	0	0	0
N_Soluble*	0.452979578	957.3671611	3.68118E-09	1868.339333	7769.606662	7769.637643	535.4973263
N_Insoluble*	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0
Phytate*	4.43031E-14	1.744788417	1.57907E-35	587.9845587	2508.11942	2508.135388	168.5262166
Ethanol	85.0892031	129.9148451	0.03590056	335.9170023	426.002095	425.9947014	96.27943566
1-Pentanol	57.47865572	16796.48393	0.039953404	14.81016936	9521.683153	9521.752916	4.244842442
nPentylAceta	0.001082155	12.04490044	1.77862E-05	1.71821E-08	10325.15636	10325.16017	4.92468E-09
triButylamin	0.001978817	6872.028543	8.24622E-05	4.14315E-14	2.50389E-11	1.1875E-15	1.1875E-14
TBA:HAc*	0	0	0	0	437707.4179	437708.9328	0
Ca(Ac)2*	0.097024551	119.1450364	3.61918E-09	733.6952248	21.01549299	21.02893325	210.2893325
CaCO3*	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0
Ash_Soluble*	1.95049E-07	62.06262418	5.5386E-22	2426.454652	5012.567815	5012.578709	345.9511736
Ash_Insolub*	0	0	0	0	0	0	0
Total, lb/hr	4031.483005	27375.31137	3.220797627	1629886.618	1614461.579	1614468.203	84896.87518
Heat Flow, Btu/hr	-26625345.45	-51957586.44	-714.1917966	-10567960974	-8322870319	-8322905625	-562456526.3

Stream	Wet Cake	Wet Cake-rec
Pressure, psia	14.69594446	14.69594446
Temperature, F	155.310028	155.3100284
Components, lb/hr		
Hydrogen	7.18628E-13	7.18627E-13
CO	2.19739E-12	2.19739E-12
Nitrogen	0.126185832	0.126185714
Oxygen	2.60496E-11	2.60496E-11
Argon	2.62956E-11	2.62955E-11
CO2	0	9.91428E-17
H2O	80229.65345	80229.64003
Dextrose*	705.9059059	705.9059799
Fructose*	2.684161212	2.684160101
Galactose*	2.580924241	2.580923173
Arabinose*	1.239787017	1.239786504
Xylose*	0.206631169	0.206631084
Maltose*	3.879906065	3.879905441
Isomaltose*	4.655887328	4.655886579
Gluc_Olig*	200.915093	200.9150679
LacticAcid	19.07956616	19.07955832
Ammonia	0	0
N_Soluble*	522.7373704	522.737165
N_Insoluble*	0	0
Cell_Mass*	0	0
Phytate*	164.8433259	164.8432681
Ethanol	88.85255422	88.85253254
1-Pentanol	54.15310084	54.1529762
nPentylAceta	54.58200112	54.58191538
triButylamin	1.06875E-14	1.06875E-14
TBA:HAc*	2313.861885	2313.861629
Ca(Ac)2*	189.2604335	189.2603992
CaCO3*	85918.9065	85918.89225
Ca(OH)2*	0	0
Ash_Soluble*	337.671265	337.6711811
Ash_Insolub*	0	0
Total, lb/hr	170815.7959	170815.7674
Heat Flow, Btu/hr	-986287184.1	-986287019.8



Formulation Calcs	
Fermentables, g/l	58.26
Soluble_N, g/l	5.000
Reductant, g/l	9.067e-002
Minerals, g/l	0.5000

Agitator Calcs		
HP.A-1001	5.0	hp
HP.A-1002	2.5	hp
HP.A-1005	300.0	hp

CaCO3 Calcs	
CaCO3 in Nutrient+CaCO3, wt%	16.49

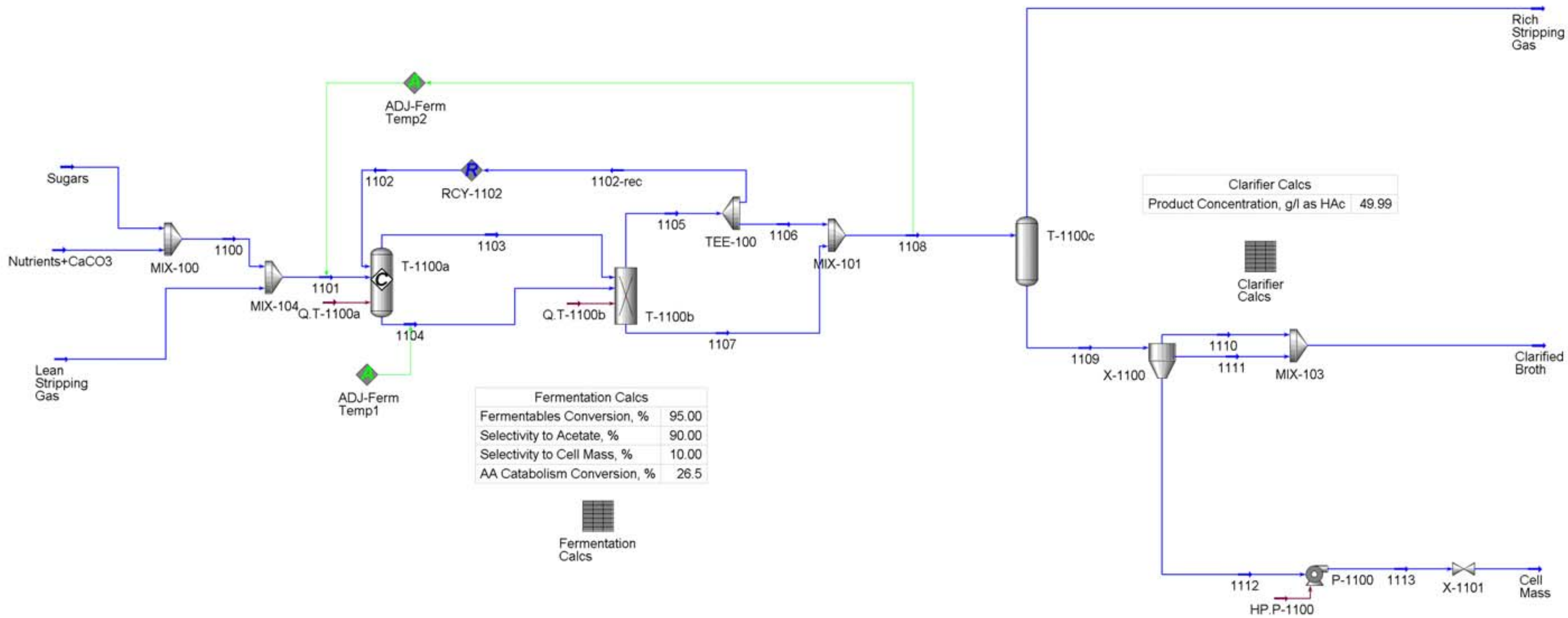
Flowsheet: Feed Prep (FEED)

Stream	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014
Pressure, psia	14.69594446	14.69594446	44.69594446	34.69594446	14.69594446	14.69594446	44.69594446	34.69594446	14.69594446	14.69594446	44.69594446	34.69594446	14.69594446	14.69594446	71.69594446
Temperature, F	158	158	158.0912782	158.1110374	105.6275727	105.6275727	105.6425385	105.6516973	105.6275727	105.6275727	105.6425385	105.6516973	122	122	122.076207
Components, lb/hr															
Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2O	0	257834.3456	257834.3456	257834.3456	0	9290.212649	9290.212649	9290.212649	0	1684.729438	1684.729438	1684.729438	0	328725.7005	328725.7005
Dextrose*	0	106080.4165	106080.4165	106080.4165	0	0	0	0	0	0	0	0	0	1028.142085	1028.142085
Fructose*	0	0	0	0	0	0	0	0	0	0	0	0	0	763.7626914	763.7626914
Galactose*	0	0	0	0	0	0	0	0	0	0	0	0	0	734.3872032	734.3872032
Arabinose*	0	0	0	0	0	0	0	0	0	0	0	0	0	352.5058576	352.5058576
Xylose*	0	0	0	0	0	0	0	0	0	0	0	0	0	58.75097626	58.75097626
Maltose*	0	1105.004338	1105.004338	1105.004338	0	0	0	0	0	0	0	0	0	0	0
Isomaltose*	0	1326.005206	1326.005206	1326.005206	0	0	0	0	0	0	0	0	0	0	0
Gluc_Olig*	0	1989.007809	1989.007809	1989.007809	0	0	0	0	0	0	0	0	0	0	0
LacticAcid	0	0	0	0	0	0	0	0	0	0	0	0	0	5455.447795	5455.447795
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	881.2646439	881.2646439
N_Soluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	7931.381795	7931.381795
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	0	0	0	0	0	0	0	0	0	0	0	0	1636.634339	1636.634339
Ethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Pentanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
nPentylAceta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
triButylamin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TBA:HAc*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(Ac)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	0	0	0	0	1032.24585	1032.24585	1032.24585	0	187.1921598	187.1921598	187.1921598	0	2140.214135	2140.214135
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	0	368334.7794	368334.7794	368334.7794	0	10322.4585	10322.4585	10322.4585	0	1871.921598	1871.921598	1871.921598	0	349708.192	349708.192
Heat Flow, Btu/hr	0	-2060504984	-2060457406	-2060457406	0	-64959272.89	-64958141.41	-64958141.41	0	-11780010.15	-11779804.96	-11779804.96	0	-2272679400	-2272599578

Stream	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029
Pressure, psia	61.69594446	14.69594446	14.69594446	71.69594446	61.69594446	61.69594446	56.69594446	51.69594446	49.69594446	44.69594446	34.69594446	14.69594446	14.69594446	34.69594446	14.69594446
Temperature, F	122.0963658	155.3730559	155.3730559	155.4545238	155.4643624	132.2554712	229.8011002	249.8	249.8011002	160.3840777	134.8197707	134.8607011	155.3730559	134.8197707	60
Components, lb/hr															
Hydrogen	0	0	7.18628E-13	7.18628E-13	7.18628E-13	7.18628E-13	7.18628E-13	7.18628E-13	7.18628E-13	7.18628E-13	0	0	7.18628E-13	0	0
CO	0	0	2.19739E-12	2.19739E-12	2.19739E-12	2.19739E-12	2.19739E-12	2.19739E-12	2.19739E-12	2.19739E-12	0	0	2.19739E-12	0	0
Nitrogen	0	0	0.126185832	0.126185832	0.126185832	0.126185832	0.126185832	0.126185832	0.126185832	0.126185832	0	0	0.126185832	0	0
Oxygen	0	0	2.60496E-11	2.60496E-11	2.60496E-11	2.60496E-11	2.60496E-11	2.60496E-11	2.60496E-11	2.60496E-11	0	0	2.60496E-11	0	0
Argon	0	0	2.62956E-11	2.62956E-11	2.62956E-11	2.62956E-11	2.62956E-11	2.62956E-11	2.62956E-11	2.62956E-11	0	0	2.62956E-11	0	0
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2O	328725.7005	0	80229.65345	80229.65345	80229.65345	408955.3539	408955.3539	408955.3539	408955.3539	408955.3539	0	0	80229.65345	288108.3427	953153.9795
Dextrose*	1028.142085	0	705.9059059	705.9059059	705.9059059	1734.04799	1734.04799	1734.04799	1734.04799	1734.04799	0	0	705.9059059	2510.351107	0
Fructose*	763.7626914	0	2.684161212	2.684161212	2.684161212	766.4468526	766.4468526	766.4468526	766.4468526	766.4468526	0	0	2.684161212	9.545450511	0
Galactose*	734.3872032	0	2.580924241	2.580924241	2.580924241	736.9681275	736.9681275	736.9681275	736.9681275	736.9681275	0	0	2.580924241	9.178317799	0
Arabinose*	352.5058576	0	1.239787017	1.239787017	1.239787017	353.7456446	353.7456446	353.7456446	353.7456446	353.7456446	0	0	1.239787017	4.405355638	0
Xylose*	58.75097626	0	0.206631169	0.206631169	0.206631169	58.95760743	58.95760743	58.95760743	58.95760743	58.95760743	0	0	0.206631169	0.73422594	0
Maltose*	0	0	3.879906065	3.879906065	3.879906065	3.879906065	3.879906065	3.879906065	3.879906065	3.879906065	0	0	3.879906065	13.81097122	0
Isomaltose*	0	0	4.655887328	4.655887328	4.655887328	4.655887328	4.655887328	4.655887328	4.655887328	4.655887328	0	0	4.655887328	16.57316545	0
Gluc_Olig*	0	0	200.915093	200.915093	200.915093	200.915093	200.915093	200.915093	200.915093	200.915093	0	0	200.915093	714.577016	0
LacticAcid	5455.447795	0	19.07956616	19.07956616	19.07956616	5474.527362	5474.527362	5474.527362	5474.527362	5474.527362	0	0	19.07956616	68.19796482	0
Ammonia	881.2646439	0	0	0	0	881.2646439	881.2646439	881.2646439	881.2646439	881.2646439	0	0	0	0	0
N_Soluble*	7931.381795	0	522.7373704	522.7373704	522.7373704	8454.119165	8454.119165	8454.119165	8454.119165	8454.119165	0	0	522.7373704	1868.339333	0
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	1636.634339	0	164.8433259	164.8433259	164.8433259	1801.477665	1801.477665	1801.477665	1801.477665	1801.477665	0	0	164.8433259	587.9845587	0
Ethanol	0	0	88.85255422	88.85255422	88.85255422	88.85255422	88.85255422	88.85255422	88.85255422	88.85255422	0	0	88.85255422	335.9170023	0
1-Pentanol	0	0	54.15310084	54.15310084	54.15310084	54.15310084	54.15310084	54.15310084	54.15310084	54.15310084	0	0	54.15310084	14.81016936	0
nPentylAceta	0	0	54.58200112	54.58200112	54.58200112	54.58200112	54.58200112	54.58200112	54.58200112	54.58200112	0	0	54.58200112	1.71821E-08	0
triButylamin	0	0	1.06875E-14	1.06875E-14	1.06875E-14	1.06875E-14	1.06875E-14	1.06875E-14	1.06875E-14	1.06875E-14	0	0	1.06875E-14	4.14315E-14	0
TBA:HAc*	0	0	2313.861885	2313.861885	2313.861885	2313.861885	2313.861885	2313.861885	2313.861885	2313.861885	0	0	2313.861885	0	0
Ca(Ac)2*	0	0	189.2604335	189.2604335	189.2604335	189.2604335	189.2604335	189.2604335	189.2604335	189.2604335	0	0	189.2604335	733.6952248	0
CaCO3*	0	0	85790.19858	85790.19858	85790.19858	85790.19858	85790.19858	85790.19858	85790.19858	85790.19858	0	0	85790.19858	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	2140.214135	0	337.671265	337.671265	337.671265	2477.8854	2477.8854	2477.8854	2477.8854	2477.8854	0	0	337.671265	1207.016642	0
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	349708.192	0	170687.088	170687.088	170687.088	520395.28	520395.28	520395.28	520395.28	520395.28	0	0	170687.088	296203.4792	953153.9795
Heat Flow, Btu/hr	-2272599578	0	-985617858.5	-985591049.4	-985591105.6	-3258191458	-3183704277	-3165011717	-3165012354	-3239499515	0	0	-985617858.5	-1962399436	-6496901915

Stream	1030	1031	1032	1033	1034	1035	1036	1037	1038	Backset	Fermentation Water	Fresh CaCO3	Light Steep Water	Minerals	Nutrients+CaCO3
Pressure, psia	34.69594446	14.69594446	14.69594446	14.69594446	14.69594446	34.69594446	24.69594446	19.69594446	44.69594446	34.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	60.06020506	60	60	60	60	94.74245329	94.76783992	111.3828485	60.03192311	134.8197707	60	60	122	60	160.4260667
Components, lb/hr															
Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.18628E-13
CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.19739E-12
Nitrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.126185832
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.60496E-11
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.62956E-11
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2O	953153.9795	1684.729438	953153.9795	9290.212649	0	1510071.61	1510071.61	1510071.61	953153.9795	288108.3427	964128.9216	0	328725.7005	0	408955.3539
Dextrose*	0	0	0	0	0	108590.7676	108590.7676	108590.7676	0	2510.351107	0	0	1028.142085	0	1734.04799
Fructose*	0	0	0	0	0	9.545450511	9.545450511	9.545450511	0	9.545450511	0	0	763.7626914	0	766.4468526
Galactose*	0	0	0	0	0	9.178317799	9.178317799	9.178317799	0	9.178317799	0	0	734.3872032	0	736.9681275
Arabinose*	0	0	0	0	0	4.405355638	4.405355638	4.405355638	0	4.405355638	0	0	352.5058576	0	353.7456446
Xylose*	0	0	0	0	0	0.73422594	0.73422594	0.73422594	0	0.73422594	0	0	58.75097626	0	58.95760743
Maltose*	0	0	0	0	0	1118.815309	1118.815309	1118.815309	0	13.81097122	0	0	0	0	3.879906065
Isomaltose*	0	0	0	0	0	1342.578371	1342.578371	1342.578371	0	16.57316545	0	0	0	0	4.655887328
Gluc_Olig*	0	0	0	0	0	2703.584825	2703.584825	2703.584825	0	714.577016	0	0	0	0	200.915093
LacticAcid	0	0	0	0	0	68.19796482	68.19796482	68.19796482	0	68.19796482	0	0	5455.447795	0	5474.527362
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	881.2646439	0	881.2646439
N_Soluble*	0	0	0	0	0	1868.339333	1868.339333	1868.339333	0	1868.339333	0	0	7931.381795	0	8454.119165
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	0	0	0	0	587.9845587	587.9845587	587.9845587	0	587.9845587	0	0	1636.634339	0	1801.477665
Ethanol	0	0	0	0	0	335.9170023	335.9170023	335.9170023	0	335.9170023	0	0	0	0	88.85255422
1-Pentanol	0	0	0	0	0	14.81016936	14.81016936	14.81016936	0	14.81016936	0	0	0	0	54.15310084
nPentylAceta	0	0	0	0	0	1.71821E-08	1.71821E-08	1.71821E-08	0	1.71821E-08	0	0	0	0	54.58200112
triButylamin	0	0	0	0	0	4.14315E-14	4.14315E-14	4.14315E-14	0	4.14315E-14	0	0	0	0	1.06875E-14
TBA:HAc*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2313.861885
Ca(Ac)2*	0	0	0	0	0	733.6952248	733.6952248	733.6952248	0	733.6952248	0	0	0	0	189.2604335
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	-128.7079172	0	0	85790.19858
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	0	0	0	0	2426.454652	2426.454652	2426.454652	0	1207.016642	0	0	2140.214135	1032.24585	2477.8854
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	953153.9795	1684.729438	953153.9795	9290.212649	0	1629886.618	1629886.618	1629886.618	953153.9795	296203.4792	964128.9216	-128.7079172	349708.192	1032.24585	520395.28
Heat Flow, Btu/hr	-6496790503	-11483477.12	-6496901915	-63324081.56	0	-10596385292	-10596385292	-10569580124	-6496790503	-1962399436	-6571709473	669441.6227	-2272679400	-1635191.323	-3239499538

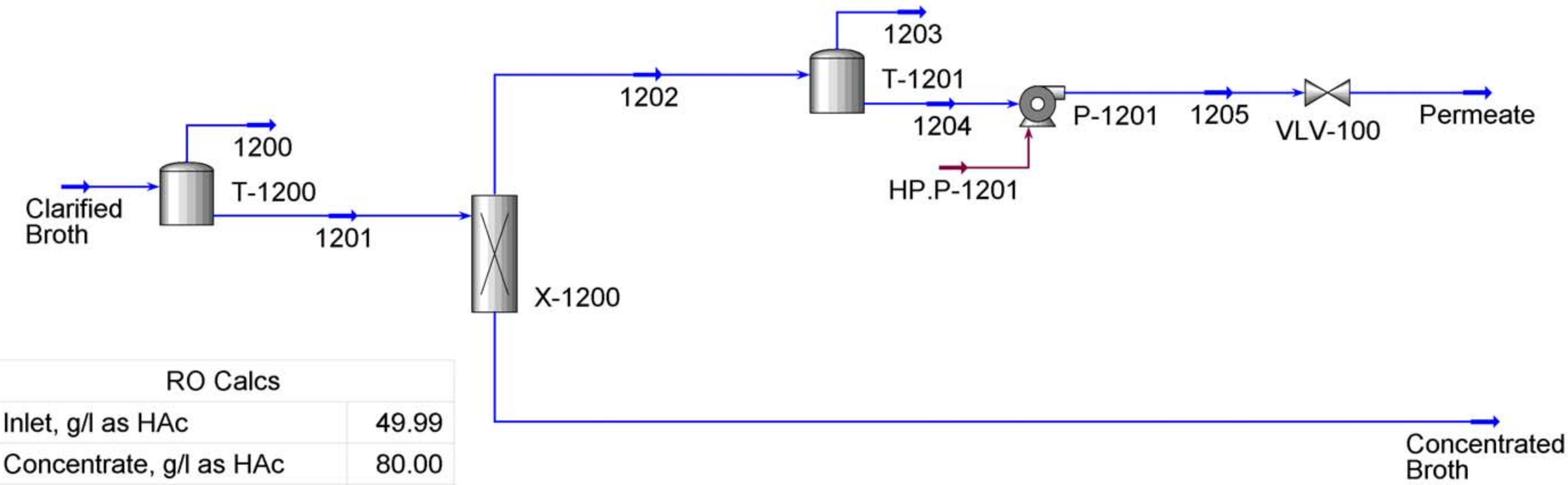
Stream	Reductant	Starch Hydrolyzate	Sugars	Wet Cake
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	60	158	112.3828485	155.3097282
Components, lb/hr				
Hydrogen	0	0	0	7.18628E-13
CO	0	0	0	2.19739E-12
Nitrogen	0	0	0	0.126185832
Oxygen	0	0	0	2.60496E-11
Argon	0	0	0	2.62956E-11
CO2	0	0	0	0
H2O	0	257834.3456	1510071.61	80229.65345
Dextrose*	0	106080.4165	108590.7676	705.9059059
Fructose*	0	0	9.545450511	2.684161212
Galactose*	0	0	9.178317799	2.580924241
Arabinose*	0	0	4.405355638	1.239787017
Xylose*	0	0	0.73422594	0.206631169
Maltose*	0	1105.004338	1118.815309	3.879906065
Isomaltose*	0	1326.005206	1342.578371	4.655887328
Gluc_Olig*	0	1989.007809	2703.584825	200.915093
LacticAcid	0	0	68.19796482	19.07956616
Ammonia	0	0	0	0
N_Soluble*	0	0	1868.339333	522.7373704
N_Insoluble*	0	0	0	0
Cell_Mass*	0	0	0	0
Phytate*	0	0	587.9845587	164.8433259
Ethanol	0	0	335.9170023	88.85255422
1-Pentanol	0	0	14.81016936	54.15310084
nPentylAceta	0	0	1.71821E-08	54.58200112
triButylamin	0	0	4.14315E-14	1.06875E-14
TBA:HAc*	0	0	0	2313.861885
Ca(Ac)2*	0	0	733.6952248	189.2604335
CaCO3*	0	0	0	85918.9065
Ca(OH)2*	0	0	0	0
Ash_Soluble*	187.1921598	0	2426.454652	337.671265
Ash_Insolub*	0	0	0	0
Total, lb/hr	187.1921598	368334.7794	1629886.618	170815.7959
Heat Flow, Btu/hr	-296533.0357	-2060504984	-10567960974	-986287241.9


Rich Stripping Gas
ADJ-Ferm Temp2
Sugars
1102
RCY-1102
1102-rec
Clarifier Calcs
Product Concentration, g/l as HAc 49.99
1105
TEE-100
1106
1108
T-1100c
Nutrients+CaCO3
MIX-100
1100
1103
T-1100a
MIX-101
Clarifier Calcs
1101
MIX-104
Q.T-1100a
Q.T-1100b
T-1100b
1104
1107
1110
1109
X-1100
1111
MIX-103
Clarified Broth
Lean Stripping Gas
ADJ-Ferm Temp1
Fermentation Calcs
Fermentables Conversion, % 95.00
Selectivity to Acetate, % 90.00
Selectivity to Cell Mass, % 10.00
AA Catabolism Conversion, % 26.5
Fermentation Calcs
1112
P-1100
1113
X-1101
Cell Mass
HP.P-1100

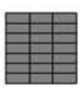
Flowsheet: Fermentation (FERM)

Stream	1100	1101	1102	1102-rec	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	114.6959445
Temperature, F	126.0087138	121.3614403	137.3542469	137.3542181	137.3542181	137.3542181	137.3542181	137.3542181	137.3542181	136.4255512	136.4255512	136.4255512	136.4255512	136.4255512	136.5944213
Components, lb/hr															
Hydrogen	7.18628E-13	7.94711E-07	0	0	7.94632E-07	7.9512E-11	0	0	7.94711E-07	7.94711E-07	8.03266E-11	1.55566E-16	7.89417E-11	1.38471E-12	1.38471E-12
CO	2.19739E-12	1.97663E-07	0	0	1.97228E-07	4.35383E-10	0	0	1.97663E-07	1.97663E-07	4.37113E-10	3.86113E-17	4.29577E-10	7.53515E-12	7.53515E-12
Nitrogen	0.126185832	283591.8172	0	0	283576.965	14.85220418	0	0	283591.8172	283591.8172	14.92292356	5.55163E-05	14.66562057	0.257247473	0.257247473
Oxygen	2.60496E-11	1.81345E-05	0	0	1.81317E-05	2.7624E-09	0	0	1.81345E-05	1.81345E-05	2.79766E-09	3.54967E-15	2.74943E-09	4.82273E-11	4.82273E-11
Argon	2.62956E-11	2.26792E-05	0	0	2.2676E-05	3.1715E-09	0	0	2.26792E-05	2.26792E-05	3.20614E-09	4.43932E-15	3.15087E-09	5.52689E-11	5.52689E-11
CO2	0	23.62865649	1374.120457	1374.130894	38462.39426	82.71343655	38545.1077	37170.97681	0	37170.97681	81.02955135	7.26117E-06	79.6327184	1.396825689	1.396825689
H2O	1919026.964	1929780.993	0	0	44247.74077	1902855.28	0	0	1947103.021	1947103.021	1904262.124	8.38703E-06	1871435.551	32826.57312	32826.57312
Dextrose*	110324.8156	110324.8156	0	0	4.34311E-14	10203.83549	0	0	10203.83549	10203.83549	10203.83549	7.67352E-24	10027.93694	175.8985528	175.8985528
Fructose*	775.9923031	775.9923031	0	0	1.65131E-16	38.79961515	0	0	38.79961515	38.79961515	38.79961515	2.91757E-26	38.130769	0.668846157	0.668846157
Galactose*	746.1464453	746.1464453	0	0	1.5878E-16	37.30732226	0	0	37.30732226	37.30732226	37.30732226	2.80536E-26	36.66420096	0.643121305	0.643121305
Arabinose*	358.1510002	358.1510002	0	0	1.25078E-12	17.90755001	0	0	17.90755001	17.90755001	17.90755001	2.24428E-22	17.59885118	0.308698835	0.308698835
Xylose*	59.69183337	59.69183337	0	0	2.08464E-13	2.984591668	0	0	2.984591668	2.984591668	2.984591668	3.74047E-23	2.933141863	0.051449806	0.051449806
Maltose*	1122.695215	1122.695215	0	0	1.37499E-17	56.13476077	0	0	56.13476077	56.13476077	56.13476077	2.47593E-27	55.16708316	0.967677614	0.967677614
Isomaltose*	1347.234259	1347.234259	0	0	1.64999E-17	67.36171293	0	0	67.36171293	67.36171293	67.36171293	2.97111E-27	66.20049979	1.161213137	1.161213137
Gluc_Olig*	2904.499918	2904.499918	0	0	6.03204E-07	2904.499917	0	0	2904.499918	2904.499918	2904.499917	1.07976E-16	2854.430771	50.06914631	50.06914631
LacticAcid	5542.725326	5542.727679	0	0	0.024053262	277.1123307	0	0	277.136384	277.136384	277.1136296	4.45469E-12	272.3366135	4.777016099	4.777016099
Ammonia	881.2646439	881.2646439	0	0	1.16764E-13	2.24493E-14	0	0	1.39213E-13	1.39213E-13	2.28579E-14	2.27791E-23	2.24639E-14	3.94035E-16	3.94035E-16
N_Soluble*	10322.4585	10322.5218	0	0	0.710580093	7591.344829	0	0	7592.05541	7592.05541	7591.376572	1.32899E-10	7460.512824	130.8637477	130.8637477
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	8934.834519	0	0	8934.834519	8934.834519	8934.834519	0	0	8934.834519	8934.834519
Phytate*	2389.462223	2389.462223	0	0	1.1384E-16	2389.462223	0	0	2389.462223	2389.462223	2389.462223	1.99379E-26	2348.271541	41.19068241	41.19068241
Ethanol	424.7695565	456.1676353	0	0	95.03275411	361.1348812	0	0	456.1676353	456.1676353	363.4529647	1.8151E-08	357.1875902	6.265374481	6.265374481
1-Pentanol	68.9632702	628.7145305	0	0	208.4980885	420.216442	0	0	628.7145305	628.7145305	424.9343032	3.98948E-08	417.6090842	7.325218937	7.325218937
nPentylAceta	54.58200114	2780.816449	0	0	1991.763713	789.0527361	0	0	2780.816449	2780.816449	804.6319915	3.86885E-07	790.7613634	13.87062766	13.87062766
triButylamin	5.21189E-14	5.21189E-14	0	0	0	0	0	0	0	0	0	0	0	0	0
TBA:HAc*	2313.861885	2313.868437	0	0	0.000443337	2313.867993	0	0	2313.868437	2313.868437	2313.868016	8.24398E-14	2273.980462	39.88755363	39.88755363
Ca(Ac)2*	922.9556582	922.9556582	0	0	22.60858228	136474.0922	0	0	136496.7007	136496.7007	136474.8769	4.27253E-09	134122.2583	2352.618618	2352.618618
CaCO3*	85790.19858	85790.19858	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	4904.340052	4904.340052	0	0	8.8509E-08	4904.340052	0	0	4904.340052	4904.340052	4904.340052	1.63332E-17	4819.796714	84.54333848	84.54333848
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	2150281.898	2447968.703	1374.120457	1374.130894	368605.7383	2080737.135	38545.1077	37170.97681	2410797.765	2447968.742	2082165.799	7.16138E-05	2037491.626	44674.17259	44674.17259
Heat Flow, Btu/hr	-13807460557	-13867504279	-5268640.731	-5268680.756	-400258078.3	-13468939839	-147789317.6	-142520636.9	-13724983605	-13867508513	-13480512642	-0.075762845	-13234892953	-245619688.7	-245603553.1

Stream	Cell Mass	Clarified Broth	Lean Stripping Gas	Nutrients+CaCO3	Rich Stripping Gas	Sugars
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	136.769661	136.4255512	172.0250768	160.4260018	136.4255512	112.3828485
Components, lb/hr						
Hydrogen	1.38471E-12	7.89419E-11	7.9471E-07	7.18628E-13	7.94631E-07	0
CO	7.53515E-12	4.29577E-10	1.97661E-07	2.19739E-12	1.97226E-07	0
Nitrogen	0.257247473	14.66567609	283591.691	0.126185832	283576.8943	0
Oxygen	4.82273E-11	2.74943E-09	1.81344E-05	2.60496E-11	1.81317E-05	0
Argon	5.52689E-11	3.15087E-09	2.26792E-05	2.62956E-11	2.2676E-05	0
CO2	1.396825689	79.63272566	23.62865649	0	37089.94725	0
H2O	32826.57312	1871435.551	10754.02876	408955.3539	42840.89663	1510071.61
Dextrose*	175.8985528	10027.93694	0	1734.04799	3.91961E-14	108590.7676
Fructose*	0.668846157	38.130769	0	766.4468526	1.49029E-16	9.545450511
Galactose*	0.643121305	36.66420096	0	736.9681275	1.43297E-16	9.178317799
Arabinose*	0.308698835	17.59885118	0	353.7456446	1.14637E-12	4.405355638
Xylose*	0.051449806	2.933141863	0	58.95760743	1.91062E-13	0.73422594
Maltose*	0.967677614	55.16708316	0	3.879906065	1.2647E-17	1118.815309
Isomaltose*	1.161213137	66.20049979	0	4.655887328	1.51764E-17	1342.578371
Gluc_Olig*	50.06914631	2854.430771	2.27136E-09	200.915093	5.51534E-07	2703.584825
LacticAcid	4.777016099	272.3366135	0.002352667	5474.527362	0.022754378	68.19796482
Ammonia	3.94035E-16	2.24639E-14	0	881.2646439	1.16355E-13	0
N_Soluble*	130.8637477	7460.512824	0.063296921	8454.119165	0.678837581	1868.339333
N_Insoluble*	0	0	0	0	0	0
Cell_Mass*	8934.834519	0	0	0	0	0
Phytate*	41.19068241	2348.271541	0	1801.477665	1.01842E-16	587.9845587
Ethanol	6.265374481	357.1875902	31.39807879	88.85255422	92.71467068	335.9170023
1-Pentanol	7.325218937	417.6090842	559.7512603	54.15310084	203.7802273	14.81016936
nPentylAceta	13.87062766	790.7613638	2726.234448	54.58200112	1976.184458	1.71821E-08
triButylamin	0	0	0	1.06875E-14	0	4.14315E-14
TBA:HAc*	39.88755363	2273.980462	0.006552077	2313.861885	0.000421096	0
Ca(Ac)2*	2352.618618	134122.2583	0	189.2604335	21.82379007	733.6952248
CaCO3*	0	0	0	85790.19858	0	0
Ca(OH)2*	0	0	0	0	0	0
Ash_Soluble*	84.54333848	4819.796714	8.9717E-09	2477.8854	8.34297E-08	2426.454652
Ash_Insolub*	0	0	0	0	0	0
Total, lb/hr	44674.17259	2037491.626	297686.8045	520395.28	365802.9434	1629886.618
Heat Flow, Btu/hr	-245603556.4	-13234892953	-60043809.72	-3239499583	-386995871	-10567960974



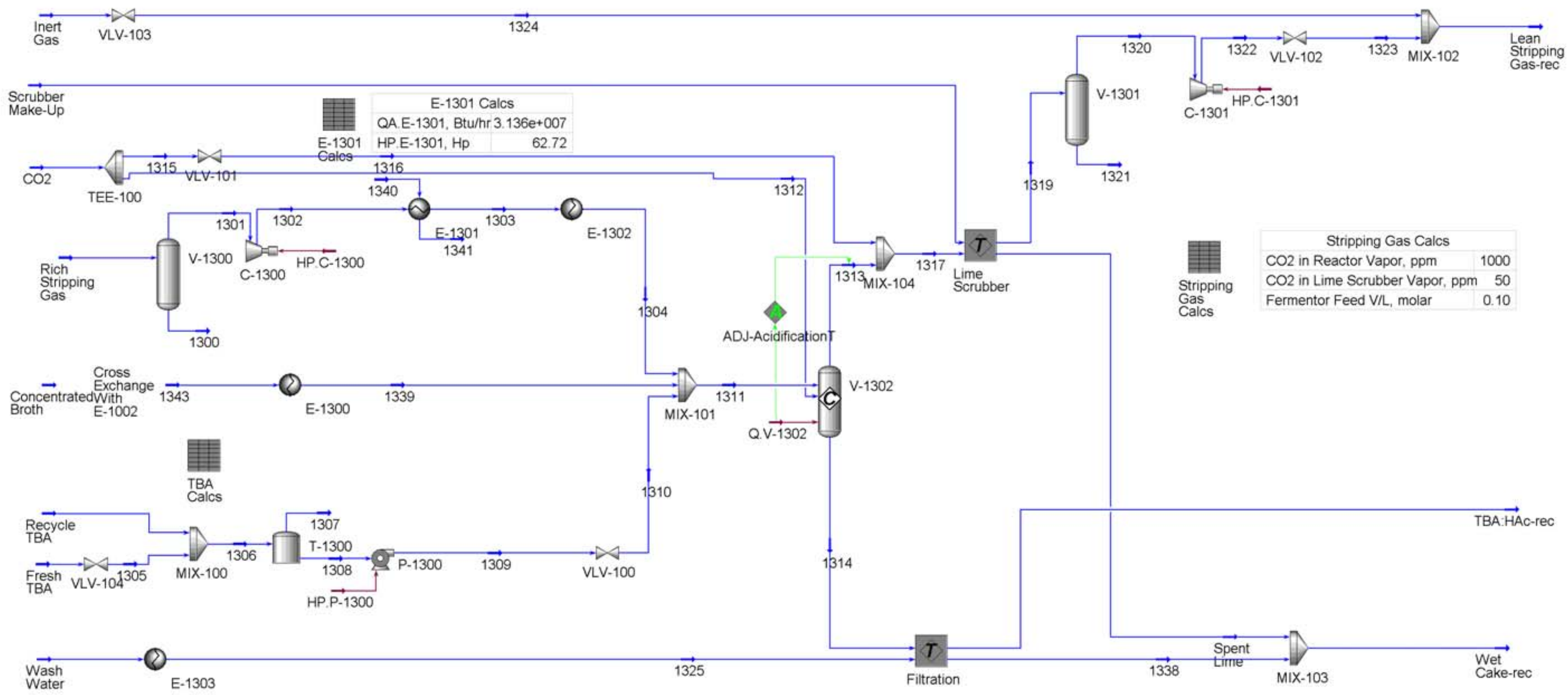
RO Calcs	
Inlet, g/l as HAc	49.99
Concentrate, g/l as HAc	80.00
H2O Recovery in Permeate	0.4085
Membrane Area, m2	22799
Power, kW	1734



RO Calcs

Flowsheet: Pre-Concentration (PREC)

Stream	1200	1201	1202	1203	1204	1205	Clarified Broth	Concentrated Broth	Permeate
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	24.69594446	14.69594446	24.696	14.69594446
Temperature, F	136.4255512	136.4255512	136.412727	136.412727	136.412727	136.427836	136.4255512	136.4127328	136.4527309
Components, lb/hr									
Hydrogen	1.00404E-16	7.89418E-11	0	0	0	0	7.89419E-11	7.89418E-11	0
CO	2.49202E-17	4.29577E-10	0	0	0	0	4.29577E-10	4.29577E-10	0
Nitrogen	3.58309E-05	14.66564025	0	0	0	0	14.66567609	14.66564025	0
Oxygen	2.291E-15	2.74943E-09	0	0	0	0	2.74943E-09	2.74943E-09	0
Argon	2.86519E-15	3.15087E-09	0	0	0	0	3.15087E-09	3.15087E-09	0
CO2	4.68643E-06	79.63272097	0	0	0	0	79.63272566	79.63272097	0
H2O	5.41305E-06	1871435.551	764411.1569	0	764411.1569	764411.1569	1871435.551	1107024.394	764411.1569
Dextrose*	4.95248E-24	10027.93694	0	0	0	0	10027.93694	10027.93694	0
Fructose*	1.883E-26	38.130769	0	0	0	0	38.130769	38.130769	0
Galactose*	1.81057E-26	36.66420096	0	0	0	0	36.66420096	36.66420096	0
Arabinose*	1.44846E-22	17.59885118	0	0	0	0	17.59885118	17.59885118	0
Xylose*	2.41411E-23	2.933141863	0	0	0	0	2.933141863	2.933141863	0
Maltose*	1.59797E-27	55.16708316	0	0	0	0	55.16708316	55.16708316	0
Isomaltose*	1.91756E-27	66.20049979	0	0	0	0	66.20049979	66.20049979	0
Gluc_Olig*	6.96879E-17	2854.430771	0	0	0	0	2854.430771	2854.430771	0
LacticAcid	2.87508E-12	272.3366135	0	0	0	0	272.3366135	272.3366135	0
Ammonia	1.47019E-23	2.24639E-14	0	0	0	0	2.24639E-14	2.24639E-14	0
N_Soluble*	8.57736E-11	7460.512824	0	0	0	0	7460.512824	7460.512824	0
N_Insoluble*	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0
Phytate*	1.28679E-26	2348.271541	0	0	0	0	2348.271541	2348.271541	0
Ethanol	1.17148E-08	357.1875902	0	0	0	0	357.1875902	357.1875902	0
1-Pentanol	2.57484E-08	417.6090842	0	0	0	0	417.6090842	417.6090842	0
nPentylAceta	2.49699E-07	790.7613636	0	0	0	0	790.7613638	790.7613636	0
triButylamin	0	0	0	0	0	0	0	0	0
TBA:HAc*	5.32071E-14	2273.980462	0	0	0	0	2273.980462	2273.980462	0
Ca(Ac)2*	2.75752E-09	134122.2583	0	0	0	0	134122.2583	134122.2583	0
CaCO3*	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0
Ash_Soluble*	1.05415E-17	4819.796714	0	0	0	0	4819.796714	4819.796714	0
Ash_Insolub*	0	0	0	0	0	0	0	0	0
Total, lb/hr	4.62204E-05	2037491.626	764411.1569	0	764411.1569	764411.1569	2037491.626	1273080.469	764411.1569
Heat Flow, Btu/hr	-0.048897992	-13234892953	-5151522553	0	-5151522553	-5151491787	-13234892953	-8083370400	-5151491787

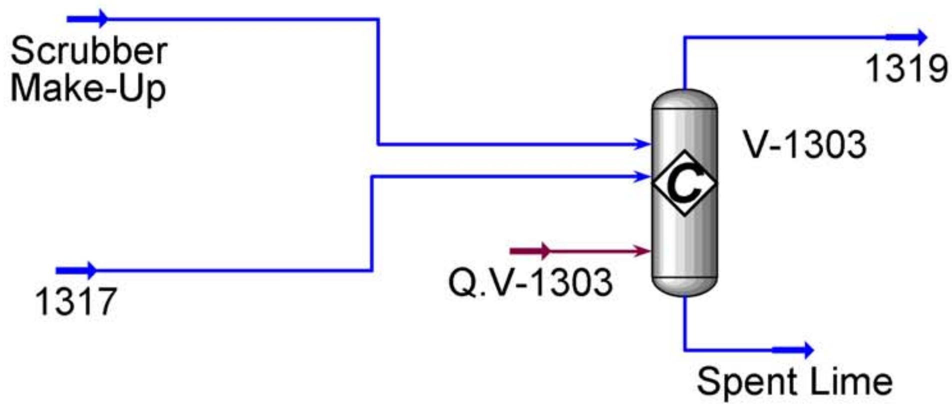

Inert Gas
VLV-103
1324
MIX-102
Lean Stripping Gas-rec
1320
1322
VLV-102
1323
V-1301
C-1301
HP.C-1301
1321
1319
Scrubber Make-Up
E-1301 Calcs
QA.E-1301, Btu/hr 3.136e+007
HP.E-1301, Hp 62.72
CO2
TEE-100
1315
VLV-101
1316
1340
1312
Rich Stripping Gas
V-1300
1301
1302
C-1300
HP.C-1300
E-1301
1341
1303
E-1302
1300
1304
MIX-104
1313
1317
Lime Scrubber
ADJ-AcidificationT
Stripping Gas Calcs
Stripping Gas Calcs
CO2 in Reactor Vapor, ppm 1000
CO2 in Lime Scrubber Vapor, ppm 50
Fermentor Feed V/L, molar 0.10
Concentrated Broth
Cross Exchange With E-1002
1343
E-1300
1339
MIX-101
1311
V-1302
Q.V-1302
TBA Calcs
1310
Recycle TBA
Fresh TBA
VLV-104
1305
MIX-100
1306
T-1300
1307
1308
P-1300
HP.P-1300
1309
VLV-100
1314
TBA:HAc-rec
Wash Water
E-1303
1325
Filtration
1338
Spent Lime
MIX-103
Wet Cake-rec

Flowsheet: Acidification (ACID)

Stream	1300	1301	1302	1303	1304	1305	1306	1307	1308	1309	1310	1311	1312	1313	1314
Pressure, psia	14.69594446	14.69594446	26.696	25.696	24.696	14.69594446	14.69594446	14.69594446	14.69594446	34.696	24.696	24.696	24.696	19.696	19.696
Temperature, F	136.4255512	136.4255512	273.7516964	140	110	60	109.9955309	109.9955309	109.9955309	110.1900444	110.1900444	110.1514996	60	104.6136311	104.6136311
Components, lb/hr															
Hydrogen	0	7.94631E-07	7.94631E-07	7.94631E-07	7.94631E-07	0	4.78634E-28	0	0	0	0	7.9471E-07	0	7.94573E-07	1.3666E-10
CO	0	1.97226E-07	1.97226E-07	1.97226E-07	1.97226E-07	0	6.65404E-27	0	0	0	0	1.97656E-07	0	1.97238E-07	4.17874E-10
Nitrogen	0	283576.8943	283576.8943	283576.8943	283576.8943	0	1.0394E-28	0	0	0	0	283591.5599	0	283567.5632	23.99650432
Oxygen	0	1.81317E-05	1.81317E-05	1.81317E-05	1.81317E-05	0	7.60314E-27	0	0	0	0	1.81344E-05	0	1.81295E-05	4.9538E-09
Argon	0	2.2676E-05	2.2676E-05	2.2676E-05	2.2676E-05	0	9.49153E-27	0	0	0	0	2.26791E-05	0	2.26741E-05	5.00057E-09
CO2	0	37089.94725	37089.94725	37089.94725	37089.94725	0	1.04565E-26	0	0	0	0	37169.57998	160.7302216	4.82846E-12	1.88538E-14
H2O	0	42840.89663	42840.89663	42840.89663	42840.89663	0	0.003380807	0	0.003380807	0.003380807	0.003380807	1149865.294	0	10570.03763	1124014.324
Dextrose*	0	3.91961E-14	3.91961E-14	3.91961E-14	3.91961E-14	0	1068.032045	0	1068.032045	1068.032045	1068.032045	11095.96898	0	1.04716E-15	11095.96899
Fructose*	0	1.49029E-16	1.49029E-16	1.49029E-16	1.49029E-16	0	4.060469274	0	4.060469274	4.060469274	4.060469274	42.19123827	0	3.9811E-18	42.19123828
Galactose*	0	1.43297E-16	1.43297E-16	1.43297E-16	1.43297E-16	0	3.904297286	0	3.904297286	3.904297286	3.904297286	40.56849824	0	3.82798E-18	40.56849825
Arabinose*	0	1.14637E-12	1.14637E-12	1.14637E-12	1.14637E-12	0	2.065050402	0	2.065050402	2.065050402	2.065050402	19.66390158	0	5.48261E-14	19.66390158
Xylose*	0	1.91062E-13	1.91062E-13	1.91062E-13	1.91062E-13	0	0.344175008	0	0.344175008	0.344175008	0.344175008	3.277316871	0	9.13767E-15	3.277316872
Maltose*	0	1.2647E-17	1.2647E-17	1.2647E-17	1.2647E-17	0	5.172409956	0	5.172409956	5.172409956	5.172409956	60.33949312	0	5.46845E-19	60.33949313
Isomaltose*	0	1.51764E-17	1.51764E-17	1.51764E-17	1.51764E-17	0	6.206902106	0	6.206902106	6.206902106	6.206902106	72.4074019	0	6.56215E-19	72.40740191
Gluc_Olig*	0	5.51534E-07	5.51534E-07	5.51534E-07	5.51534E-07	0	299.756696	0	299.756696	299.756696	299.756696	3154.187467	0	2.27133E-09	3154.187468
LacticAcid	0	0.022754378	0.022754378	0.022754378	0.022754378	0	10.52722031	0	10.52722031	10.52722031	10.52722031	282.8865882	0	0.002352697	282.8842355
Ammonia	0	1.16355E-13	1.16355E-13	1.16355E-13	1.16355E-13	0	0	0	0	0	0	1.38819E-13	0	0	0
N_Soluble*	0	0.678837581	0.678837581	0.678837581	0.678837581	0	295.7491163	0	295.7491163	295.7491163	295.7491163	7756.940778	0	0.063297928	7756.877482
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	1.01842E-16	1.01842E-16	1.01842E-16	1.01842E-16	0	156.1808986	0	156.1808986	156.1808986	156.1808986	2504.452439	0	1.84118E-18	2504.45244
Ethanol	0	92.71467068	92.71467068	92.71467068	92.71467068	0	2.69409E-06	0	2.69409E-06	2.69409E-06	2.69409E-06	449.9022635	0	31.33446532	418.5677982
1-Pentanol	0	203.7802273	203.7802273	203.7802273	203.7802273	0	9510.020228	0	9510.020228	9510.020228	9510.020228	10131.40954	0	559.7484906	9571.661049
nPentylAceta	0	1976.184458	1976.184458	1976.184458	1976.184458	0	10338.97649	0	10338.97649	10338.97649	10338.97649	13105.92231	0	2726.18022	10379.74209
triButylamin	0	0	0	0	0	32.53251004	314445.3309	0	314445.3309	314445.3309	314445.3309	314445.3309	0	0	0
TBA:HAc*	0	0.000421096	0.000421096	0.000421096	0.000421096	0	21430.49241	0	21430.49241	21430.49241	21430.49241	23704.4733	0	0.006552057	440022.7945
Ca(Ac)2*	0	21.82379007	21.82379007	21.82379007	21.82379007	0	17.94925201	0	17.94925201	17.94925201	17.94925201	134162.0314	0	0	0
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84896.87518
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	8.34297E-08	8.34297E-08	8.34297E-08	8.34297E-08	0	184.5020024	0	184.5020024	184.5020024	184.5020024	5004.298716	0	8.97162E-09	5004.298717
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	0	365802.9434	365802.9434	365802.9434	365802.9434	32.53251004	357779.274	0	357779.274	357779.274	357779.274	1996662.687	160.7302216	297454.9362	1699365.078
Heat Flow, Btu/hr	0	-386995871	-373316001.3	-404675939.2	-422695905.5	-21771.70188	-271399409.4	0	-271399409.4	-271362666.7	-271362666.7	-8812354824	-618878.3861	-64081074.93	-8748892510

Stream	1315	1316	1317	1319	1320	1321	1322	1323	1324	1325	1338	1339	1340	1341	1343
Pressure, psia	24.696	19.696	19.696	14.69594446	14.69594446	14.69594446	19.69594446	14.69594446	14.69594446	14.696	14.696	24.696	14.76812681	14.69594446	24.696
Temperature, F	60	60	104.5562363	107.8503743	107.8503743	107.8503743	172.0372421	172.0341059	60	200	155.5633506	110	90	150	116.4040141
Components, lb/hr															
Hydrogen	0	0	7.94573E-07	7.94573E-07	7.94573E-07	0	7.94573E-07	7.94573E-07	0	0	7.18627E-13	7.89418E-11	0	0	7.89418E-11
CO	0	0	1.97238E-07	1.97238E-07	1.97238E-07	0	1.97238E-07	1.97238E-07	0	0	2.19739E-12	4.29577E-10	0	0	4.29577E-10
Nitrogen	0	0	283567.5632	283567.5632	283567.5632	0	283567.5632	283567.5632	24.44081797	0	0.126185714	14.66564025	1579166.346	1579166.346	14.66564025
Oxygen	0	0	1.81295E-05	1.81295E-05	1.81295E-05	0	1.81295E-05	1.81295E-05	0	0	2.60496E-11	2.74943E-09	483895.6456	483895.6456	2.74943E-09
Argon	0	0	2.26741E-05	2.26741E-05	2.26741E-05	0	2.26741E-05	2.26741E-05	0	0	2.62955E-11	3.15087E-09	26936.58741	26936.58741	3.15087E-09
CO2	473.0235043	473.0235043	473.0235043	23.62870548	23.62870548	0	23.62870548	23.62870548	0	0	9.91428E-17	79.63272097	1112.031519	1112.031519	79.63272097
H2O	0	0	10570.03763	10753.99462	10753.99462	0	10753.99462	10753.99462	0	82576.67356	80229.64003	1107024.394	41764.02678	41764.02678	1107024.394
Dextrose*	0	0	1.04716E-15	0	0	0	0	0	0	719.5086473	705.9059799	10027.93694	0	0	10027.93694
Fructose*	0	0	3.9811E-18	0	0	0	0	0	0	2.735885894	2.684160101	38.130769	0	0	38.130769
Galactose*	0	0	3.82798E-18	0	0	0	0	0	0	2.630659514	2.580923173	36.66420096	0	0	36.66420096
Arabinose*	0	0	5.48261E-14	0	0	0	0	0	0	1.262648666	1.239786504	17.59885118	0	0	17.59885118
Xylose*	0	0	9.13767E-15	0	0	0	0	0	0	0.210441444	0.206631084	2.933141863	0	0	2.933141863
Maltose*	0	0	5.46845E-19	0	0	0	0	0	0	3.958455527	3.879905441	55.16708316	0	0	55.16708316
Isomaltose*	0	0	6.56215E-19	0	0	0	0	0	0	4.750146629	4.655886579	66.20049979	0	0	66.20049979
Gluc_Olig*	0	0	2.27133E-09	2.27133E-09	2.27133E-09	0	2.27133E-09	2.27133E-09	0	204.8097338	200.9150679	2854.430771	0	0	2854.430771
LacticAcid	0	0	0.002352697	0.002352697	0.002352697	0	0.002352697	0.002352697	0	19.54667826	19.07955832	272.3366135	0	0	272.3366135
Ammonia	0	0	0	0	0	0	0	0	0	0	0	2.24639E-14	0	0	2.24639E-14
N_Soluble*	0	0	0.063297928	0.063297928	0.063297928	0	0.063297928	0.063297928	0	535.4973263	522.737165	7460.512824	0	0	7460.512824
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	0	1.84118E-18	0	0	0	0	0	0	168.5262166	164.8432681	2348.271541	0	0	2348.271541
Ethanol	0	0	31.33446532	31.33446532	31.33446532	0	31.33446532	31.33446532	0	96.27943566	88.85253254	357.1875902	0	0	357.1875902
1-Pentanol	0	0	559.7484906	559.7484906	559.7484906	0	559.7484906	559.7484906	0	4.244842442	54.1529762	417.6090842	0	0	417.6090842
nPentylAceta	0	0	2726.18022	2726.18022	2726.18022	0	2726.18022	2726.18022	0	4.92468E-09	54.58191538	790.7613636	0	0	790.7613636
triButylamin	0	0	0	0	0	0	0	0	0	1.1875E-14	1.06875E-14	0	0	0	0
TBA:HAc*	0	0	0.006552057	0.006552057	0.006552057	0	0.006552057	0.006552057	0	0	2313.861629	2273.980462	0	0	2273.980462
Ca(Ac)2*	0	0	0	0	0	0	0	0	0	210.2893325	189.2603992	134122.2583	0	0	134122.2583
CaCO3*	0	0	0	0	0	0	0	0	0	0	84896.87518	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	0	8.97162E-09	8.97162E-09	8.97162E-09	0	8.97162E-09	8.97162E-09	0	345.9511736	337.6711811	4819.796714	0	0	4819.796714
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	473.0235043	473.0235043	297927.9597	297662.5219	297662.5219	0	297662.5219	297662.5219	24.44081797	84896.87518	169793.7504	1273080.469	2132874.637	2132874.637	1273080.469
Heat Flow, Btu/hr	-1821337.767	-1821337.767	-65902412.7	-64978732.87	-64978732.87	0	-60043260.65	-60043260.65	-103.139474	-555032812.5	-981019985	-8118296252	-237567797.7	-206207859.7	-8110175567

Stream	CO2	Concentrated Broth	Fresh TBA	Inert Gas	Lean Stripping Gas-rec	Recycle TBA	Rich Stripping Gas	Scrubber Make-Up	Spent Lime	TBA:HAc-rec	Wash Water	Wet Cake-rec
Pressure, psia	24.696	24.696	14.69594446	30	14.69594446	14.69594446	14.69594446	19.69594446	14.69594446	14.696	14.696	14.69594446
Temperature, F	60	136.4127328	60	60	172.0252577	110	136.4255512	60	107.8503743	105.3861267	134.860701	155.3103282
Components, lb/hr												
Hydrogen	0	7.89418E-11	0	0	7.94573E-07	4.78634E-28	7.94631E-07	0	0	1.35941E-10	0	7.18627E-13
CO	0	4.29577E-10	0	0	1.97238E-07	6.65404E-27	1.97226E-07	0	0	4.15677E-10	0	2.19739E-12
Nitrogen	0	14.66564025	0	24.44081797	283592.004	1.0394E-28	283576.8943	0	0	23.8703186	0	0.126185714
Oxygen	0	2.74943E-09	0	0	1.81295E-05	7.60314E-27	1.81317E-05	0	0	4.92775E-09	0	2.60496E-11
Argon	0	3.15087E-09	0	0	2.26741E-05	9.49153E-27	2.2676E-05	0	0	4.97428E-09	0	2.62955E-11
CO2	633.7537259	79.63272097	0	0	23.62870548	1.04565E-26	37089.94725	0	0	1.87547E-14	0	9.91428E-17
H2O	0	1107024.394	0	0	10753.99462	0.003380807	42840.89663	0	0	1126361.357	82576.67356	80229.64003
Dextrose*	0	10027.93694	0	0	0	1068.032045	3.91961E-14	0	0	11109.57165	719.5086473	705.9059799
Fructose*	0	38.130769	0	0	0	4.060469274	1.49029E-16	0	0	42.24296407	2.735885894	2.684160101
Galactose*	0	36.66420096	0	0	0	3.904297286	1.43297E-16	0	0	40.61823459	2.630659514	2.580923173
Arabinose*	0	17.59885118	0	0	0	2.065050402	1.14637E-12	0	0	19.68676374	1.262648666	1.239786504
Xylose*	0	2.933141863	0	0	0	0.344175008	1.91062E-13	0	0	3.281127232	0.210441444	0.206631084
Maltose*	0	55.16708316	0	0	0	5.172409956	1.2647E-17	0	0	60.41804321	3.958455527	3.879905441
Isomaltose*	0	66.20049979	0	0	0	6.206902106	1.51764E-17	0	0	72.50166196	4.750146629	4.655886579
Gluc_Olig*	0	2854.430771	0	0	2.27133E-09	299.756696	5.51534E-07	0	0	3158.082134	204.8097338	200.9150679
LacticAcid	0	272.3366135	0	0	0.002352697	10.52722031	0.022754378	0	0	283.3513555	19.54667826	19.07955832
Ammonia	0	2.24639E-14	0	0	0	0	1.16355E-13	0	0	0	0	0
N_Soluble*	0	7460.512824	0	0	0.063297928	295.7491163	0.678837581	0	0	7769.637643	535.4973263	522.737165
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	2348.271541	0	0	0	156.1808986	1.01842E-16	0	0	2508.135388	168.5262166	164.8432681
Ethanol	0	357.1875902	0	0	31.33446532	2.69409E-06	92.71467068	0	0	425.9947014	96.27943566	88.85253254
1-Pentanol	0	417.6090842	0	0	559.7484906	9510.020228	203.7802273	0	0	9521.752916	4.244842442	54.1529762
nPentylAceta	0	790.7613636	0	0	2726.18022	10338.97649	1976.184458	0	0	10325.16017	4.92468E-09	54.58191538
triButylamin	0	0	32.53251004	0	0	314412.7984	0	0	0	1.1875E-15	1.1875E-14	1.06875E-14
TBA:HAc*	0	2273.980462	0	0	0.006552057	21430.49241	0.000421096	0	0	437708.9328	0	2313.861629
Ca(Ac)2*	0	134122.2583	0	0	0	17.94925201	21.82379007	0	0	21.02893325	210.2893325	189.2603992
CaCO3*	0	0	0	0	0	0	0	0	1022.017067	0	0	85918.89225
Ca(OH)2*	0	0	0	0	0	0	0	756.5803021	0	0	0	0
Ash_Soluble*	0	4819.796714	0	0	8.97162E-09	184.5020024	8.34297E-08	0	0	5012.578709	345.9511736	337.6711811
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	633.7537259	1273080.469	32.53251004	24.44081797	297686.9627	357746.7415	365802.9434	756.5803021	1022.017067	1614468.203	84896.87518	170815.7674
Heat Flow, Btu/hr	-2440216.153	-8083370400	-21771.70188	-103.139474	-60043363.79	-271377637.7	-386995871	-4344073.363	-5266919.193	-8322905625	-562456526.3	-986286962

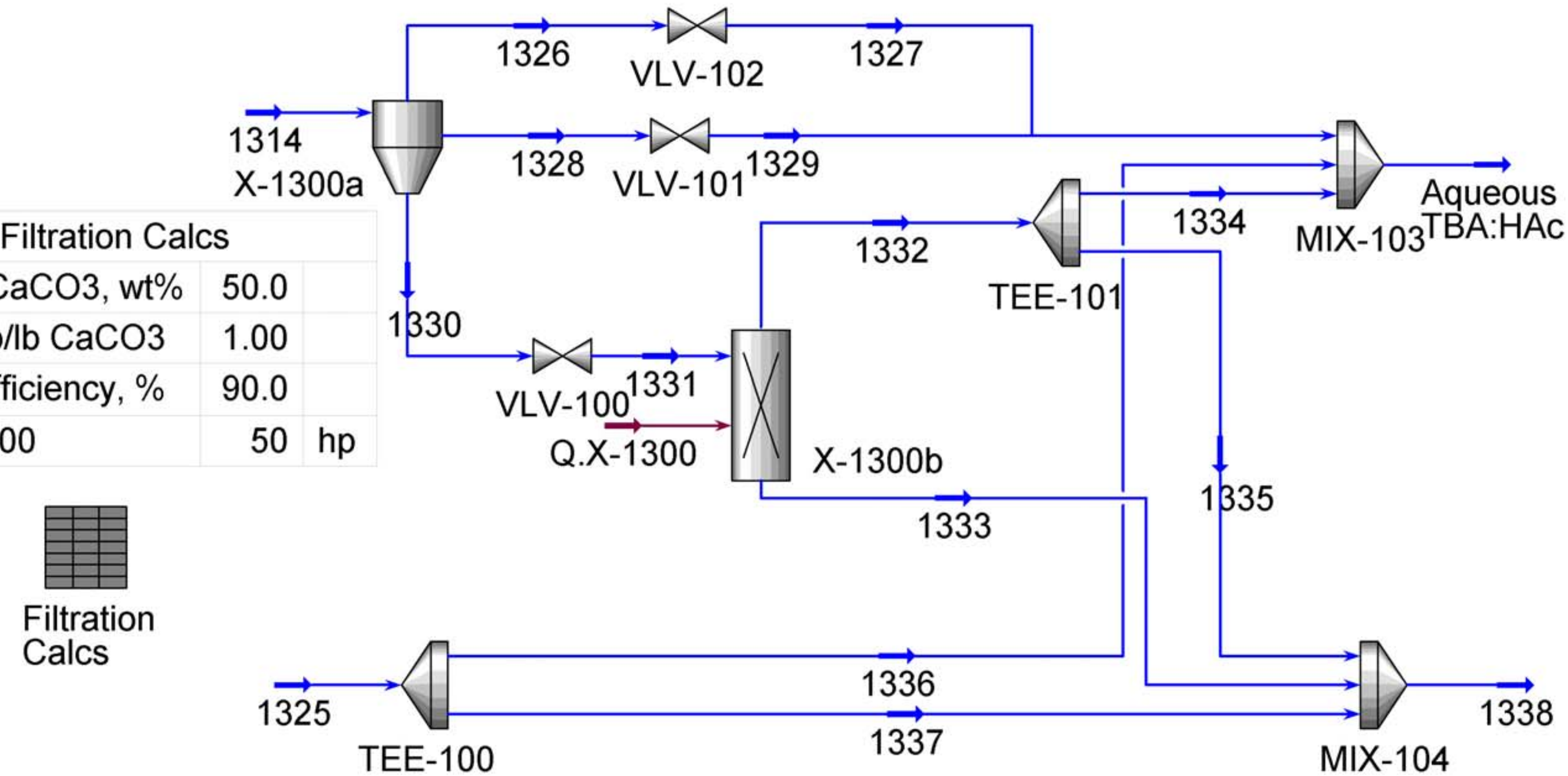


Scrubber Calcs		
Inlet CO2, ppm mol	1000	
Outlet CO2, ppm mol	49.95	
HP.V-1303	25	hp

Scrubber Calcs

Flowsheet: Lime Scrubber (SCRB)

Stream	1317	1319	Scrubber Make-Up	Spent Lime
Pressure, psia	19.696	14.69594446	19.69594446	14.69594446
Temperature, F	104.5562363	107.8503743	60	107.8503743
Components, lb/hr				
Hydrogen	7.94573E-07	7.94573E-07	0	0
CO	1.97238E-07	1.97238E-07	0	0
Nitrogen	283567.5632	283567.5632	0	0
Oxygen	1.81295E-05	1.81295E-05	0	0
Argon	2.26741E-05	2.26741E-05	0	0
CO2	473.0235043	23.62870548	0	0
H2O	10570.03763	10753.99462	0	0
Dextrose*	1.04716E-15	0	0	0
Fructose*	3.9811E-18	0	0	0
Galactose*	3.82798E-18	0	0	0
Arabinose*	5.48261E-14	0	0	0
Xylose*	9.13767E-15	0	0	0
Maltose*	5.46845E-19	0	0	0
Isomaltose*	6.56215E-19	0	0	0
Gluc_Olig*	2.27133E-09	2.27133E-09	0	0
LacticAcid	0.002352697	0.002352697	0	0
Ammonia	0	0	0	0
N_Soluble*	0.063297928	0.063297928	0	0
N_Insoluble*	0	0	0	0
Cell_Mass*	0	0	0	0
Phytate*	1.84118E-18	0	0	0
Ethanol	31.33446532	31.33446532	0	0
1-Pentanol	559.7484906	559.7484906	0	0
nPentylAceta	2726.18022	2726.18022	0	0
triButylamin	0	0	0	0
TBA:HAc*	0.006552057	0.006552057	0	0
Ca(Ac)2*	0	0	0	0
CaCO3*	0	0	0	1022.017067
Ca(OH)2*	0	0	756.5803021	0
Ash_Soluble*	8.97162E-09	8.97162E-09	0	0
Ash_Insolub*	0	0	0	0
Total, lb/hr	297927.9597	297662.5219	756.5803021	1022.017067
Heat Flow, Btu/hr	-65902412.7	-64978732.87	-4344073.363	-5266919.193

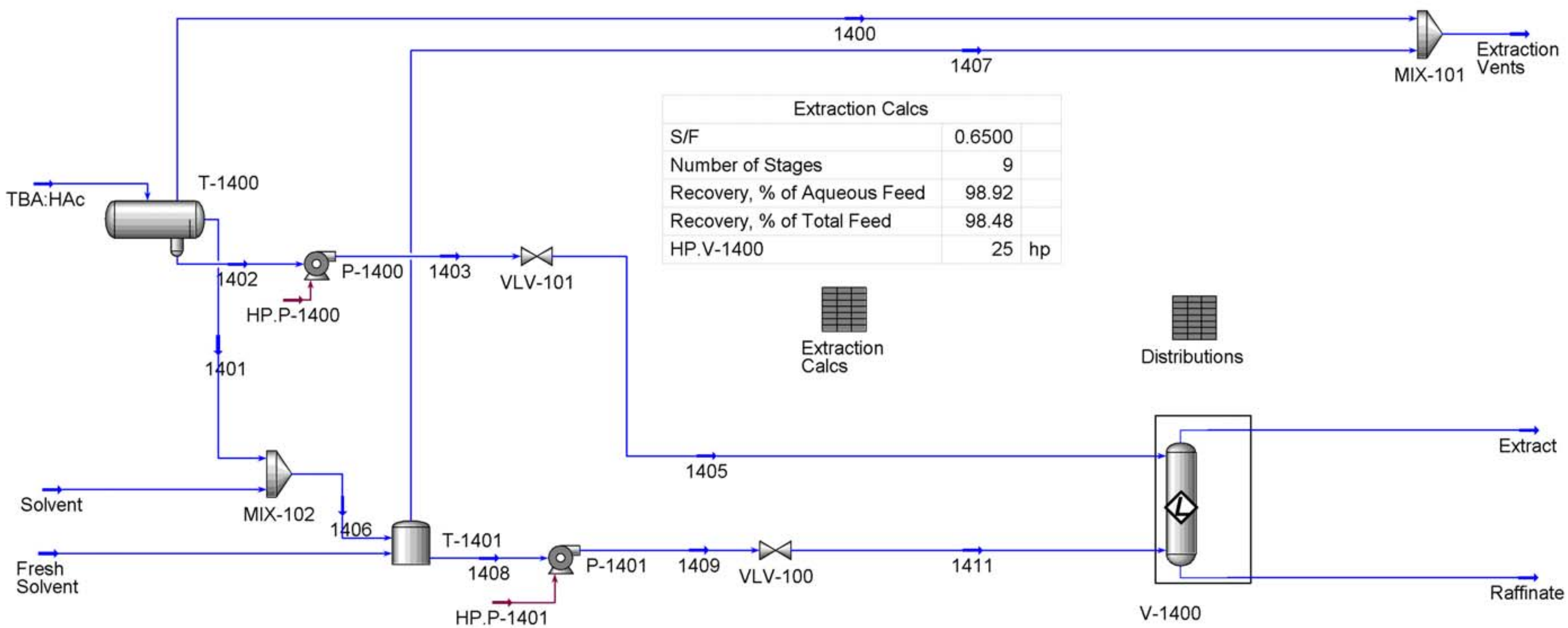


Filtration Calcs		
FIltrate CaCO3, wt%	50.0	
Wash, lb/lb CaCO3	1.00	
Wash Efficiency, %	90.0	
HP.X-1300	50	hp

Flowsheet: Filtration (FILT)

Stream	1314	1325	1326	1327	1328	1329	1330	1331	1332	1333	1334	1335	1336	1337	1338
Pressure, psia	19.696	14.696	19.696	14.696	19.696	14.696	19.696	14.696	14.696	14.696	14.696	14.696	14.696	14.696	14.696
Temperature, F	104.6135358	200	104.6135358	104.6235105	104.6135358	104.6242393	104.6135358	104.618221	104.618221	104.618221	104.618221	104.618221	200	200	155.5636652
Components, lb/hr															
Hydrogen	1.3666E-10	0	0	0	1.29474E-10	1.29474E-10	7.18627E-12	7.18627E-12	7.18627E-12	0	6.46764E-12	7.18627E-13	0	0	7.18627E-13
CO	4.17874E-10	0	0	0	3.959E-10	3.959E-10	2.19739E-11	2.19739E-11	2.19739E-11	0	1.97765E-11	2.19739E-12	0	0	2.19739E-12
Nitrogen	23.99650432	0	0	0	22.73464717	22.73464717	1.261857142	1.261857142	1.261857142	0	1.135671427	0.126185714	0	0	0.126185714
Oxygen	4.9538E-09	0	0	0	4.6933E-09	4.6933E-09	2.60496E-10	2.60496E-10	2.60496E-10	0	2.34446E-10	2.60496E-11	0	0	2.60496E-11
Argon	5.00057E-09	0	0	0	4.73762E-09	4.73762E-09	2.62955E-10	2.62955E-10	2.62955E-10	0	2.3666E-10	2.62955E-11	0	0	2.62955E-11
CO2	1.88538E-14	0	0	0	1.78624E-14	1.78624E-14	9.91428E-16	9.91428E-16	9.91428E-16	0	8.92285E-16	9.91428E-17	0	0	9.91428E-17
H2O	1124014.324	82576.67356	0	0	1064907.986	1064907.986	59106.33828	59106.33828	59106.33828	0	53195.70446	5910.633828	8257.667356	74319.0062	80229.64003
Dextrose*	11095.96899	719.5086473	0	0	10512.48701	10512.48701	583.481974	583.481974	583.481974	0	525.1337766	58.3481974	71.95086473	647.5577825	705.9059799
Fructose*	42.19123828	2.735885894	0	0	39.97261032	39.97261032	2.218627957	2.218627957	2.218627957	0	1.996765161	0.221862796	0.273588589	2.462297305	2.684160101
Galactose*	40.56849825	2.630659514	0	0	38.43520214	38.43520214	2.133296107	2.133296107	2.133296107	0	1.919966496	0.213329611	0.263065951	2.367593562	2.580923173
Arabinose*	19.66390158	1.262648666	0	0	18.62987453	18.62987453	1.034027053	1.034027053	1.034027053	0	0.930624348	0.103402705	0.126264867	1.136383799	1.239786504
Xylose*	3.277316872	0.210441444	0	0	3.104979032	3.104979032	0.172337839	0.172337839	0.172337839	0	0.155104055	0.017233784	0.021044144	0.1893973	0.206631084
Maltose*	60.33949313	3.958455527	0	0	57.16653846	57.16653846	3.172954665	3.172954665	3.172954665	0	2.855659199	0.317295467	0.395845553	3.562609975	3.879905441
Isomaltose*	72.40740191	4.750146629	0	0	68.59985578	68.59985578	3.807546133	3.807546133	3.807546133	0	3.426791519	0.380754613	0.475014663	4.275131966	4.655886579
Gluc_Olig*	3154.187468	204.8097338	0	0	2988.324393	2988.324393	165.8630745	165.8630745	165.8630745	0	149.276767	16.58630745	20.48097338	184.3287604	200.9150679
LacticAcid	282.8842355	19.54667826	0	0	268.0087566	268.0087566	14.87547887	14.87547887	14.87547887	0	13.38793098	1.487547887	1.954667826	17.59201043	19.07955832
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	7756.877482	535.4973263	0	0	7348.981768	7348.981768	407.8957134	407.8957134	407.8957134	0	367.106142	40.78957134	53.54973263	481.9475937	522.737165
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	2504.45244	168.5262166	0	0	2372.755708	2372.755708	131.696732	131.696732	131.696732	0	118.5270588	13.1696732	16.85262166	151.6735949	164.8432681
Ethanol	418.5677982	96.27943566	0	0	396.5573938	396.5573938	22.01040445	22.01040445	22.01040445	0	19.80936401	2.201040445	9.627943566	86.6514921	88.85253254
1-Pentanol	9571.661049	4.244842442	0	0	9068.334869	9068.334869	503.3261801	503.3261801	503.3261801	0	452.9935621	50.33261801	0.424484244	3.820358198	54.1529762
nPentylAceta	10379.74209	4.92468E-09	0	0	9833.922933	9833.922933	545.8191538	545.8191538	545.8191538	0	491.2372384	54.58191538	4.92468E-10	4.43221E-09	54.58191538
triButylamin	0	1.1875E-14	0	0	0	0	0	0	0	0	0	0	1.1875E-15	1.06875E-14	1.06875E-14
TBA:HAc*	440022.7945	0	0	0	416884.1782	416884.1782	23138.61629	23138.61629	23138.61629	0	20824.75466	2313.861629	0	0	2313.861629
Ca(Ac)2*	0	210.2893325	0	0	0	0	0	0	0	0	0	0	21.02893325	189.2603992	189.2603992
CaCO3*	84896.87518	0	0	0	0	0	84896.87518	84896.87518	0	84896.87518	0	0	0	0	84896.87518
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	5004.298717	345.9511736	0	0	4741.147468	4741.147468	263.1512487	263.1512487	263.1512487	0	236.8361238	26.31512487	34.59511736	311.3560562	337.6711811
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	1699365.078	84896.87518	0	0	1529571.328	1529571.328	169793.7504	169793.7504	84896.87518	84896.87518	76407.18766	8489.687518	8489.687518	76407.18766	169793.7504
Heat Flow, Btu/hr	-8748892647	-555032812.5	0	0	-7874066104	-7874066104	-874826543	-874826572.6	-437040266.2	-437786306.5	-393336239.5	-43704026.62	-55503281.25	-499529531.3	-981019924.7

Stream	Aqueous TBA:HAc
Pressure, psia	14.696
Temperature, F	105.3861267
Components, lb/hr	
Hydrogen	1.35941E-10
CO	4.15677E-10
Nitrogen	23.8703186
Oxygen	4.92775E-09
Argon	4.97428E-09
CO2	1.87547E-14
H2O	1126361.357
Dextrose*	11109.57165
Fructose*	42.24296407
Galactose*	40.61823459
Arabinose*	19.68676374
Xylose*	3.281127232
Maltose*	60.41804321
Isomaltose*	72.50166196
Gluc_Olig*	3158.082134
LacticAcid	283.3513555
Ammonia	0
N_Soluble*	7769.637643
N_Insoluble*	0
Cell_Mass*	0
Phytate*	2508.135388
Ethanol	425.9947014
1-Pentanol	9521.752916
nPentylAceta	10325.16017
triButylamin	1.1875E-15
TBA:HAc*	437708.9328
Ca(Ac)2*	21.02893325
CaCO3*	0
Ca(OH)2*	0
Ash_Soluble*	5012.578709
Ash_Insolub*	0
Total, lb/hr	1614468.203
Heat Flow, Btu/hr	-8322905625



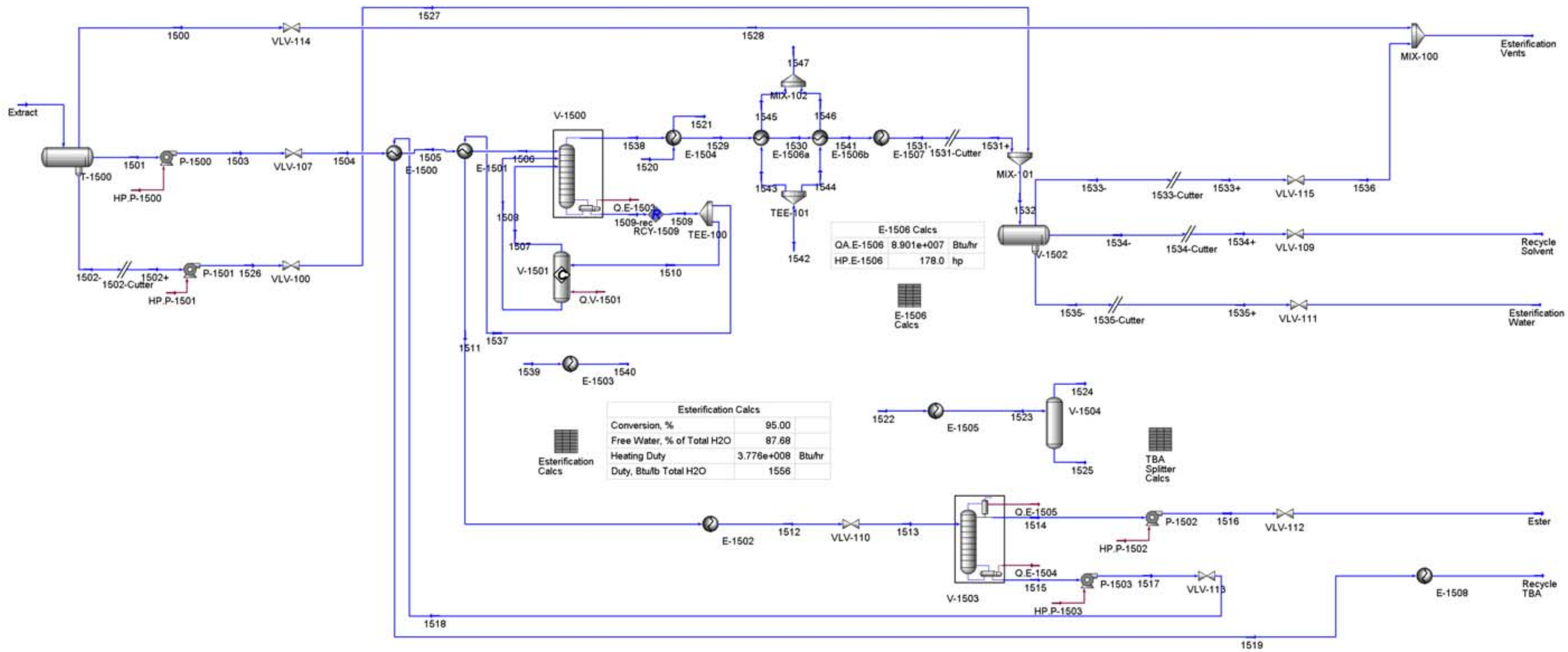
Extraction Calcs		
S/F	0.6500	
Number of Stages	9	
Recovery, % of Aqueous Feed	98.92	
Recovery, % of Total Feed	98.48	
HP.V-1400	25	hp

Flowsheet: Extraction (EXTR)

Stream	1400	1401	1402	1403	1405	1406	1407
Pressure, psia	14.696	14.696	14.696	24.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	105.3860813	105.3860813	105.3860813	105.4133827	105.4352371	109.7855463	109.7781592
Components, lb/hr							
Hydrogen	2.26005E-11	0	1.13341E-10	1.13341E-10	1.13341E-10	9.9472E-11	0
CO	6.5722E-12	0	4.09104E-10	4.09104E-10	4.09104E-10	2.02361E-10	0
Nitrogen	6.87105847	0	16.99924147	16.99924147	16.99924147	20.47385602	0
Oxygen	5.50648E-10	0	4.37709E-09	4.37709E-09	4.37709E-09	4.69776E-09	0
Argon	6.69845E-10	0	4.30443E-09	4.30443E-09	4.30443E-09	4.52827E-09	0
CO2	1.9362E-16	0	2.19085E-14	2.19085E-14	2.19085E-14	3.93915E-14	0
H2O	0.360455042	0	1126356.185	1126356.185	1126356.185	31469.82368	0
Dextrose*	9.00467E-18	0	11109.43947	11109.43947	11109.43947	38.54107372	0
Fructose*	3.4236E-20	0	42.2422827	42.2422827	42.2422827	0.146546413	0
Galactose*	3.29192E-20	0	40.61757943	40.61757943	40.61757943	0.140910012	0
Arabinose*	2.02112E-16	0	19.68647623	19.68647623	19.68647623	0.052458629	0
Xylose*	3.36853E-17	0	3.281079313	3.281079313	3.281079313	0.008743104	0
Maltose*	2.98958E-19	0	60.41668285	60.41668285	60.41668285	3.124017058	0
Isomaltose*	3.5875E-19	0	72.50002952	72.50002952	72.50002952	3.748820048	0
Gluc_Olig*	2.97953E-11	0	3158.060949	3158.060949	3158.060949	89.37730056	0
LacticAcid	4.13455E-08	0	283.350163	283.350163	283.350163	5.147297724	0
Ammonia	0	0	0	0	0	0	0
N_Soluble*	7.95093E-07	0	7769.606661	7769.606661	7769.606661	957.325565	0
N_Insoluble*	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0
Phytate*	6.75158E-21	0	2508.11942	2508.11942	2508.11942	4.469264578	0
Ethanol	0.002206489	0	425.9998885	425.9998885	425.9998885	1185.865745	0
1-Pentanol	0.02223405	0	9521.660918	9521.660918	9521.660918	999272.0239	0
nPentylAceta	1.090079792	0	10324.06628	10324.06628	10324.06628	6645.15143	0
triButylamin	5.6155E-15	0	2.50333E-11	2.50333E-11	2.50333E-11	7428.232131	0
TBA:HAc*	5.84776E-09	0	437707.4179	437707.4179	437707.4179	1927.998476	0
Ca(Ac)2*	1.03036E-08	0	21.01549298	21.01549298	21.01549298	119.1985361	0
CaCO3*	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0
Ash_Soluble*	1.6357E-13	0	5012.567815	5012.567815	5012.567815	62.08964536	0
Ash_Insolub*	0	0	0	0	0	0	0
Total, lb/hr	8.346034695	0	1614453.233	1614453.233	1614453.233	1049232.939	0
Heat Flow, Btu/hr	-3865.150357	0	-8322866267	-8322799650	-8322799650	-1943331992	0

Stream	1408	1409	1411	Extract	Extraction Vents	Fresh Solvent	Raffinate	Solvent
Pressure, psia	14.69594446	24.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	109.7781592	109.8544993	109.8557362	105.4953106	127.3951588	60	108.3517867	109.7855463
Components, lb/hr								
Hydrogen	9.9472E-11	9.9472E-11	9.9472E-11	1.85461E-10	2.26005E-11	0	2.73517E-11	9.9472E-11
CO	2.02361E-10	2.02361E-10	2.02361E-10	2.19826E-10	6.5722E-12	0	3.91639E-10	2.02361E-10
Nitrogen	20.47385602	20.47385602	20.47385602	35.60724675	6.87105847	0	1.865850735	20.47385602
Oxygen	4.69776E-09	4.69776E-09	4.69776E-09	7.53699E-09	5.50648E-10	0	1.53786E-09	4.69776E-09
Argon	4.52827E-09	4.52827E-09	4.52827E-09	7.65553E-09	6.69845E-10	0	1.17716E-09	4.52827E-09
CO2	3.93915E-14	3.93915E-14	3.93915E-14	5.43509E-14	1.9362E-16	0	6.94906E-15	3.93915E-14
H2O	31469.82368	31469.82368	31469.82368	293779.4817	0.360455042	0	864046.5266	31469.82368
Dextrose*	38.54107372	38.54107372	38.54107372	1965.757989	9.00467E-18	0	9182.222552	38.54107372
Fructose*	0.146546413	0.146546413	0.146546413	7.474115092	3.4236E-20	0	34.91471402	0.146546413
Galactose*	0.140910012	0.140910012	0.140910012	7.186649048	3.29192E-20	0	33.57184039	0.140910012
Arabinose*	0.052458629	0.052458629	0.052458629	3.137094565	2.02112E-16	0	16.60184029	0.052458629
Xylose*	0.008743104	0.008743104	0.008743104	0.522849031	3.36853E-17	0	2.766973386	0.008743104
Maltose*	3.124017058	3.124017058	3.124017058	28.36192934	2.98958E-19	0	35.17877057	3.124017058
Isomaltose*	3.748820048	3.748820048	3.748820048	34.03432051	3.5875E-19	0	42.21452906	3.748820048
Gluc_Olig*	89.37730056	89.37730056	89.37730056	306.8185984	2.97953E-11	0	2940.619651	89.37730056
LacticAcid	5.147297724	5.147297724	5.147297724	10.82664003	4.13455E-08	0	277.6708207	5.147297724
Ammonia	0	0	0	0	0	0	0	0
N_Soluble*	957.325565	957.325565	957.325565	297.0980589	7.95093E-07	0	8429.834168	957.325565
N_Insoluble*	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0
Phytate*	4.469264578	4.469264578	4.469264578	299.7740519	6.75158E-21	0	2212.814633	4.469264578
Ethanol	1185.865745	1185.865745	1185.865745	244.0434874	0.002206489	0	1367.822146	1185.865745
1-Pentanol	999433.6859	999433.6859	999433.6859	996471.3063	0.02223405	161.661996	12484.04051	999272.0239
nPentylAceta	6645.15143	6645.15143	6645.15143	16961.95626	1.090079792	0	7.261448046	6645.15143
triButylamin	7428.232131	7428.232131	7428.232131	7427.767183	5.6155E-15	0	0.464948088	7428.232131
TBA:HAc*	1927.998476	1927.998476	1927.998476	432965.5098	5.84776E-09	0	6669.906593	1927.998476
Ca(Ac)2*	119.1985361	119.1985361	119.1985361	18.15337534	1.03036E-08	0	122.0606538	119.1985361
CaCO3*	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0
Ash_Soluble*	62.08964536	62.08964536	62.08964536	191.5272141	1.6357E-13	0	4883.130246	62.08964536
Ash_Insolub*	0	0	0	0	0	0	0	0
Total, lb/hr	1049394.601	1049394.601	1049394.601	1751056.345	8.346034695	161.661996	912791.4895	1049232.939
Heat Flow, Btu/hr	-1943612735	-1943561197	-1943561197	-4315096441	-3865.150357	-280742.9036	-5951266354	-1943331992

Stream	TBA:HAc
Pressure, psia	14.696
Temperature, F	105.3860813
Components, lb/hr	
Hydrogen	1.35941E-10
CO	4.15676E-10
Nitrogen	23.87029995
Oxygen	4.92774E-09
Argon	4.97427E-09
CO2	2.21021E-14
H2O	1126356.545
Dextrose*	11109.43947
Fructose*	42.2422827
Galactose*	40.61757943
Arabinose*	19.68647623
Xylose*	3.281079313
Maltose*	60.41668285
Isomaltose*	72.50002952
Gluc_Olig*	3158.060949
LacticAcid	283.3501631
Ammonia	0
N_Soluble*	7769.606662
N_Insoluble*	0
Cell_Mass*	0
Phytate*	2508.11942
Ethanol	426.002095
1-Pentanol	9521.683153
nPentylAceta	10325.15636
triButylamin	2.50389E-11
TBA:HAc*	437707.4179
Ca(Ac)2*	21.01549299
CaCO3*	0
Ca(OH)2*	0
Ash_Soluble*	5012.567815
Ash_Insolub*	0
Total, lb/hr	1614461.579
Heat Flow, Btu/hr	-8322870132



E-1506 Calcs		
QA.E-1506	8.901e+007	Btu/hr
HP.E-1506	178.0	hp

Esterification Calcs		
Conversion, %	95.00	
Free Water, % of Total H2O	87.68	
Heating Duty	3.776e+008	Btu/hr
Duty, Btu/lb Total H2O	1556	

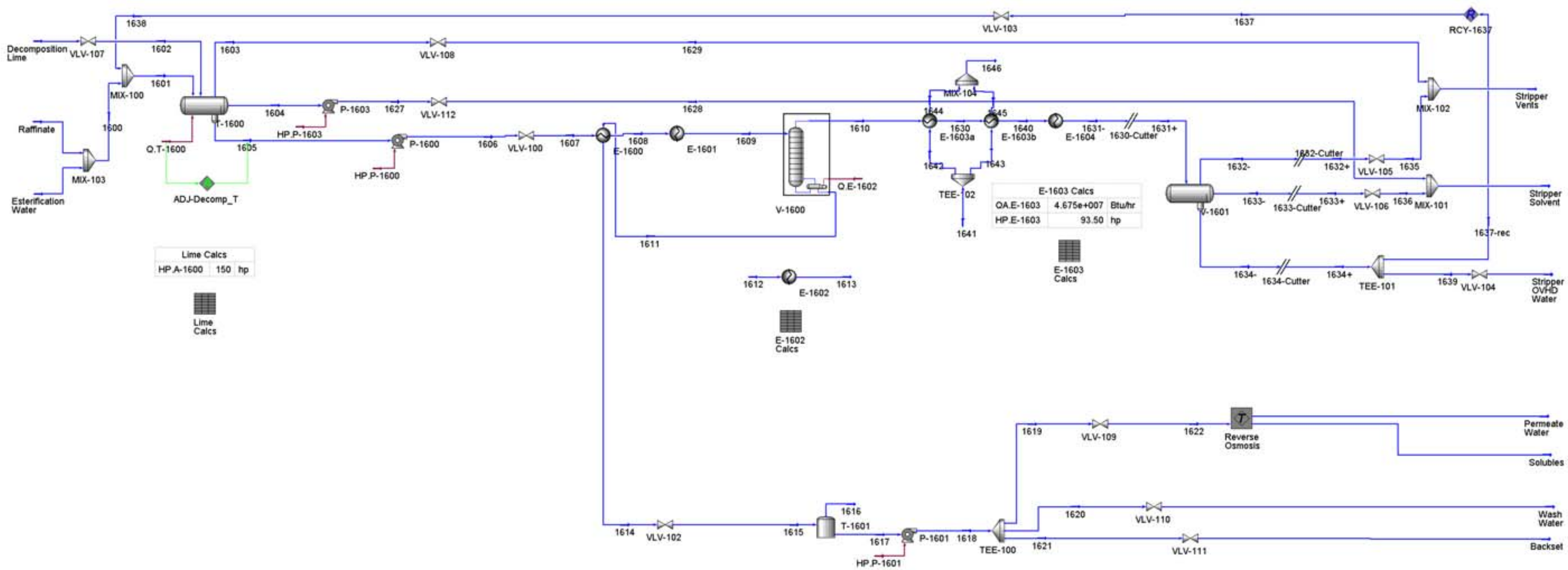
Flowsheet: Esterification + Fractionation (ESTR)

Stream	1500	1501	1502+	1502-	1503	1504	1505	1506	1507	1508	1509	1509-rec	1510	1511	1512
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	55	45	40	35	35.5	35.5	35.5	35.5	35.5	30.5	25.5
Temperature, F	105.4953106	105.4953106	105.4953106	105.4953106	105.8037919	105.8096281	129.925007	251.051995	338.7898794	338.7898794	344.6094308	344.6094306	344.6094308	191.9243211	173.9262749
Components, lb/hr															
Hydrogen	0	1.82594E-10	2.86707E-12	2.86707E-12	1.82594E-10	1.82594E-10	1.82594E-10	1.82594E-10	0	0	5.11847E-26	5.12237E-26	4.86255E-26	2.55923E-27	2.55923E-27
CO	0	1.96368E-10	2.34577E-11	2.34577E-11	1.96368E-10	1.96368E-10	1.96368E-10	1.96368E-10	0	0	7.11578E-25	7.09388E-25	6.75999E-25	3.55789E-26	3.55789E-26
Nitrogen	0	35.42741854	0.179831043	0.179831043	35.42741854	35.42741854	35.42741854	35.42741854	0	3.55872E-23	3.74603E-23	3.74623E-23	3.55872E-23	1.87301E-24	1.87301E-24
Oxygen	0	7.39598E-09	1.41008E-10	1.41008E-10	7.39598E-09	7.39598E-09	7.39598E-09	7.39598E-09	0	0	8.13074E-25	8.13074E-25	7.7242E-25	4.06537E-26	4.06537E-26
Argon	0	7.54534E-09	1.10191E-10	1.10191E-10	7.54534E-09	7.54534E-09	7.54534E-09	7.54534E-09	0	0	1.01502E-24	1.04023E-25	9.64266E-25	5.07508E-26	5.07508E-26
CO2	0	5.36688E-14	6.82107E-16	6.82107E-16	5.36688E-14	5.36688E-14	5.36688E-14	5.36688E-14	0	0	1.1182E-24	1.11822E-24	1.06229E-24	5.59102E-26	5.59102E-26
H2O	0	212756.8568	81022.60565	81022.60565	212756.8568	212756.8568	212756.8568	212756.8568	0	41170.02741	11872.68626	11872.68661	11279.05195	593.634313	593.634313
Dextrose*	0	1068.032429	897.72524	897.72524	1068.032429	1068.032429	1068.032429	1068.032429	0	20292.60885	21360.64089	21360.64128	20292.60885	1068.032045	1068.032045
Fructose*	0	4.060470735	3.41364314	3.41364314	4.060470735	4.060470735	4.060470735	4.060470735	0	77.1489162	81.20938547	81.20938694	77.1489162	4.060469274	4.060469274
Galactose*	0	3.90429869	3.282349187	3.282349187	3.90429869	3.90429869	3.90429869	3.90429869	0	74.18164843	78.08594571	78.08594712	74.18164843	3.904297286	3.904297286
Arabinose*	0	2.065051147	1.072043101	1.072043101	2.065051147	2.065051147	2.065051147	2.065051147	0	39.23595763	41.30100803	41.30100877	39.23595763	2.065050402	2.065050402
Xylose*	0	0.344175133	0.178673846	0.178673846	0.344175133	0.344175133	0.344175133	0.344175133	0	6.539325161	6.88350017	6.883500294	6.539325161	0.344175008	0.344175008
Maltose*	0	5.172411825	23.1895074	23.1895074	5.172411825	5.172411825	5.172411825	5.172411825	0	98.27578917	103.4481991	103.448201	98.27578917	5.172409956	5.172409956
Isomaltose*	0	6.206904349	27.82740402	27.82740402	6.206904349	6.206904349	6.206904349	6.206904349	0	117.93114	124.1380421	124.1380444	117.93114	6.206902106	6.206902106
Gluc_Olig*	0	299.7568347	7.061785144	7.061785144	299.7568347	299.7568347	299.7568347	299.7568347	0	5695.377223	5995.133919	5995.134027	5695.377223	299.756696	299.756696
LacticAcid	0	10.56127241	0.265368364	0.265368364	10.56127241	10.56127241	10.56127241	10.56127241	0	200.0171859	210.5444062	210.54441	200.0171859	10.52722031	10.52722031
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	0	295.8631636	1.234919048	1.234919048	295.8631636	295.8631636	295.8631636	295.8631636	0	5619.23321	5914.982327	5914.982432	5619.23321	295.7491163	295.7491163
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	156.1809546	143.5930449	143.5930449	156.1809546	156.1809546	156.1809546	156.1809546	0	2967.437073	3123.617972	3123.618028	2967.437073	156.1808986	156.1808986
Ethanol	0	235.972378	8.071125152	8.071125152	235.972378	235.972378	235.972378	235.972378	0	1.57922116	1.662338063	1.662363943	1.57922116	0.083116903	0.083116903
1-Pentanol	0	994970.9774	1500.410289	1500.410289	994970.9774	994970.9774	994970.9774	994970.9774	0	11605183.8	12369940.9	12369941.15	11751443.86	618497.0451	618497.0451
nPentylAceta	0	16958.12943	3.828232178	3.828232178	16958.12943	16958.12943	16958.12943	16958.12943	0	4588290.247	4602403.484	4602403.345	4372283.31	230120.1742	230120.1742
triButylamin	0	7427.639223	0.128572193	0.128572193	7427.639223	7427.639223	7427.639223	7427.639223	0	6284425.28	6291455.386	6291455.495	5976882.617	314572.7693	314572.7693
TBA:HAc*	0	428611.0354	4354.507774	4354.507774	428611.0354	428611.0354	428611.0354	428611.0354	0	0	428609.8483	428609.8483	407179.3559	21430.49241	21430.49241
Ca(Ac)2*	0	17.95710168	0.196275043	0.196275043	17.95710168	17.95710168	17.95710168	17.95710168	0	341.0357881	358.9850401	358.9850467	341.0357881	17.94925201	17.94925201
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	184.5020681	7.025157981	7.025157981	184.5020681	184.5020681	184.5020681	184.5020681	0	3505.538045	3690.040048	3690.040113	3505.538045	184.5020024	184.5020024
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	0	1663050.645	88005.79688	88005.79688	1663050.645	1663050.645	1663050.645	1663050.645	0	22558105.5	23745372.98	23745373.2	22558104.33	1187268.649	1187268.649
Heat Flow, Btu/hr	0	-3754782382	-560314113.7	-560314113.7	-3754464333	-3754464333	-3731156981	-3607516596	0	-29169039760	-30632851428	-30632851641	-29101208857	-1655282957	-1668492567

Stream	1513	1514	1515	1516	1517	1518	1519	1520	1521	1522	1523	1524	1525	1526	1527
Pressure, psia	1.166838719	0.966838719	1.166838719	24.69594446	34.69594446	24.69594446	19.69594446	1.166838719	1.166838719	0.966838719	0.966838719	0.966838719	0.966838719	30	20
Temperature, F	173.9263115	161.0240141	233.1629224	161.2181206	233.4428591	233.4428591	125.8096213	190.9818519	233.1629725	163.605609	161.0240175	161.0240175	161.0240175	105.52073	105.5459404
Components, lb/hr															
Hydrogen	2.55923E-27	2.0806E-27	4.78634E-28	2.0806E-27	4.78634E-28	4.78634E-28	4.78634E-28	2.72587E-27	2.72587E-27	2.59153E-27	2.59153E-27	0	0	2.86707E-12	2.86707E-12
CO	3.55789E-26	2.89248E-26	6.65404E-27	2.89248E-26	6.65404E-27	6.65404E-27	6.65404E-27	3.78954E-26	3.78954E-26	3.60279E-26	3.60279E-26	0	0	2.34577E-11	2.34577E-11
Nitrogen	1.87301E-24	1.87204E-24	1.0394E-28	1.87204E-24	1.0394E-28	1.0394E-28	1.0394E-28	4.74566E-27	4.74566E-27	2.33262E-24	2.33262E-24	0	2.33262E-24	0.179831043	0.179831043
Oxygen	4.06537E-26	3.30506E-26	7.60314E-27	3.30506E-26	7.60314E-27	7.60314E-27	7.60314E-27	4.33007E-26	4.33007E-26	4.11668E-26	4.11668E-26	0	0	1.41008E-10	1.41008E-10
Argon	5.07508E-26	4.12593E-26	9.49153E-27	4.12593E-26	9.49153E-27	9.49153E-27	9.49153E-27	5.40552E-26	5.40552E-26	5.13913E-26	5.13913E-26	0	0	1.10191E-10	1.10191E-10
CO2	5.59102E-26	4.54538E-26	1.04565E-26	4.54538E-26	1.04565E-26	1.04565E-26	1.04565E-26	5.95506E-26	5.95506E-26	5.66158E-26	5.66158E-26	0	0	6.82107E-16	6.82107E-16
H2O	593.634313	593.6307834	0.003380807	593.6307834	0.003380807	0.003380807	0.003380807	0.958684915	0.958684915	739.4085139	739.4085139	0	739.4085139	81022.60565	81022.60565
Dextrose*	1068.032045	1.55486E-24	1068.032045	1.55486E-24	1068.032045	1068.032045	1068.032045	1068.032045	1068.032045	1.93668E-24	1.93668E-24	0	0	897.72524	897.72524
Fructose*	4.060469274	1.55486E-24	4.060469274	1.55486E-24	4.060469274	4.060469274	4.060469274	4.060469274	4.060469274	1.93668E-24	1.93668E-24	0	0	3.41364314	3.41364314
Galactose*	3.904297286	1.55486E-24	3.904297286	1.55486E-24	3.904297286	3.904297286	3.904297286	3.904297286	3.904297286	1.93668E-24	1.93668E-24	0	1.93668E-24	3.282349187	3.282349187
Arabinose*	2.065050402	1.2938E-24	2.065050402	1.2938E-24	2.065050402	2.065050402	2.065050402	2.06505065	2.06505065	1.61152E-24	1.61152E-24	0	0	1.072043101	1.072043101
Xylose*	0.344175008	1.26928E-24	0.344175008	1.26928E-24	0.344175008	0.344175008	0.344175008	0.34417505	0.34417505	1.58098E-24	1.58098E-24	0	0	0.178673846	0.178673846
Maltose*	5.172409956	2.95423E-24	5.172409956	2.95423E-24	5.172409956	5.172409956	5.172409956	5.172409956	5.172409956	3.6797E-24	3.6797E-24	0	3.6797E-24	23.1895074	23.1895074
Isomaltose*	6.206902106	2.95423E-24	6.206902106	2.95423E-24	6.206902106	6.206902106	6.206902106	6.206902106	6.206902106	3.6797E-24	3.6797E-24	0	0	27.82740402	27.82740402
Gluc_Olig*	299.756696	1.39938E-24	299.756696	1.39938E-24	299.756696	299.756696	299.756696	299.7645612	299.7645612	1.74302E-24	1.74302E-24	0	0	7.061785144	7.061785144
LacticAcid	10.52722031	5.89242E-14	10.52722031	5.89242E-14	10.52722031	10.52722031	10.52722031	15.53650193	15.53650193	7.33942E-14	7.33942E-14	0	7.33942E-14	0.265368364	0.265368364
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	295.7491163	2.75602E-19	295.7491163	2.75602E-19	295.7491163	295.7491163	295.7491163	326.0436397	326.0436397	3.43282E-19	3.43282E-19	0	3.43282E-19	1.234919048	1.234919048
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	156.1808986	1.55486E-24	156.1808986	1.55486E-24	156.1808986	156.1808986	156.1808986	156.1808986	156.1808986	1.93668E-24	1.93668E-24	0	0	143.5930449	143.5930449
Ethanol	0.083116903	0.083114192	2.69409E-06	0.083114192	2.69409E-06	2.69409E-06	2.69409E-06	0.000451216	0.000451216	0.103524515	0.103524515	0	0.103524515	8.071125152	8.071125152
1-Pentanol	618497.0451	608987.0178	9510.020228	608987.0178	9510.020228	9510.020228	9510.020228	337557.8655	337557.8655	758535.6285	758535.6285	0	758535.6285	1500.410289	1500.410289
nPentylAceta	230120.1742	219781.1953	10338.97649	219781.1953	10338.97649	10338.97649	10338.97649	244872.9739	244872.9739	273752.7437	273752.7437	0	273752.7437	3.828232178	3.828232178
triButylamin	314572.7693	159.9708869	314412.7984	159.9708869	314412.7984	314412.7984	314412.7984	1018431.047	1018431.047	199.2548489	199.2548489	0	199.2548489	0.128572193	0.128572193
TBA:HAc*	21430.49241	1.98753E-24	21430.49241	1.98753E-24	21430.49241	21430.49241	21430.49241	21471.28138	21471.28138	2.4756E-24	2.4756E-24	0	0	4354.507774	4354.507774
Ca(Ac)2*	17.94925201	1.63115E-15	17.94925201	1.63115E-15	17.94925201	17.94925201	17.94925201	21.07377036	21.07377036	2.03171E-15	2.03171E-15	0	2.03171E-15	0.196275043	0.196275043
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	184.5020024	1.64342E-63	184.5020024	1.64342E-63	184.5020024	184.5020024	184.5020024	184.5020326	184.5020326	2.04699E-63	2.04699E-63	0	0	7.025157981	7.025157981
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	1187268.649	829521.8979	357746.7415	829521.8979	357746.7415	357746.7415	357746.7415	1624427.014	1624427.014	1033227.139	1033227.139	0	1033227.139	88005.79688	88005.79688
Heat Flow, Btu/hr	-1668492567	-1416569124	-245101681.9	-1416470805	-245035074.1	-245035074.1	-268342429	-1634771734	-1397293377	-1533778572	-1764435232	0	-1764435232	-560308705.6	-560308705.6

Stream	1528	1529	1530	1531+	1531-	1532	1533+	1533-	1534+	1534-	1535+	1535-	1536	1537	1538
Pressure, psia	14.69594446	30	25	20	20	20	20	20	20	20	20	20	14.69594446	35.5	35
Temperature, F	137.28878	241.1254875	230.9563043	110	110	109.2057697	109.2057697	109.2057697	109.2057697	109.2057697	109.2057697	109.2057697	108.9952216	344.6094308	255.7355964
Components, lb/hr															
Hydrogen	0	1.82594E-10	1.82594E-10	1.82594E-10	1.82594E-10	1.85461E-10	6.84691E-11	6.84691E-11	8.05679E-11	8.05679E-11	3.64239E-11	3.64239E-11	6.84691E-11	2.55923E-27	1.82594E-10
CO	0	1.96368E-10	1.96368E-10	1.96368E-10	1.96368E-10	2.19826E-10	1.61207E-11	1.61207E-11	3.87253E-11	3.87253E-11	1.6498E-10	1.6498E-10	1.61207E-11	3.55789E-26	1.96368E-10
Nitrogen	0	35.42741854	35.42741854	35.42741854	35.42741854	35.60724959	13.89665466	13.89665466	18.38850952	18.38850952	3.322085414	3.322085414	13.89665466	1.87301E-24	35.42741854
Oxygen	0	7.39598E-09	7.39598E-09	7.39598E-09	7.39598E-09	7.53699E-09	2.12564E-09	2.12564E-09	3.48901E-09	3.48901E-09	1.92234E-09	1.92234E-09	2.12564E-09	4.06537E-26	7.39598E-09
Argon	0	7.54534E-09	7.54534E-09	7.54534E-09	7.54534E-09	7.65553E-09	2.28812E-09	2.28812E-09	3.4707E-09	3.4707E-09	1.89671E-09	1.89671E-09	2.28812E-09	5.07508E-26	7.54534E-09
CO2	0	5.36688E-14	5.36688E-14	5.36688E-14	5.36688E-14	5.43509E-14	9.22134E-16	9.22134E-16	3.9393E-14	3.9393E-14	1.40358E-14	1.40358E-14	9.22134E-16	5.59102E-26	5.36688E-14
H2O	0	242054.1976	242054.1976	242054.1976	242054.1976	323076.8032	0.595246974	0.595246974	29148.23041	29148.23041	293927.9775	293927.9775	0.595246974	593.634313	242054.1976
Dextrose*	0	8.86734E-10	8.86734E-10	8.86734E-10	8.86734E-10	897.72524	7.17413E-18	7.17413E-18	31.03817124	31.03817124	866.6870688	866.6870688	7.17413E-18	1068.032045	8.86734E-10
Fructose*	0	3.37118E-12	3.37118E-12	3.37118E-12	3.37118E-12	3.41364314	2.72792E-20	2.72792E-20	0.118021246	0.118021246	3.295621893	3.295621893	2.72792E-20	4.060469274	3.37118E-12
Galactose*	0	3.24152E-12	3.24152E-12	3.24152E-12	3.24152E-12	3.282349187	2.623E-20	2.623E-20	0.113481968	0.113481968	3.168867219	3.168867219	2.623E-20	3.904297286	3.24152E-12
Arabinose*	0	3.45801E-09	3.45801E-09	3.45801E-09	3.45801E-09	1.072043105	9.95692E-17	9.95692E-17	0.031798871	0.031798871	1.040244234	1.040244234	9.95692E-17	2.065050402	3.45801E-09
Xylose*	0	5.76335E-10	5.76335E-10	5.76335E-10	5.76335E-10	0.178673846	1.65949E-17	1.65949E-17	0.005299812	0.005299812	0.173374035	0.173374035	1.65949E-17	0.344175008	5.76335E-10
Maltose*	0	1.68002E-13	1.68002E-13	1.68002E-13	1.68002E-13	23.1895074	1.2306E-18	1.2306E-18	3.11321795	3.11321795	20.07628945	20.07628945	1.2306E-18	5.172409956	1.68002E-13
Isomaltose*	0	2.01602E-13	2.01602E-13	2.01602E-13	2.01602E-13	27.82740402	1.47672E-18	1.47672E-18	3.735861113	3.735861113	24.09154291	24.09154291	1.47672E-18	6.206902106	2.01602E-13
Gluc_Olig*	0	3.14E-05	3.14E-05	3.14E-05	3.14E-05	7.061816544	5.30634E-13	5.30634E-13	0.107174683	0.107174683	6.954641862	6.954641862	5.30634E-13	299.756696	3.14E-05
LacticAcid	0	0.034048349	0.034048349	0.034048349	0.034048349	0.299416713	2.82654E-10	2.82654E-10	0.001117087	0.001117087	0.298299625	0.298299625	2.82654E-10	10.52722031	0.034048349
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	0	0.113942501	0.113942501	0.113942501	0.113942501	1.348861549	8.46807E-10	8.46807E-10	0.00503544	0.00503544	1.343826108	1.343826108	8.46807E-10	295.7491163	0.113942501
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	0	3.7077E-12	3.7077E-12	3.7077E-12	3.7077E-12	143.5930449	3.72241E-21	3.72241E-21	2.724654964	2.724654964	140.8683899	140.8683899	3.72241E-21	156.1808986	3.7077E-12
Ethanol	0	235.8892352	235.8892352	235.8892352	235.8892352	243.9603604	0.006415634	0.006415634	53.03987565	53.03987565	190.9140691	190.9140691	0.006415634	0.083116903	235.8892352
1-Pentanol	0	230213.6299	230213.6299	230213.6299	230213.6299	231714.0402	0.223233362	0.223233362	227284.6112	227284.6112	4429.205792	4429.205792	0.223233362	618497.0451	230213.6299
nPentylAceta	0	2845.030842	2845.030842	2845.030842	2845.030842	2848.859075	0.006915831	0.006915831	2844.067607	2844.067607	4.784552148	4.784552148	0.006915831	230120.1742	2845.030842
triButylamin	0	397.4242069	397.4242069	397.4242069	397.4242069	397.5527791	0.000131178	0.000131178	397.521365	397.521365	0.031282878	0.031282878	0.000131178	314572.7693	397.4242069
TBA:HAc*	0	1.187126887	1.187126887	1.187126887	1.187126887	4355.694901	1.36524E-10	1.36524E-10	1927.8493	1927.8493	2427.845602	2427.845602	1.36524E-10	21430.49241	1.187126887
Ca(Ac)2*	0	0.007843155	0.007843155	0.007843155	0.007843155	0.204118199	3.91854E-10	3.91854E-10	0.067676313	0.067676313	0.136441886	0.136441886	3.91854E-10	17.94925201	0.007843155
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	0	3.37345E-07	3.37345E-07	3.37345E-07	3.37345E-07	7.025158319	1.49869E-15	1.49869E-15	0.026210004	0.026210004	6.998948314	6.998948314	1.49869E-15	184.5020024	3.37345E-07
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	0	475782.9422	475782.9422	475782.9422	475782.9422	563788.7391	14.72859764	14.72859764	261714.796	261714.796	302059.2145	302059.2145	14.72859764	1187268.649	475782.9422
Heat Flow, Btu/hr	0	-1935750773	-1985797615	-2036487749	-2036487770	-2596796454	-3650.552596	-3649.791816	-593371190.8	-593371190.8	-2003421613	-2003421614	-3650.552596	-1531642571	-1698272416

Stream	1539	1540	1541	1542	1543	1544	1545	1546	1547	Ester	Esterification Vents	Esterification Water	Extract	Recycle Solvent	Recycle TBA
Pressure, psia	35.5	35.5	25	14.76812681	14.76812681	14.76812681	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	341.648235	344.609443	140	90	90	90	150	150	150	161.2181489	108.9952216	109.219099	105.4953106	109.2062421	110
Components, lb/hr															
Hydrogen	5.6571E-26	5.6571E-26	1.82594E-10	0	0	0	0	0	0	2.0806E-27	6.84691E-11	3.64239E-11	1.85461E-10	8.05679E-11	4.78634E-28
CO	7.83441E-25	7.83441E-25	1.96368E-10	0	0	0	0	0	0	2.89248E-26	1.61207E-11	1.6498E-10	2.19826E-10	3.87253E-11	6.65404E-27
Nitrogen	1.48086E-21	1.48086E-21	35.42741854	4482184.003	2520165.604	1962018.399	2520165.604	1962018.399	4482184.003	1.87204E-24	13.89665466	3.322085414	35.60724675	18.38850952	1.0394E-28
Oxygen	8.97952E-25	8.97952E-25	7.39598E-09	1373452.092	772241.1039	601210.9884	772241.1039	601210.9884	1373452.092	3.30506E-26	2.12564E-09	1.92234E-09	7.53699E-09	3.48901E-09	7.60314E-27
Argon	1.14882E-25	1.14882E-25	7.54534E-09	76454.73291	42987.65692	33467.07599	42987.65692	33467.07599	76454.73291	4.12593E-26	2.28812E-09	1.89671E-09	7.65553E-09	3.4707E-09	9.49153E-27
CO2	1.23496E-24	1.23496E-24	5.36688E-14	3156.304525	1774.672815	1381.63171	1774.672815	1381.63171	3156.304525	4.54538E-26	9.22134E-16	1.40358E-14	5.43509E-14	3.9393E-14	1.04565E-26
H2O	25477.90057	25477.90057	242054.1976	118539.7936	66650.52358	51889.27002	66650.52358	51889.27002	118539.7936	593.6307834	0.595246974	293927.9775	293779.4817	29148.23041	0.003380807
Dextrose*	21360.64129	21360.64129	8.86734E-10	0	0	0	0	0	0	1.55486E-24	7.17413E-18	866.6870688	1965.757989	31.03817124	1068.032045
Fructose*	81.20938696	81.20938696	3.37118E-12	0	0	0	0	0	0	1.55486E-24	2.72792E-20	3.295621893	7.474115092	0.118021246	4.060469274
Galactose*	78.08594714	78.08594714	3.24152E-12	0	0	0	0	0	0	1.55486E-24	2.623E-20	3.168867219	7.186649048	0.113481968	3.904297286
Arabinose*	41.30101497	41.30101497	3.45801E-09	0	0	0	0	0	0	1.2938E-24	9.95692E-17	1.040244234	3.137094565	0.031798871	2.065050402
Xylose*	6.883501327	6.883501327	5.76335E-10	0	0	0	0	0	0	1.26928E-24	1.65949E-17	0.173374035	0.522849031	0.005299812	0.344175008
Maltose*	103.448201	103.448201	1.68002E-13	0	0	0	0	0	0	2.95423E-24	1.2306E-18	20.07628945	28.36192934	3.11321795	5.172409956
Isomaltose*	124.1380444	124.1380444	2.01602E-13	0	0	0	0	0	0	2.95423E-24	1.47672E-18	24.09154291	34.03432051	3.735861113	6.206902106
Gluc_Olig*	5995.171017	5995.171017	3.14E-05	0	0	0	0	0	0	1.39938E-24	5.30634E-13	6.954641862	306.8185984	0.107174683	299.756696
LacticAcid	212.1733023	212.1733023	0.034048349	0	0	0	0	0	0	5.89242E-14	2.82654E-10	0.298299625	10.82664003	0.001117087	10.52722031
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	5920.531159	5920.531159	0.113942501	0	0	0	0	0	0	2.75602E-19	8.46807E-10	1.343826108	297.0980589	0.00503544	295.7491163
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	3123.618028	3123.618028	3.7077E-12	0	0	0	0	0	0	1.55486E-24	3.72241E-21	140.8683899	299.7740519	2.724654964	156.1808986
Ethanol	2.915087162	2.915087162	235.8892352	0	0	0	0	0	0	0.083114192	0.006415634	190.9140691	244.0434874	53.03987565	2.69409E-06
1-Pentanol	13960401.47	13960401.47	230213.6299	0	0	0	0	0	0	608987.0178	0.223233362	4429.205792	996471.3063	227284.6112	9510.020228
nPentylAceta	4955213.278	4955213.278	2845.030842	0	0	0	0	0	0	219781.1953	0.006915831	4.784552148	16961.95626	2844.067607	10338.97649
triButylamin	6413079.365	6413079.365	397.4242069	0	0	0	0	0	0	159.9708869	0.000131178	0.031282878	7427.767183	397.521365	314412.7984
TBA:HAc*	428618.2997	428618.2997	1.187126887	0	0	0	0	0	0	1.98753E-24	1.36524E-10	2427.845602	432965.5098	1927.8493	21430.49241
Ca(Ac)2*	359.2396102	359.2396102	0.007843155	0	0	0	0	0	0	1.63115E-15	3.91854E-10	0.136441886	18.15337534	0.067676313	17.94925201
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	3690.040137	3690.040137	3.37345E-07	0	0	0	0	0	0	1.64342E-63	1.49869E-15	6.998948314	191.5272141	0.026210004	184.5020024
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	25823889.7	25823889.7	475782.9422	6053786.926	3403819.561	2649967.365	3403819.561	2649967.365	6053786.926	829521.8979	14.72859764	302059.2145	1751056.345	261714.796	357746.7415
Heat Flow, Btu/hr	-33891470648	-33446038347	-2024760438	-674294120.4	-379130541.8	-295163578.6	-329083732.5	-256200757.9	-585284490.3	-1416470805	-3650.552596	-2003421613	-4315096496	-593371190.8	-271377637.7


Decomposition Lime
VLV-107
1638
1602
1601
MIX-100
1600
Raffinate
MIX-103
Esterification Water
T-1600
Q.T-1600
ADJ-Decomp_T
1603
1605
1604
P-1603
HP.P-1603
1627
VLV-112
VLV-108
1629
1628
P-1600
HP.P-1600
1606
VLV-100
1607
E-1600
1608
E-1601
1609
V-1600
Q.E-1602
1610
1611
Lime Calcs
HP.A-1600 150 hp
1612
E-1602
1613
E-1602 Calcs
VLV-103
1637
RCY-1637
1646
MIX-104
1644
1645
1630
E-1603a
1640
E-1603b
E-1604
1631-
1630-Cutter
1631+
1642
1643
TEE-102
1641
E-1603 Calcs
QA.E-1603 4.675e+007 Btu/hr
HP.E-1603 93.50 hp
V-1601
1632-
1632-Cutter
1632+
VLV-105
1635
MIX-102
Stripper Vents
1633-
1633-Cutter
1633+
VLV-106
1636
MIX-101
Stripper Solvent
1637-rec
1634-
1634-Cutter
1634+
TEE-101
1639
VLV-104
Stripper OVHD Water
1619
VLV-109
1622
Reverse Osmosis
Permeate Water
Solubles
1620
VLV-110
Wash Water
1621
VLV-111
Backset
1614
VLV-102
1615
1616
T-1601
1617
P-1601
HP.P-1601
1618
TEE-100

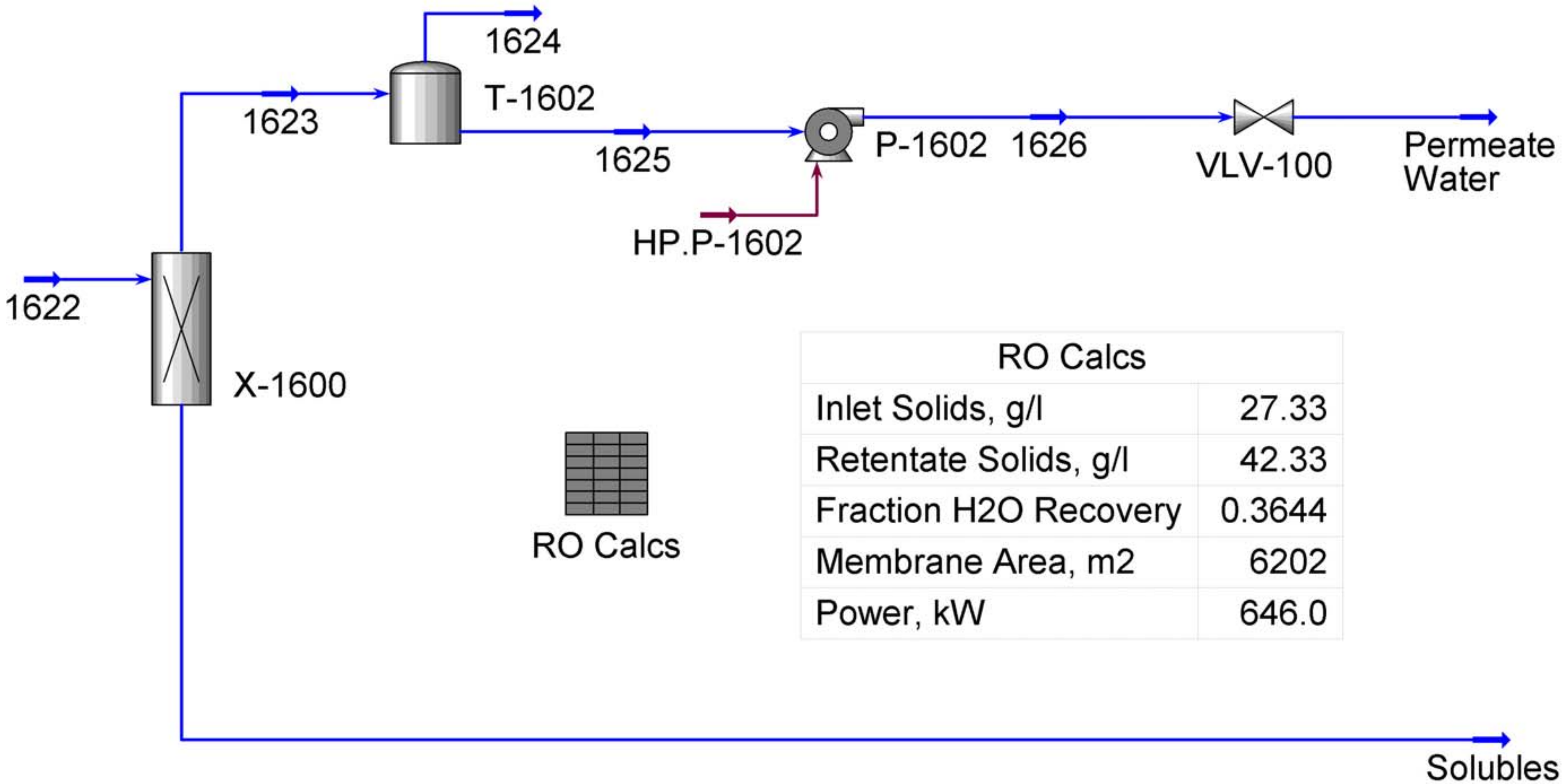
Flowsheet: Water Management (WATR)

Stream	1600	1601	1602	1603	1604	1605	1606	1607	1608	1609	1610	1611	1612	1613	1614
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	50	40	35	30	30	30	30	30	25
Temperature, F	108.5537748	108.5939396	60	109.330374	109.330374	109.330374	109.3786839	109.4021783	230.2955643	237.0863806	246.6606772	250.2955447	250.1168612	250.2955244	134.738582
Components, lb/hr															
Hydrogen	6.37756E-11	8.05519E-11	0	0	3.72928E-12	7.68227E-11	7.68227E-11	7.68227E-11	7.68227E-11	7.68227E-11	7.68227E-11	1.12982E-48	3.61101E-45	3.61101E-45	1.12982E-48
CO	5.56619E-10	2.14289E-09	0	0	9.99185E-12	2.1329E-09	2.1329E-09	2.1329E-09	2.1329E-09	2.1329E-09	2.1329E-09	1.79976E-24	1.91218E-24	1.91218E-24	1.79976E-24
Nitrogen	5.187936149	5.756055464	0	0	0.883104461	4.872951004	4.872951004	4.872951004	4.872951004	4.872951004	4.872951004	1.79982E-24	1.91224E-24	1.91224E-24	1.79982E-24
Oxygen	3.4602E-09	4.85755E-09	0	0	1.77271E-10	4.68027E-09	4.68027E-09	4.68027E-09	4.68027E-09	4.68027E-09	4.68027E-09	2.05375E-24	2.18203E-24	2.18203E-24	2.05375E-24
Argon	3.07387E-09	4.29646E-09	0	0	2.07795E-10	4.08866E-09	4.08866E-09	4.08866E-09	4.08866E-09	4.08866E-09	4.08866E-09	2.56636E-24	2.72667E-24	2.72667E-24	2.56636E-24
CO2	2.09848E-14	2.09848E-14	0	0	0	0	0	0	0	0	0	0	0	0	0
H2O	1157974.504	1192968.701	0	0	832.8636524	1192803.702	1192803.702	1192803.702	1192803.702	1192803.702	40370.33127	1152433.371	1224372.973	1224372.973	1152433.371
Dextrose*	10048.90962	10048.90962	0	0	7.505191164	10041.40443	10041.40443	10041.40443	10041.40443	10041.40443	7.05073E-11	10041.40443	10041.40443	10041.40443	10041.40443
Fructose*	38.21033592	38.21033592	0	0	0.028533872	38.18180204	38.18180204	38.18180204	38.18180204	38.18180204	2.68081E-13	38.18180204	38.18180204	38.18180204	38.18180204
Galactose*	36.74070761	36.74070761	0	0	0.027436415	36.7132712	36.7132712	36.7132712	36.7132712	36.7132712	2.5777E-13	36.7132712	36.7132712	36.7132712	36.7132712
Arabinose*	17.64208453	17.64208453	0	0	0.020661974	17.62142255	17.62142255	17.62142255	17.62142255	17.62142255	4.35766E-10	17.62142255	17.62142255	17.62142255	17.62142255
Xylose*	2.940347421	2.940347421	0	0	0.003443662	2.936903759	2.936903759	2.936903759	2.936903759	2.936903759	7.26276E-11	2.936903759	2.936903759	2.936903759	2.936903759
Maltose*	55.25506001	55.25506001	0	0	0.01117515	55.24388486	55.24388486	55.24388486	55.24388486	55.24388486	3.64812E-15	55.24388486	55.24388486	55.24388486	55.24388486
Isomaltose*	66.30607197	66.30607197	0	0	0.013410184	66.29266178	66.29266178	66.29266178	66.29266178	66.29266178	4.37774E-15	66.29266178	66.29266178	66.29266178	66.29266178
Gluc_Olig*	2947.574293	2947.574638	0	0	89.26618804	2858.30845	2858.30845	2858.30845	2858.30845	2858.30845	0.00038632	2858.308064	2858.309084	2858.309084	2858.308064
LacticAcid	277.9691204	278.2496458	0	0	5.14562451	273.1040213	273.1040213	273.1040213	273.1040213	273.1040213	0.312162033	272.7918593	273.4531584	273.4531584	272.7918593
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	8431.177994	8435.254289	0	0	957.3604031	7477.893886	7477.893886	7477.893886	7477.893886	7477.893886	4.536553834	7473.357332	7483.109408	7483.109408	7473.357332
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	2353.683023	2353.683023	0	0	1.744788417	2351.938235	2351.938235	2351.938235	2351.938235	2351.938235	4.46488E-13	2351.938235	2351.938235	2351.938235	2351.938235
Ethanol	1558.736215	2324.510786	0	0	36.71801412	2287.792772	2287.792772	2287.792772	2287.792772	2287.792772	944.1247626	1343.668009	2208.748619	2208.748619	1343.668009
1-Pentanol	16913.2463	17430.55112	0	0	4683.175847	12747.37527	12747.37527	12747.37527	12747.37527	12747.37527	12688.1346	59.24067745	165.5342355	165.5342355	59.24067745
nPentylAceta	12.04600019	12.05573985	0	0	9.638363921	2.417375929	2.417375929	2.417375929	2.417375929	2.417375929	2.417375861	6.87284E-08	4.61347E-07	4.61347E-07	6.87284E-08
triButylamin	0.496230966	0.514037954	0	0	6790.410382	81.63803202	81.63803202	81.63803202	81.63803202	81.63803202	81.63803202	1.65726E-13	4.48338E-12	4.48338E-12	1.65726E-13
TBA:HAc*	9097.752195	9097.752195	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(Ac)2*	122.1970957	123.0701375	0	0	118.9560387	2935.940142	2935.940142	2935.940142	2935.940142	2935.940142	1.159243219	2934.780899	2937.234475	2937.234475	2934.780899
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	1373.40037	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	4890.129194	4890.129196	0	0	62.06262417	4828.066572	4828.066572	4828.066572	4828.066572	4828.066572	1.95336E-06	4828.06657	4828.066574	4828.066574	4828.06657
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	1214850.704	1251133.806	1373.40037	0	13595.83488	1238911.444	1238911.444	1238911.444	1238911.444	1238911.444	54097.52734	1184813.917	1257737.761	1257737.761	1184813.917
Heat Flow, Btu/hr	-7954687967	-8194314556	-7885682.388	0	-20929997.04	-8181270163	-8181096031	-8181096031	-7980992856	-7967325558	-249045974.4	-7649637394	-8128931015	-8060288923	-7849740570

Stream	1615	1616	1617	1618	1619	1620	1621	1622	1627	1628	1629	1630	1631+	1631-	1632+
Pressure, psia	14.69594446	14.69594446	14.69594446	44.69594446	44.69594446	44.69594446	44.69594446	14.69594446	24.69594446	14.69594446	14.69594446	27.5	25	25	25
Temperature, F	134.7596793	134.7596793	134.7596793	134.7993012	134.7993012	134.7993012	134.7993012	134.8607011	109.4000599	109.4024166	121.7364611	233.9403346	110	110	110
Components, lb/hr															
Hydrogen	1.12982E-48	0	0	0	0	0	0	0	3.72928E-12	3.72928E-12	0	7.68227E-11	7.68227E-11	7.68227E-11	4.30074E-11
CO	1.79976E-24	0	0	0	0	0	0	0	9.99185E-12	9.99185E-12	0	2.1329E-09	2.1329E-09	2.1329E-09	2.16602E-10
Nitrogen	1.79982E-24	0	0	0	0	0	0	0	0.883104461	0.883104461	0	4.872951004	4.872951004	4.872951004	3.039690842
Oxygen	2.05375E-24	0	0	0	0	0	0	0	1.77271E-10	1.77271E-10	0	4.68027E-09	4.68027E-09	4.68027E-09	2.09612E-09
Argon	2.56636E-24	0	0	0	0	0	0	0	2.07795E-10	2.07795E-10	0	4.08866E-09	4.08866E-09	4.08866E-09	1.88041E-09
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2O	1152433.371	0	1152433.371	1152433.371	781748.3545	82576.67356	288108.3427	781748.3545	832.8636524	832.8636524	0	40370.33127	40370.33127	40370.33127	0.10515256
Dextrose*	10041.40443	0	10041.40443	10041.40443	6811.544675	719.5086473	2510.351107	6811.544675	7.505191164	7.505191164	0	7.05073E-11	7.05073E-11	7.05073E-11	7.49995E-31
Fructose*	38.18180204	0	38.18180204	38.18180204	25.90046564	2.735885894	9.545450511	25.90046564	0.028533872	0.028533872	0	2.68081E-13	2.68081E-13	2.68081E-13	2.85161E-33
Galactose*	36.7132712	0	36.7132712	36.7132712	24.90429388	2.630659514	9.178317799	24.90429388	0.027436415	0.027436415	0	2.5777E-13	2.5777E-13	2.5777E-13	2.74193E-33
Arabinose*	17.62142255	0	17.62142255	17.62142255	11.95341825	1.262648666	4.405355638	11.95341825	0.020661974	0.020661974	0	4.35766E-10	4.35766E-10	4.35766E-10	5.32609E-26
Xylose*	2.936903759	0	2.936903759	2.936903759	1.992236375	0.210441444	0.73422594	1.992236375	0.003443662	0.003443662	0	7.26276E-11	7.26276E-11	7.26276E-11	8.87682E-27
Maltose*	55.24388486	0	55.24388486	55.24388486	37.47445812	3.958455527	13.81097122	37.47445812	0.01117515	0.01117515	0	3.64812E-15	3.64812E-15	3.64812E-15	2.52066E-34
Isomaltose*	66.29266178	0	66.29266178	66.29266178	44.96934971	4.750146629	16.57316545	44.96934971	0.013410184	0.013410184	0	4.37774E-15	4.37774E-15	4.37774E-15	3.02479E-34
Gluc_Olig*	2858.308064	0	2858.308064	2858.308064	1938.921314	204.8097338	714.577016	1938.921314	89.26618804	89.26618804	0	0.00038632	0.00038632	0.00038632	3.80412E-17
LacticAcid	272.7918593	0	272.7918593	272.7918593	185.0472162	19.54667826	68.19796482	185.0472162	5.14562451	5.14562451	0	0.312162033	0.312162033	0.312162033	3.90793E-10
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	7473.357332	0	7473.357332	7473.357332	5069.520673	535.4973263	1868.339333	5069.520673	957.3604031	957.3604031	0	4.536553834	4.536553834	4.536553834	3.68118E-09
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	2351.938235	0	2351.938235	2351.938235	1595.427459	168.5262166	587.9845587	1595.427459	1.744788417	1.744788417	0	4.46488E-13	4.46488E-13	4.46488E-13	1.57907E-35
Ethanol	1343.668009	0	1343.668009	1343.668009	911.4715713	96.27943566	335.9170023	911.4715713	36.71801412	36.71801412	0	944.1247626	944.1247626	944.1247626	0.03590056
1-Pentanol	59.24067745	0	59.24067745	59.24067745	40.18566565	4.244842442	14.81016936	40.18566565	4683.175847	4683.175847	0	12688.1346	12688.1346	12688.1346	0.039953404
nPentylAceta	6.87284E-08	0	6.87284E-08	6.87284E-08	4.66216E-08	4.92468E-09	1.71821E-08	4.66216E-08	9.638363921	9.638363921	0	2.417375861	2.417375861	2.417375861	1.77862E-05
triButylamin	1.65726E-13	0	1.65726E-13	1.65726E-13	1.12419E-13	1.1875E-14	4.14315E-14	1.12419E-13	6790.410382	6790.410382	0	81.63803202	81.63803202	81.63803202	8.24622E-05
TBA:HAc*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(Ac)2*	2934.780899	0	2934.780899	2934.780899	1990.796342	210.2893325	733.6952248	1990.796342	118.9560387	118.9560387	0	1.159243219	1.159243219	1.159243219	3.61918E-09
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	4828.06657	0	4828.06657	4828.06657	3275.098754	345.9511736	1207.016642	3275.098754	62.06262417	62.06262417	0	1.95336E-06	1.95336E-06	1.95336E-06	5.5386E-22
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	1184813.917	0	1184813.917	1184813.917	803713.5624	84896.87518	296203.4792	803713.5624	13595.83488	13595.83488	0	54097.52734	54097.52734	54097.52734	3.220797627
Heat Flow, Btu/hr	-7849740570	0	-7849740570	-7849597745	-5324741782	-562456526.3	-1962399436	-5324741782	-20929331.93	-20929331.93	0	-290702426.5	-297282423	-297282426.1	-714.1917966

Stream	1632-	1633+	1633-	1634+	1634-	1635	1636	1637	1637-rec	1638	1639	1640	1641	1642	1643
Pressure, psia	25	25	25	25	25	14.69594446	14.69594446	25	25	14.69594446	25	27.5	14.76812681	14.76812681	14.76812681
Temperature, F	110	110	110	110	110	109.8070734	110.0004036	110	110	110.0254341	110	140	90	90	90
Components, lb/hr															
Hydrogen	4.30074E-11	1.51731E-11	1.51731E-11	1.86422E-11	1.86422E-11	4.30074E-11	1.51731E-11	1.67763E-11	1.6778E-11	1.67763E-11	1.86422E-12	7.68227E-11	0	0	0
CO	2.16602E-10	1.53628E-10	1.53628E-10	1.76267E-09	1.76267E-09	2.16602E-10	1.53628E-10	1.58627E-09	1.5864E-09	1.58627E-09	1.76267E-10	2.1329E-09	0	0	0
Nitrogen	3.039690842	1.202012482	1.202012482	0.631247679	0.631247679	3.039690842	1.202012482	0.568119316	0.568122911	0.568119316	0.063124768	4.872951004	2354213.015	2097659.356	256553.6592
Oxygen	2.09612E-09	1.03137E-09	1.03137E-09	1.55279E-09	1.55279E-09	2.09612E-09	1.03137E-09	1.39734E-09	1.39751E-09	1.39734E-09	1.55279E-10	4.68027E-09	721389.1239	642774.7342	78614.38971
Argon	1.88041E-09	8.49697E-10	8.49697E-10	1.35856E-09	1.35856E-09	1.88041E-09	8.49697E-10	1.22258E-09	1.2227E-09	1.22258E-09	1.35856E-10	4.08866E-09	40156.92509	35780.76796	4376.157131
CO2	0	0	0	0	0	0	0	0	0	0	0	0	1657.810832	1477.148576	180.6622563
H2O	0.10515256	1487.548648	1487.548648	38882.67747	38882.67747	0.10515256	1487.548648	34994.19692	34994.40973	34994.19692	3888.267747	40370.33127	62261.59495	55476.55048	6785.044475
Dextrose*	7.49995E-31	1.01374E-12	1.01374E-12	6.94936E-11	6.94936E-11	7.49995E-31	1.01374E-12	6.2544E-11	6.25442E-11	6.2544E-11	6.94936E-12	7.05073E-11	0	0	0
Fructose*	2.85161E-33	3.8544E-15	3.8544E-15	2.64226E-13	2.64226E-13	2.85161E-33	3.8544E-15	2.37803E-13	2.37804E-13	2.37803E-13	2.64226E-14	2.68081E-13	0	0	0
Galactose*	2.74193E-33	3.70615E-15	3.70615E-15	2.54064E-13	2.54064E-13	2.74193E-33	3.70615E-15	2.28656E-13	2.28657E-13	2.28656E-13	2.54064E-14	2.5777E-13	0	0	0
Arabinose*	5.32609E-26	5.34413E-12	5.34413E-12	4.30422E-10	4.30422E-10	5.32609E-26	5.34413E-12	3.87379E-10	3.87379E-10	3.87379E-10	4.30422E-11	4.35766E-10	0	0	0
Xylose*	8.87682E-27	8.90688E-13	8.90688E-13	7.17369E-11	7.17369E-11	8.87682E-27	8.90688E-13	6.45632E-11	6.45632E-11	6.45632E-11	7.17369E-12	7.26276E-11	0	0	0
Maltose*	2.52066E-34	2.20103E-16	2.20103E-16	3.42801E-15	3.42801E-15	2.52066E-34	2.20103E-16	3.08524E-15	3.08521E-15	3.08524E-15	3.42801E-16	3.64812E-15	0	0	0
Isomaltose*	3.02479E-34	2.64124E-16	2.64124E-16	4.11362E-15	4.11362E-15	3.02479E-34	2.64124E-16	3.70229E-15	3.70226E-15	3.70229E-15	4.11362E-16	4.37774E-15	0	0	0
Gluc_Olig*	3.80412E-17	2.42359E-06	2.42359E-06	0.000383896	0.000383896	3.80412E-17	2.42359E-06	0.000345493	0.000345507	0.000345493	3.83896E-05	0.00038632	0	0	0
LacticAcid	3.90793E-10	0.000458507	0.000458507	0.311703526	0.311703526	3.90793E-10	0.000458507	0.28052546	0.280533173	0.28052546	0.031170353	0.312162033	0	0	0
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N_Soluble*	3.68118E-09	0.006758049	0.006758049	4.529795781	4.529795781	3.68118E-09	0.006758049	4.076295729	4.076816203	4.076295729	0.452979578	4.536553834	0	0	0
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phytate*	1.57907E-35	3.45717E-15	3.45717E-15	4.43031E-13	4.43031E-13	1.57907E-35	3.45717E-15	3.98722E-13	3.98728E-13	3.98722E-13	4.43031E-14	4.46488E-13	0	0	0
Ethanol	0.03590056	93.19683101	93.19683101	850.892031	850.892031	0.03590056	93.19683101	765.7745709	765.8028279	765.7745709	85.0892031	944.1247626	0	0	0
1-Pentanol	0.039953404	12113.30808	12113.30808	574.7865572	574.7865572	0.039953404	12113.30808	517.3048189	517.3079015	517.3048189	57.47865572	12688.1346	0	0	0
nPentylAceta	1.77862E-05	2.406536523	2.406536523	0.010821552	0.010821552	1.77862E-05	2.406536523	0.009739657	0.009739396	0.009739657	0.001082155	2.417375861	0	0	0
triButylamin	8.24622E-05	81.61816139	81.61816139	0.019788169	0.019788169	8.24622E-05	81.61816139	0.017806988	0.017809352	0.017806988	0.001978817	81.63803202	0	0	0
TBA:HAc*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(Ac)2*	3.61918E-09	0.188997706	0.188997706	0.97024551	0.97024551	3.61918E-09	0.188997706	0.873041807	0.873220959	0.873041807	0.097024551	1.159243219	0	0	0
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash_Soluble*	5.5386E-22	2.86911E-09	2.86911E-09	1.95049E-06	1.95049E-06	5.5386E-22	2.86911E-09	1.7554E-06	1.75544E-06	1.7554E-06	1.95049E-07	1.95336E-06	0	0	0
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	3.220797627	13779.47649	13779.47649	40314.83005	40314.83005	3.220797627	13779.47649	36283.10218	36283.34705	36283.10218	4031.483005	54097.52734	3179678.47	2833168.557	346509.9127
Heat Flow, Btu/hr	-714.0385433	-31028254.51	-31028254.42	-266253454.5	-266253454.5	-714.1917966	-31028254.51	-239626589.5	-239628109.1	-239626589.5	-26625345.45	-295797207.5	-354164843.1	-315569233.5	-38595609.6

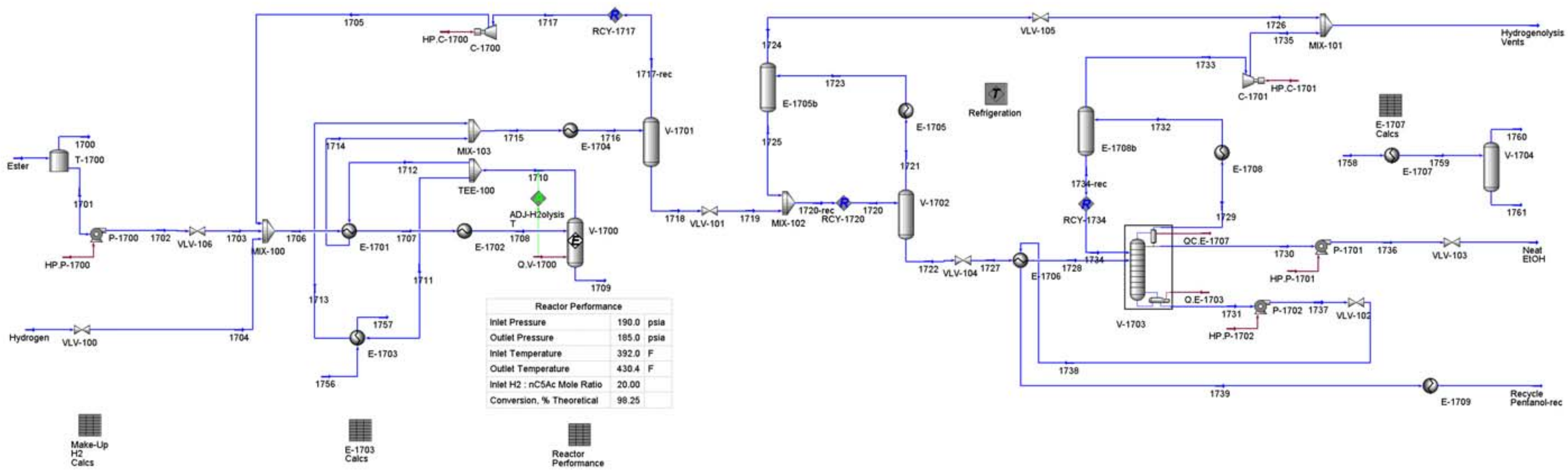
Stream	1644	1645	1646	Backset	Decomposition Lime	Esterification Water	Permeate Water	Raffinate	Solubles	Stripper OVHD Water	Stripper Solvent	Stripper Vents	Wash Water		
Pressure, psia	14.69594446	14.69594446	14.69594446	34.69594446	19.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.696		
Temperature, F	150	150	150	134.8197707	60	109.219099	134.9006685	108.3517867	134.8607011	110.0254341	109.7014753	109.8070734	134.860701		
Components, lb/hr															
Hydrogen	0	0	0	0	0	3.64239E-11	0	2.73517E-11	0	1.86422E-12	1.89024E-11	4.30074E-11	0		
CO	0	0	0	0	0	1.6498E-10	0	3.91639E-10	0	1.76267E-10	1.6362E-10	2.16602E-10	0		
Nitrogen	2097659.356	256553.6592	2354213.015	0	0	3.322085414	0	1.865850735	0	0.063124768	2.085116943	3.039690842	0		
Oxygen	642774.7342	78614.38971	721389.1239	0	0	1.92234E-09	0	1.53786E-09	0	1.55279E-10	1.20864E-09	2.09612E-09	0		
Argon	35780.76796	4376.157131	40156.92509	0	0	1.89671E-09	0	1.17716E-09	0	1.35856E-10	1.05749E-09	1.88041E-09	0		
CO2	1477.148576	180.6622563	1657.810832	0	0	1.40358E-14	0	6.94906E-15	0	0	0	0	0		
H2O	55476.55048	6785.044475	62261.59495	288108.3427	0	293927.9775	284840.9455	864046.5266	496907.409	3888.267747	2320.4123	0.10515256	82576.67356		
Dextrose*	0	0	0	2510.351107	0	866.6870688	0	9182.222552	6811.544675	6.94936E-12	7.505191164	7.49995E-31	719.5086473		
Fructose*	0	0	0	9.545450511	0	3.295621893	0	34.91471402	25.90046564	2.64226E-14	0.028533872	2.85161E-33	2.735885894		
Galactose*	0	0	0	9.178317799	0	3.168867219	0	33.57184039	24.90429388	2.54064E-14	0.027436415	2.74193E-33	2.630659514		
Arabinose*	0	0	0	4.405355638	0	1.040244234	0	16.60184029	11.95341825	4.30422E-11	0.020661974	5.32609E-26	1.262648666		
Xylose*	0	0	0	0.73422594	0	0.173374035	0	2.766973386	1.992236375	7.17369E-12	0.003443662	8.87682E-27	0.210441444		
Maltose*	0	0	0	13.81097122	0	20.07628945	0	35.17877057	37.47445812	3.42801E-16	0.01117515	2.52066E-34	3.958455527		
Isomaltose*	0	0	0	16.57316545	0	24.09154291	0	42.21452906	44.96934971	4.11362E-16	0.013410184	3.02479E-34	4.750146629		
Gluc_Olig*	0	0	0	714.577016	0	6.954641862	0	2940.619651	1938.921314	3.83896E-05	89.26619046	3.80412E-17	204.8097338		
LacticAcid	0	0	0	68.19796482	0	0.298299625	0	277.6708207	185.0472162	0.031170353	5.146083017	3.90793E-10	19.54667826		
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	0		
N_Soluble*	0	0	0	1868.339333	0	1.343826108	0	8429.834168	5069.520673	0.452979578	957.3671611	3.68118E-09	535.4973263		
N_Insoluble*	0	0	0	0	0	0	0	0	0	0	0	0	0		
Cell_Mass*	0	0	0	0	0	0	0	0	0	0	0	0	0		
Phytate*	0	0	0	587.9845587	0	140.8683899	0	2212.814633	1595.427459	4.43031E-14	1.744788417	1.57907E-35	168.5262166		
Ethanol	0	0	0	335.9170023	0	190.9140691	0	1367.822146	911.4715713	85.0892031	129.9148451	0.03590056	96.27943566		
1-Pentanol	0	0	0	14.81016936	0	4429.205792	0	12484.04051	40.18566565	57.47865572	16796.48393	0.039953404	4.244842442		
nPentylAceta	0	0	0	1.71821E-08	0	4.784552148	0	7.261448046	4.66216E-08	0.001082155	12.04490044	1.77862E-05	4.92468E-09		
triButylamin	0	0	0	4.14315E-14	0	0.031282878	0	0.464948088	1.12419E-13	0.001978817	6872.028543	8.24622E-05	1.1875E-14		
TBA:HAc*	0	0	0	0	0	2427.845602	0	6669.906593	0	0	0	0	0		
Ca(Ac)2*	0	0	0	733.6952248	0	0.136441886	0	122.0606538	1990.796342	0.097024551	119.1450364	3.61918E-09	210.2893325		
CaCO3*	0	0	0	0	0	0	0	0	0	0	0	0	0		
Ca(OH)2*	0	0	0	0	1373.40037	0	0	0	0	0	0	0	0		
Ash_Soluble*	0	0	0	1207.016642	0	6.998948314	0	4883.130246	3275.098754	1.95049E-07	62.06262418	5.5386E-22	345.9511736		
Ash_Insolub*	0	0	0	0	0	0	0	0	0	0	0	0	0		
Total, lb/hr	2833168.557	346509.9127	3179678.47	296203.4792	1373.40037	302059.2145	284840.9455	912791.4895	518872.6169	4031.483005	27375.31137	3.220797627	84896.87518		
Heat Flow, Btu/hr	-273912781.4	-33500828.51	-307413609.9	-1962399436	-7885682.388	-2003421613	-1920034548	-5951266354	-3404695778	-26625345.45	-51957586.44	-714.1917966	-562456526.3		



RO Calcs	
Inlet Solids, g/l	27.33
Retentate Solids, g/l	42.33
Fraction H2O Recovery	0.3644
Membrane Area, m2	6202
Power, kW	646.0

Flowsheet: Reverse Osmosis (RO2)

Stream	1622	1623	1624	1625	1626	Permeate Water	Solubles
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	24.69594446	14.69594446	14.69594446
Temperature, F	134.8607011	134.8607011	134.8607011	134.8607011	134.875719	134.9006685	134.8607011
Components, lb/hr							
Hydrogen	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0
Nitrogen	0	0	0	0	0	0	0
Oxygen	0	0	0	0	0	0	0
Argon	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0
H2O	781748.3545	284840.9455	0	284840.9455	284840.9455	284840.9455	496907.409
Dextrose*	6811.544675	0	0	0	0	0	6811.544675
Fructose*	25.90046564	0	0	0	0	0	25.90046564
Galactose*	24.90429388	0	0	0	0	0	24.90429388
Arabinose*	11.95341825	0	0	0	0	0	11.95341825
Xylose*	1.992236375	0	0	0	0	0	1.992236375
Maltose*	37.47445812	0	0	0	0	0	37.47445812
Isomaltose*	44.96934971	0	0	0	0	0	44.96934971
Gluc_Olig*	1938.921314	0	0	0	0	0	1938.921314
LacticAcid	185.0472162	0	0	0	0	0	185.0472162
Ammonia	0	0	0	0	0	0	0
N_Soluble*	5069.520673	0	0	0	0	0	5069.520673
N_Insoluble*	0	0	0	0	0	0	0
Cell_Mass*	0	0	0	0	0	0	0
Phytate*	1595.427459	0	0	0	0	0	1595.427459
Ethanol	911.4715713	0	0	0	0	0	911.4715713
1-Pentanol	40.18566565	0	0	0	0	0	40.18566565
nPentylAceta	4.66216E-08	0	0	0	0	0	4.66216E-08
triButylamin	1.12419E-13	0	0	0	0	0	1.12419E-13
TBA:HAc*	0	0	0	0	0	0	0
Ca(Ac)2*	1990.796342	0	0	0	0	0	1990.796342
CaCO3*	0	0	0	0	0	0	0
Ca(OH)2*	0	0	0	0	0	0	0
Ash_Soluble*	3275.098754	0	0	0	0	0	3275.098754
Ash_Insolub*	0	0	0	0	0	0	0
Total, lb/hr	803713.5624	284840.9455	0	284840.9455	284840.9455	284840.9455	518872.6169
Heat Flow, Btu/hr	-5324741782	-1920046005	0	-1920046005	-1920034548	-1920034548	-3404695778



Reactor Performance		
Inlet Pressure	190.0	psia
Outlet Pressure	185.0	psia
Inlet Temperature	392.0	F
Outlet Temperature	430.4	F
Inlet H2 : nC5Ac Mole Ratio	20.00	
Conversion, % Theoretical	98.25	

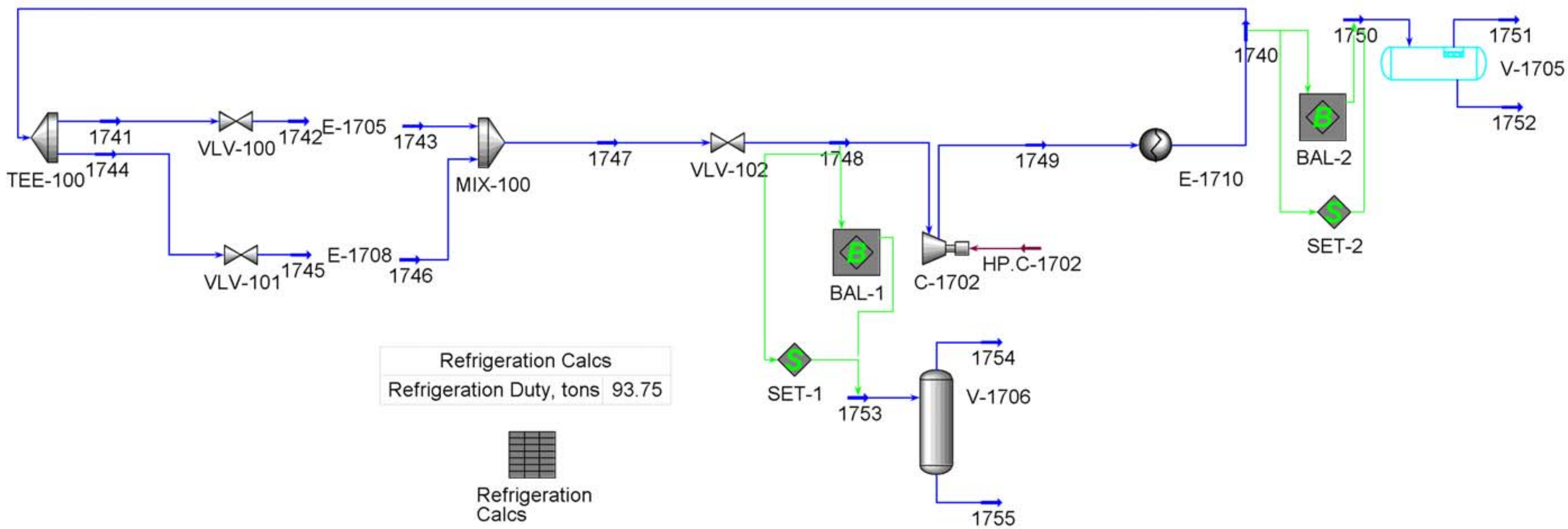
Flowsheet: Hydrogenolysis (HYDR)

Stream	1700	1701	1702	1703	1704	1705	1706	1707	1708	1709	1710	1711	1712	1713	1714
Pressure, psia	14.69594446	14.69594446	210	200	200	200	200	195	190	185	185	185	185	180	180
Temperature, F	161.2181488	161.2181488	161.9669116	162.0054463	110.0127224	137.5413209	152.1872659	330.1102053	392	430.3872161	430.3872161	430.3872161	430.3872161	238.6205775	172.1871707
Components, lb/hr															
Hydrogen	0	2.0806E-27	2.0806E-27	2.0806E-27	6766.499674	61310.85104	68077.35071	68077.35071	68077.35071	0	61388.7008	16192.98054	45195.72026	16192.98054	45195.72026
CO	0	2.89248E-26	2.89248E-26	2.89248E-26	0.940148069	312.0713041	313.0114522	313.0114522	313.0114522	0	313.0114522	82.56549312	230.4459591	82.56549312	230.4459591
H2O	0	593.6307834	593.6307834	593.6307834	0	129.5329589	723.1637423	723.1637423	723.1637423	0	723.1637423	190.7545892	532.409153	190.7545892	532.409153
Ethanol	0	0.083114192	0.083114192	0.083114192	0	4577.115313	4577.198428	4577.198428	4577.198428	0	81002.16171	21366.57742	59635.58429	21366.57742	59635.58429
1-Pentanol	0	608987.0178	608987.0178	608987.0178	0	2272.797089	611259.8149	611259.8149	611259.8149	0	757491.0918	199809.3843	557681.7076	199809.3843	557681.7076
nPentylAceta	0	219781.1953	219781.1953	219781.1953	0	28.28269644	219809.478	219809.478	219809.478	0	3845.055656	1014.240579	2830.815078	1014.240579	2830.815078
triButylamin	0	159.9708869	159.9708869	159.9708869	0	0.42227376	160.3931607	160.3931607	160.3931607	0	160.3931607	42.30816577	118.0849949	42.30816577	118.0849949
Total, lb/hr	0	829521.8979	829521.8979	829521.8979	6767.439822	68631.07268	904920.4104	904920.4104	904920.4104	0	904923.5784	238698.8111	666224.7673	238698.8111	666224.7673
Heat Flow, Btu/hr	0	-1420113394	-1419304164	-1419304164	752999.145	-1988202.566	-1420539368	-1152800292	-1090497642	0	-1090497657	-287649145.7	-802848511.5	-361835014.4	-1070587614

Stream	1715	1716	1717	1717-rec	1718	1719	1720	1720-rec	1721	1722	1723	1724	1725	1726	1727
Pressure, psia	180	175	175	175	175	24.69594446	24.69594446	24.69594446	24.69594446	24.69594446	24.69594446	24.69594446	24.69594446	14.69594446	9.350774237
Temperature, F	191.9510099	110	110	110	110	110.7064608	110.6975894	110.6975895	110.6975894	110.6975894	-20	-20	-20	-20.02536973	110.7636259
Components, lb/hr															
Hydrogen	61388.7008	61388.7008	61310.85104	61311.12732	77.57347487	77.57347487	77.57377073	77.57377515	66.84453373	10.729237	66.84453373	66.84423345	0.000300279	66.84423345	10.729237
CO	313.0114522	313.0114522	312.0713041	312.2542415	0.757210695	0.757210695	0.757218646	0.75721862	0.578587214	0.178631432	0.578587214	0.578579289	7.92514E-06	0.578579289	0.178631432
H2O	723.1637423	723.1637423	129.5329589	129.5330445	593.6306978	593.6306978	594.5665081	594.5664046	0.999859018	593.5666491	0.999859018	0.064152246	0.935706772	0.064152246	593.5666491
Ethanol	81002.16171	81002.16171	4577.115313	4577.166229	76424.99548	76424.99548	76459.36801	76459.37443	35.22157661	76424.14643	35.22157661	0.842631185	34.37894543	0.842631185	76424.14643
1-Pentanol	757491.0918	757491.0918	2272.797089	2272.820635	755218.2712	755218.2712	755235.3984	755235.4384	17.17311187	755218.2253	17.17311187	0.005872782	17.16723909	0.005872782	755218.2253
nPentylAceta	3845.055656	3845.055656	28.28269644	28.28304343	3816.772613	3816.772613	3816.977764	3816.977924	0.209709206	3816.768055	0.209709206	0.004398598	0.205310608	0.004398598	3816.768055
triButylamin	160.3931607	160.3931607	0.42227376	0.422279636	159.9708811	159.9708811	159.9731345	159.9735342	0.003021848	159.9701127	0.003021848	0.000368714	0.002653134	0.000368714	159.9701127
Total, lb/hr	904923.5784	904923.5784	68631.07268	68631.60679	836291.9716	836291.9716	836344.6148	836344.6617	121.0303995	836223.5844	121.0303995	68.34023627	52.69016324	68.34023627	836223.5844
Heat Flow, Btu/hr	-1432422628	-1513002633	-7777877.976	-7778302.74	-1505224331	-1505224331	-1505353740	-1505353825	-101145.9769	-1505252594	-154555.129	-25060.57497	-129494.554	-25060.57497	-1505252594

Stream	1728	1729	1730	1731	1732	1733	1734	1734-rec	1735	1736	1737	1738	1739	1756	1757
Pressure, psia	4.350774237	3.383935517	3.383935517	4.350774237	3.383935517	3.383935517	3.383935517	3.383935517	14.69594446	24.69594446	34.69594446	24.69594446	19.69594446	4.350774237	4.350774237
Temperature, F	184.6710987	109.9999663	109.9999663	220.5526278	-20	-20	-20	-20	290.9121561	110.0716216	220.6841057	220.7122289	123.0179499	218.6206449	220.552142
Components, lb/hr															
Hydrogen	10.729237	10.71661809	0.014127578	1.6992E-19	10.71661809	10.71510943	0.001508667	0.001508659	10.71510943	0.014127578	1.6992E-19	1.6992E-19	1.6992E-19	4.41844E-16	4.41844E-16
CO	0.178631432	0.178285483	0.000417118	4.04406E-20	0.178285483	0.178214315	7.11694E-05	7.11689E-05	0.178214315	0.000417118	4.04406E-20	4.04406E-20	4.04406E-20	6.91412E-17	6.91412E-17
H2O	593.5666491	15.3249857	593.5168899	0.039818494	15.3249857	0.011404248	15.31504497	15.31358145	0.011404248	593.5168899	0.039818494	0.039818494	0.039818494	0.380570389	0.380570389
Ethanol	76424.14643	2140.357115	75420.56099	1002.306325	2140.357115	1.296461105	2139.077997	2139.060654	1.296461105	75420.56099	1002.306325	1002.306325	1002.306325	4570.449002	4570.449002
1-Pentanol	755218.2253	0.03431625	17.06369979	755201.1615	0.03431625	3.36426E-07	0.034159225	0.034315914	3.36426E-07	17.06369979	755201.1615	755201.1615	755201.1615	1053957.172	1053957.172
nPentylAceta	3816.768055	0.434615276	34.26996007	3782.496977	0.434615276	0.000463944	0.433497788	0.434151332	0.000463944	34.26996007	3782.496977	3782.496977	3782.496977	5412.962073	5412.962073
triButylamin	159.9701127	0.001098299	0.06144299	159.9086541	0.001098299	1.68824E-05	0.001082692	0.001081417	1.68824E-05	0.06144299	159.9086541	159.9086541	159.9086541	177.2528591	177.2528591
Total, lb/hr	836223.5844	2167.047034	76065.48753	760145.9132	2167.047034	12.20167026	2154.863362	2154.845364	12.20167026	76065.48753	760145.9132	760145.9132	760145.9132	1064118.216	1064118.216
Heat Flow, Btu/hr	-1451661455	-4757927.152	-198527322.9	-1247608330	-5829577.073	-6749.605916	-5822882.389	-5822827.467	4664.06247	-198519039.4	-1247485456	-1247485456	-1301076595	-1750771656	-1676585787

Stream	1758	1759	1760	1761	Ester	Hydrogen	Hydrogenolysis Vents	Neat EtOH	Recycle Pentanol-rec						
Pressure, psia	3.867354877	2.900516158	2.900516158	2.900516158	14.69594446	225.0009644	14.69594446	14.69594446	14.69594446						
Temperature, F	118.6171142	106.2387294	106.2387294	106.2387294	161.2181489	110.0000002	23.66262013	110.1052426	110						
Components, lb/hr															
Hydrogen	10.74670166	10.74670166	10.73160676	0.015094897	2.0806E-27	6766.499674	77.55934288	0.014127578	1.6992E-19						
CO	0.179147078	0.179147078	0.178696793	0.000450285	2.89248E-26	0.940148069	0.756793603	0.000417118	4.04406E-20						
H2O	1327.238824	1327.238824	27.66864123	1299.570183	593.6307834	0	0.075556494	593.5168899	0.039818494						
Ethanol	168657.5527	168657.5527	3840.915615	164816.6371	0.083114192	0	2.13909229	75420.56099	1002.306325						
1-Pentanol	38.15818689	38.15818689	0.061089597	38.09709729	608987.0178	0	0.005873119	17.06369979	755201.1615						
nPentylAceta	76.63597255	76.63597255	0.81123728	75.82473527	219781.1953	0	0.004862542	34.26996007	3782.496977						
triButylamin	0.137415084	0.137415084	0.002133276	0.135281808	159.9708869	0	0.000385597	0.06144299	159.9086541						
Total, lb/hr	170110.6489	170110.6489	3880.36902	166230.2799	829521.8979	6767.439822	80.54190652	76065.48753	760145.9132						
Heat Flow, Btu/hr	-375289118.9	-442883993.5	-8545043.534	-434338950	-1420113394	752999.145	-20396.5125	-198519039.4	-1307950414						

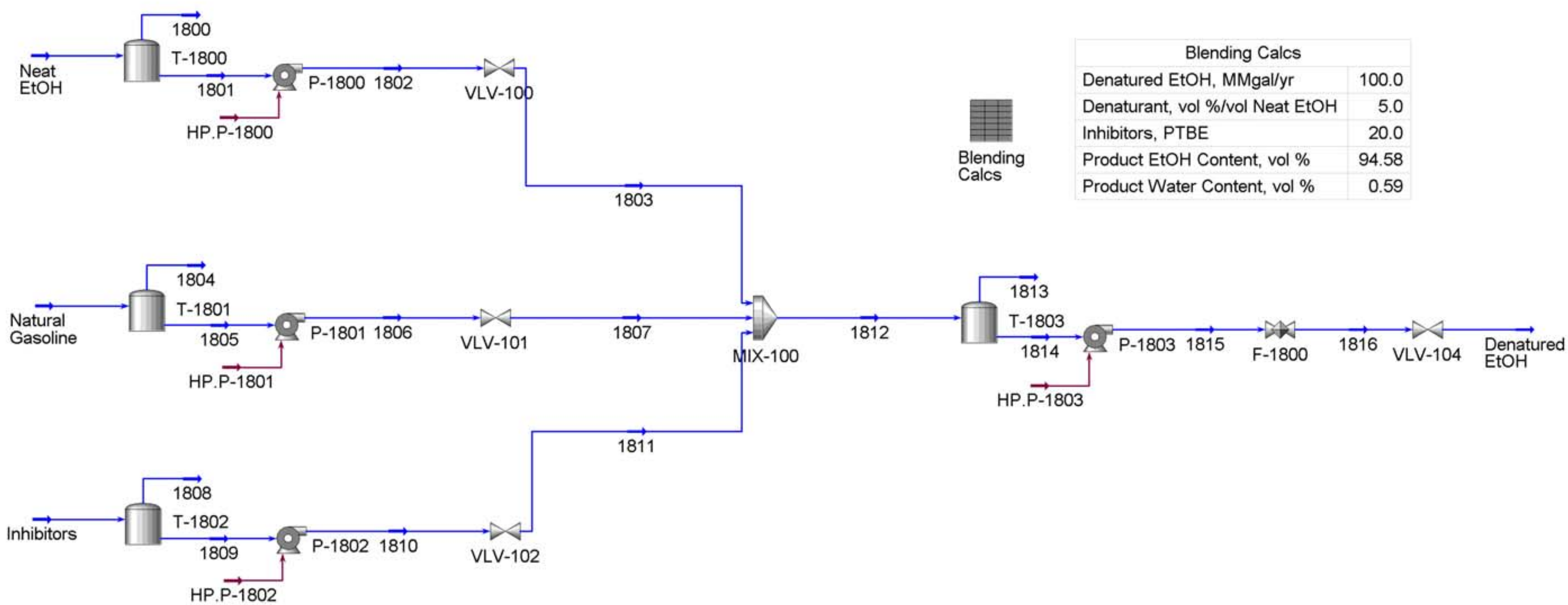

1740
1750
1751
V-1705
1752
BAL-2
TEE-100
1741
VLV-100
1742
E-1705
1743
MIX-100
1747
VLV-102
1748
1749
E-1710
SET-2
1744
VLV-101
1745
E-1708
1746
BAL-1
C-1702
HP.C-1702
SET-1
1753
V-1706
1754
1755
Refrigeration Calcs
Refrigeration Duty, tons 93.75
Refrigeration
Calcs

Flowsheet: Refrigeration (REFR)

Stream	1740	1741	1742	1743	1744	1745	1746	1747
Pressure, psia	221.230079	221.230079	21.696	19.696	221.230079	21.696	19.696	19.696
Temperature, F	110	110	-27.92757784	-31.0056889	110	-27.92938666	-31.0056889	-31.00568863
Components, lb/hr								
Ethane	126.425968	6.001733341	6.001733341	6.001733341	120.4242346	120.4242346	120.4242346	126.425968
Propane	12112.90075	575.0274366	575.0274366	575.0274366	11537.87331	11537.87331	11537.87331	12112.90075
n-Butane	81.45889973	3.867042525	3.867042525	3.867042525	77.59185721	77.59185721	77.59185721	81.45889973
Total, lb/hr	12320.78562	584.8962124	584.8962124	584.8962124	11735.88941	11735.88941	11735.88941	12320.78562
Heat Flow, Btu/hr	-14146914.8	-671586.7917	-671586.7917	-618177.6395	-13475328.01	-13475328.01	-12403678.22	-13021855.86

Stream	1748	1749	1750	1751	1752	1753	1754
Pressure, psia	16.696	226.230079	221.230079	221.230079	221.230079	16.696	16.696
Temperature, F	-31.93632443	179.0514396	109.9999197	109.9999197	109.9999197	-31.93632443	-31.93632443
Components, lb/hr							
Ethane	126.425968	126.425968	126.425968	0	126.425968	126.425968	126.425968
Propane	12112.90075	12112.90075	12112.90075	0	12112.90075	12112.90075	12112.90075
n-Butane	81.45889973	81.45889973	81.45889973	0	81.45889973	81.45889973	81.45889973
Total, lb/hr	12320.78562	12320.78562	12320.78562	0	12320.78562	12320.78562	12320.78562
Heat Flow, Btu/hr	-13021855.86	-12135119.62	-14146914.8	0	-14146914.8	-13021855.86	-13021855.86

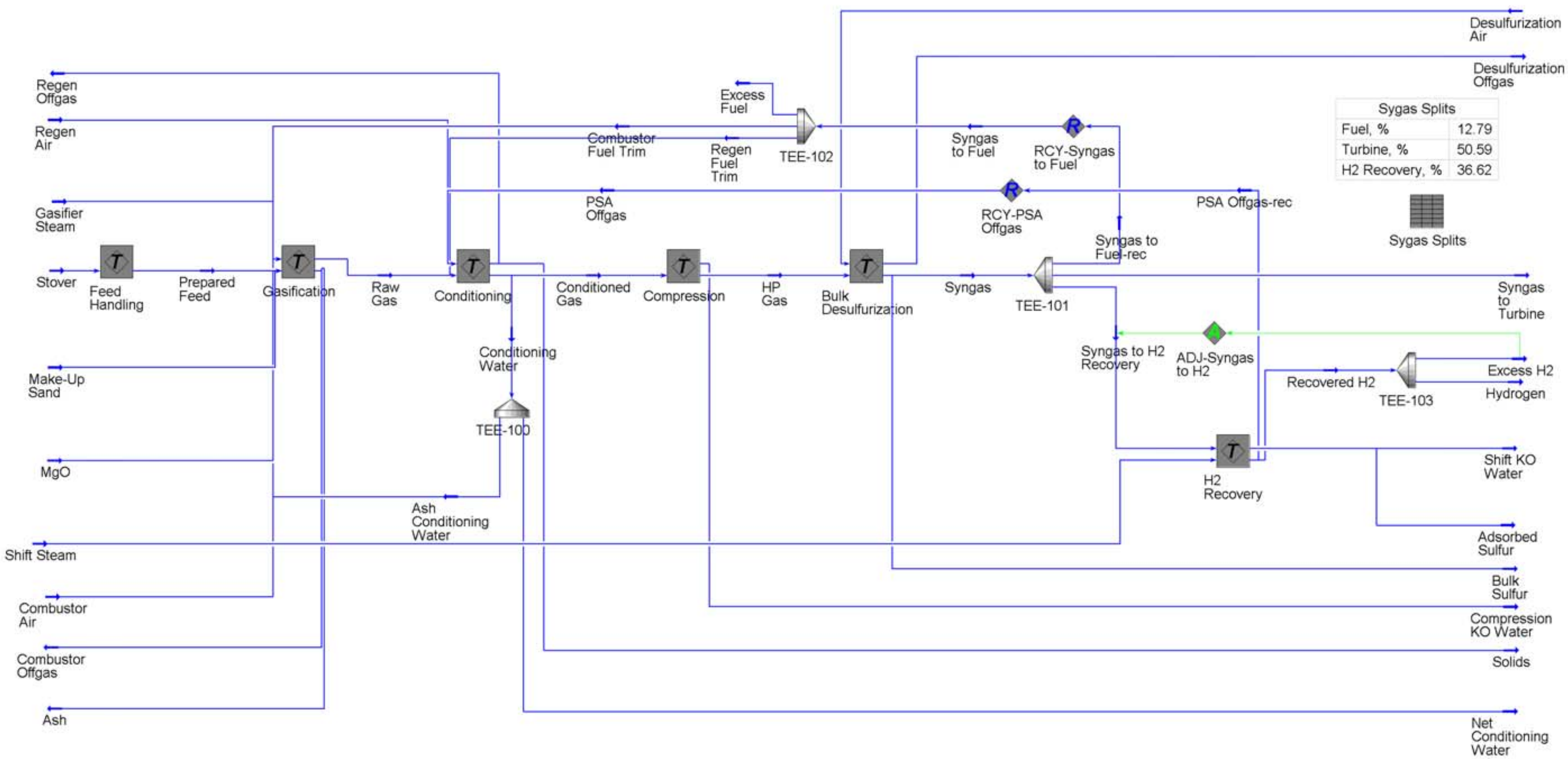
Stream	1755
Pressure, psia	16.696
Temperature, F	-31.93632443
Components, lb/hr	
Ethane	0
Propane	0
n-Butane	0
Total, lb/hr	0
Heat Flow, Btu/hr	0


Neat EtOH
1800
T-1800
1801
P-1800
1802
VLV-100
HP.P-1800
1803
Natural Gasoline
1804
T-1801
1805
P-1801
1806
VLV-101
1807
HP.P-1801
Inhibitors
1808
T-1802
1809
P-1802
1810
VLV-102
HP.P-1802
1811
MIX-100
1812
1813
T-1803
1814
P-1803
1815
F-1800
1816
VLV-104
Denatured EtOH
HP.P-1803
Blending Calcs
Blending Calcs
Denatured EtOH, MMgal/yr 100.0
Denaturant, vol %/vol Neat EtOH 5.0
Inhibitors, PTBE 20.0
Product EtOH Content, vol % 94.58
Product Water Content, vol % 0.59

Flowsheet: Denaturing (DENA)

Stream	1800	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810	1811	1812	1813	1814
Pressure, psia	14.69594446	14.69594446	24.69594446	14.69594446	14.69594446	14.69594446	24.69594446	14.69594446	14.69594446	14.69594446	24.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	110.1052426	110.1052426	110.1385613	110.1721742	60	60	60.05449494	60.1123434	60	60	60.02884415	60.06777399	104.7094544	104.7094545	104.7094545
Components, lb/hr															
Hydrogen	0	0.014127578	0.014127578	0.014127578	0	0	0	0	0	0	0	0	0.014127578	0	0.014127578
CO	0	0.000417118	0.000417118	0.000417118	0	0	0	0	0	0	0	0	0.000417118	0	0.000417118
H2O	0	593.5168899	593.5168899	593.5168899	0	0	0	0	0	0	0	0	593.5168899	0	593.5168899
Ethanol	0	75420.56099	75420.56099	75420.56099	0	0	0	0	0	5.443914015	5.443914015	5.443914015	75426.0049	0	75426.0049
1-Pentanol	0	17.06369979	17.06369979	17.06369979	0	0	0	0	0	0	0	0	17.06369979	0	17.06369979
nPentylAceta	0	34.26996007	34.26996007	34.26996007	0	0	0	0	0	0	0	0	34.26996007	0	34.26996007
triButylamin	0	0.06144299	0.06144299	0.06144299	0	0	0	0	0	0	0	0	0.06144299	0	0.06144299
n-Pentane	0	0	0	0	0	327.9458009	327.9458009	327.9458009	0	0	0	0	327.9458009	0	327.9458009
n-Hexane	0	0	0	0	0	1024.451014	1024.451014	1024.451014	0	0	0	0	1024.451014	0	1024.451014
n-Heptane	0	0	0	0	0	1856.870563	1856.870563	1856.870563	0	0	0	0	1856.870563	0	1856.870563
Total, lb/hr	0	76065.48753	76065.48753	76065.48753	0	3209.267378	3209.267378	3209.267378	0	5.443914015	5.443914015	5.443914015	79280.19882	0	79280.19882
Heat Flow, Btu/hr	0	-198519039.4	-198515153	-198515153	0	-3180098.881	-3179910.723	-3179910.723	0	-14238.63991	-14238.36965	-14238.36965	-201709302.1	0	-201709302.1

Stream	1815	1816	Denatured EtOH	Inhibitors	Natural Gasoline	Neat EtOH
Pressure, psia	29.69594446	24.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	104.7601824	104.7775619	104.8122639	60	60	110.1052426
Components, lb/hr						
Hydrogen	0.014127578	0.014127578	0.014127578	0	0	0.014127578
CO	0.000417118	0.000417118	0.000417118	0	0	0.000417118
H2O	593.5168899	593.5168899	593.5168899	0	0	593.5168899
Ethanol	75426.0049	75426.0049	75426.0049	5.443914015	0	75420.56099
1-Pentanol	17.06369979	17.06369979	17.06369979	0	0	17.06369979
nPentylAceta	34.26996007	34.26996007	34.26996007	0	0	34.26996007
triButylamin	0.06144299	0.06144299	0.06144299	0	0	0.06144299
n-Pentane	327.9458009	327.9458009	327.9458009	0	327.9458009	0
n-Hexane	1024.451014	1024.451014	1024.451014	0	1024.451014	0
n-Heptane	1856.870563	1856.870563	1856.870563	0	1856.870563	0
Total, lb/hr	79280.19882	79280.19882	79280.19882	5.443914015	3209.267378	76065.48753
Heat Flow, Btu/hr	-201703195.2	-201703195.2	-201703195.2	-14238.63991	-3180098.881	-198519039.4

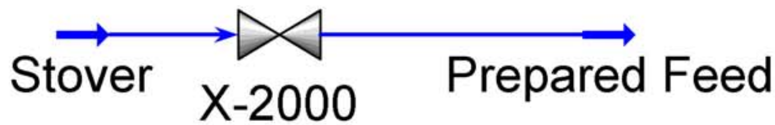

Desulfurization Air
Desulfurization Offgas
Regen Offgas
Regen Air
Excess Fuel
Combustor Fuel Trim
Regen Fuel Trim
TEE-102
Syngas to Fuel
RCY-Syngas to Fuel
Sygas Splits
Fuel, % 12.79
Turbine, % 50.59
H2 Recovery, % 36.62
Gasifier Steam
PSA Offgas
RCY-PSA Offgas
PSA Offgas-rec
Syngas to Fuel-rec
Sygas Splits
Stover
Feed Handling
Prepared Feed
Gasification
Raw Gas
Conditioning
Conditioned Gas
Compression
HP Gas
Bulk Desulfurization
Syngas
TEE-101
Syngas to Turbine
Conditioning Water
Syngas to H2 Recovery
ADJ-Syngas to H2
Excess H2
Make-Up Sand
Recovered H2
TEE-103
Hydrogen
TEE-100
MgO
H2 Recovery
Shift KO Water
Ash Conditioning Water
Adsorbed Sulfur
Shift Steam
Bulk Sulfur
Combustor Air
Compression KO Water
Combustor Offgas
Solids
Ash
Net Conditioning Water

Flowsheet: Gasification + H2 Recovery (GH2R)

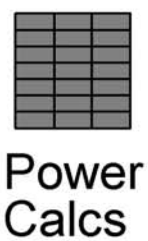
Stream	Adsorbed Sulfur	Ash	Ash Conditioning Water	Bulk Sulfur	Combustor Air	Combustor Fuel Trim	Combustor Offgas	Compression KO Water	Conditioned Gas	Conditioning Water	Desulfurization Air	Desulfurization Offgas	Excess Fuel	Excess H2	Gasifier Steam
Pressure, psia	265.0009644	14.69594446	14.69594446	14.69594446	14.69594446	274.9981307	14.69594446	14.69594446	18	14.69594446	14.69594446	14.69594446	274.9981307	225.0009644	54.696
Temperature, F	707	110.0010345	109.9999992	110.0000238	90	118.9434271	249.9999999	137.8959756	140	109.9999992	90	110	118.9434271	110.0000002	352.4429737
Components, lb/hr															
Hydrogen	0	0.000381818	0.000381817	0	0	0	0	0.036365039	15304.2277	0.006976631	0	0	0	7.458052767	0
CO	0	0.002696501	0.002696494	0	0	0	0	0.261864759	98416.59047	0.049270817	0	0	0	0.001036234	0
Nitrogen	0	0.000104972	0.000104972	0	406202.9434	0	406308.781	0.011469187	1348.119017	0.00191806	391.661554	391.6600659	0	0	0
Oxygen	0	0	0	0	124470.6336	0	11315.51214	0	0	0	120.014792	10.9104167	0	0	0
Argon	0	0	0	0	6928.795767	0	6928.795767	0	0	0	6.680756408	6.68075611	0	0	0
CO2	0	6.97362997	6.973609582	0	286.0436313	0	147462.9206	342.3073654	106111.9327	127.423039	0.275803745	0.275753186	0	0	0
H2O	0	2078.414929	2078.409204	0	10742.80151	0	59282.60829	46423.14927	47534.3177	37977.06395	10.35822709	24.85654549	0	0	103781.6441
H2S	1.73115767	0.02388774	0.023887673	0	0	0	0	1.071695845	238.1636996	0.436479829	0	0	0	0	0
SO2	0	0	0	0	0	0	40.5970779	0	0	0	0	0	0	0	0
Ammonia	0	2.915905296	2.915896946	0	0	0	0	128.5252214	128.84597	53.27978944	0	0	0	0	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	6.15941E-06	6.1594E-06	0	0	0	0	0.000163812	3422.811931	0.000112546	0	0	0	0	0
Ethane	0	1.28493E-06	1.28493E-06	0	0	0	0	4.84818E-05	12.94630101	2.34784E-05	0	0	0	0	0
Ethylene	0	8.62693E-06	8.62692E-06	0	0	0	0	0.000104412	863.7612273	0.000157633	0	0	0	0	0
Acetylene	0	1.62824E-05	1.62824E-05	0	0	0	0	7.88529E-05	51.76511755	0.000297514	0	0	0	0	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	8.87514E-08	8.87512E-08	0	0	0	0	2.29368E-05	17.12821216	1.62168E-06	0	0	0	0	0
Naphthalene	0	7.40374E-10	7.40372E-10	0	0	0	0	1.02179E-05	5.138464122	1.35282E-08	0	0	0	0	0
S_Rhombic	0	0	0	218.6587811	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	2901.527609	0	0	0	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	15893.40472	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	1.73115767	20883.2639	2088.325814	218.6587811	548631.2179	0	631339.2149	46895.36368	273455.7485	38158.26201	528.9911332	434.3835374	0	7.459089	103781.6441
Heat Flow, Btu/hr	-164.7691217	-109117723.6	-14118428.02	814147.8772	-61228507.77	0	-880130704.1	-314844327.3	-847243715.4	-257974436.8	-59036.62907	-140421.2706	0	828.7552643	-584453358

Stream	HP Gas	Hydrogen	Make-Up Sand	MgO	Net Conditioning Water	PSA Offgas	PSA Offgas-rec	Prepared Feed	Raw Gas	Recovered H2	Regen Air	Regen Fuel Trim	Regen Offgas	Shift KO Water	Shift Steam
Pressure, psia	285.0009644	225.0009644	23	23	14.69594446	25	25	14.69594446	23	225.0009644	14.69594446	274.9981307	14.69594446	14.69594446	304.696
Temperature, F	110	110.0000002	60.00317594	60.00317594	109.9999992	110	110	60.00038159	1443.742683	110.0000002	90	118.9434271	249.9999998	110.3166349	651.9141016
Components, lb/hr															
Hydrogen	15304.19134	6766.499674	0	0	0.006594814	1195.40422	1195.404305	0	2547.905306	6773.957727	0	1957.568072	0	0.052881953	0
CO	98416.32865	0.940148069	0	0	0.046574323	3187.383875	3187.383568	0	82512.51202	0.941184303	0	12588.48719	0	0.025096296	0
Nitrogen	1348.107549	0	0	0	0.001813089	493.6974901	493.6974288	0	0	0	152133.7521	172.4374412	152799.9208	0.017313529	0
Oxygen	0	0	0	0	0	5.6914E-06	5.6914E-06	0	0	0	46617.54628	2.42226E-06	4237.900932	1.2439E-06	0
Argon	0	0	0	0	0	8.95211E-08	8.95211E-08	0	0	0	2595.017379	3.81002E-08	2595.01738	1.95657E-08	0
CO2	105769.6253	0	0	0	120.4494294	90226.92175	90226.92673	0	40593.2565	0	107.1309098	13529.0579	134771.0275	128.5043149	0
H2O	1111.168312	0	0	0	35898.65474	611.5266374	611.5192468	46016.10021	149797.7443	0	4023.463465	155.9903365	37349.69699	24619.82758	45914.91934
H2S	237.0920038	0	0	0	0.412592156	0	0	0	238.6001794	0	0	0.604633276	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	1.136712744	0	0
Ammonia	0.320748371	0	0	0	50.36389249	6.58676E-07	6.58625E-07	0	1821.257595	0	0	0.041028498	0	0.117466249	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	3422.811769	0	0	0	0.000106386	1253.52776	1253.527938	0	17114.06022	0	0	437.8138044	0	0.000214867	0
Ethane	12.94625253	0	0	0	2.21935E-05	4.741274519	4.741271808	0	1294.632448	0	0	1.655963724	0	3.23653E-06	0
Ethylene	863.7611233	0	0	0	0.000149006	316.3328601	316.3329259	0	8637.613849	0	0	110.4841704	0	0.000240656	0
Acetylene	51.76503872	0	0	0	0.000281232	18.95775661	18.95776998	0	517.6541506	0	0	6.621291883	0	1.61147E-05	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	17.12818923	0	0	0	1.53293E-06	6.272817738	6.272815702	0	1712.821378	0	0	2.190877471	0	6.22024E-11	0
Naphthalene	5.138453906	0	0	0	1.27878E-08	1.881844272	1.881843662	0	5138.464135	0	0	0.657262875	0	2.58697E-14	0
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	2994.589401	196.8008162	0	0	0	0	289.8626081	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	244848.6001	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	4.017110388	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0.543212134	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0.010584999	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0.002032243	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	3.699193333	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	15909.29971	15.89499422	0	0	0	0	0	0
Total, lb/hr	226560.3848	6767.439822	2994.589401	196.8008162	36069.9362	97316.6483	97316.64586	306774	312240.5518	6774.898911	205476.9102	28963.60997	331754.7004	24748.54513	45914.91934
Heat Flow, Btu/hr	-583619880.6	751908.3602	-18244264.43	-1198991.13	-243856008.7	-357443669.5	-357443646	-1009794046	-992185452.9	752737.1154	-22931696.52	-74602433.47	-718575948.4	-167334688.3	-252614542.6

Stream	Solids	Stover	Syngas	Syngas to Fuel	Syngas to Fuel-rec	Syngas to H2 Recovery	Syngas to Turbine
Pressure, psia	34.696	14.69594446	275.0009644	274.9981307	275.0009644	275.0009644	275.0009644
Temperature, F	140.0840697	60	118.9434276	118.9434271	118.9434276	118.9434276	118.9434276
Components, lb/hr							
Hydrogen	0	0	15304.19134	1957.568072	1957.568117	5604.817326	7741.805901
CO	0	0	98416.32865	12588.48719	12588.49049	36042.77623	49785.06193
Nitrogen	0	0	1348.109037	172.4374412	172.4374199	493.7147423	681.9568745
Oxygen	0	0	1.89371E-05	2.42226E-06	2.42226E-06	6.9353E-06	9.57957E-06
Argon	0	0	2.97866E-07	3.81002E-08	3.81002E-08	1.09087E-07	1.50679E-07
CO2	0	0	105769.6254	13529.0579	13529.055	38735.75647	53504.81392
H2O	314.0297355	46016.10021	1219.515365	155.9903365	155.9889276	446.6201899	616.906247
H2S	0	0	4.726999417	0.604633276	0.604633276	1.73115767	2.391208471
SO2	0	0	0	0	0	0	0
Ammonia	0	0	0.320748371	0.041028498	0.041027113	0.117466907	0.162254351
NO2	0	0	0	0	0	0	0
Methane	0	0	3422.811769	437.8138044	437.8138668	1253.528153	1731.469749
Ethane	0	0	12.94625253	1.655963724	1.655962777	4.741275044	6.54901471
Ethylene	0	0	863.7611233	110.4841704	110.4841934	316.3331665	436.9437634
Acetylene	0	0	51.76503872	6.621291883	6.621296552	18.9577861	26.18595607
Propane	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0
Benzene	0	0	17.12818923	2.190877471	2.19087676	6.272815702	8.664496771
Naphthalene	0	0	5.138453906	0.657262875	0.657262662	1.881843662	2.599347583
S_Rhombic	0	0	0	0	0	0	0
Sand*	289.8626081	0	0	0	0	0	0
Stover*	0	244848.6001	0	0	0	0	0
Char - C*	4.017110388	0	0	0	0	0	0
Char - H*	0.543212134	0	0	0	0	0	0
Char - N*	0.010584999	0	0	0	0	0	0
Char - S*	0.002032243	0	0	0	0	0	0
Char - O*	3.699193333	0	0	0	0	0	0
Char - Ash*	15.89499422	15909.29971	0	0	0	0	0
Total, lb/hr	628.0594709	306774	226436.3684	28963.60997	28963.60908	82927.24863	114545.5107
Heat Flow, Btu/hr	-3977845.112	-1009794101	-583238820.2	-74602433.47	-74602420.57	-213598155.6	-295038244

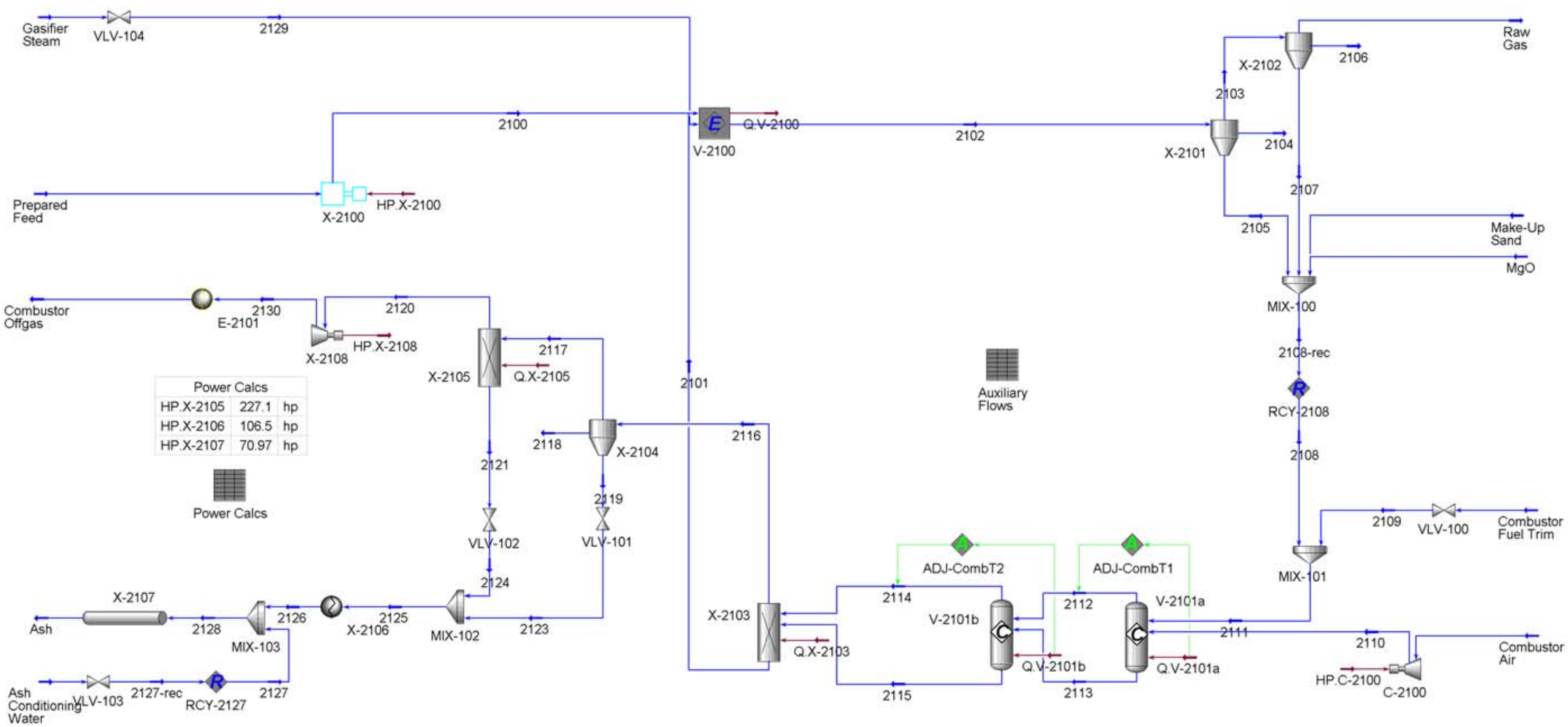


Power Calcs	
BD Stover, metric ton/d	2839
Power, Hp/(metric ton/d)	0.75
HP.X-2000, Hp	2129



Flowsheet: Feed Handling (HAND)

Stream	Prepared Feed	Stover
Pressure, psia	14.69594446	14.69594446
Temperature, F	60.0002544	60.0001272
Components, lb/hr		
Hydrogen	0	0
CO	0	0
Nitrogen	0	0
Oxygen	0	0
Argon	0	0
CO2	0	0
H2O	46016.10021	46016.10021
H2S	0	0
SO2	0	0
Ammonia	0	0
NO2	0	0
Methane	0	0
Ethane	0	0
Ethylene	0	0
Acetylene	0	0
Propane	0	0
i-Butane	0	0
n-Butane	0	0
i-Pentane	0	0
n-Pentane	0	0
n-Hexane	0	0
Benzene	0	0
Naphthalene	0	0
S_Rhombic	0	0
Sand*	0	0
Stover*	244848.6001	244848.6001
Char - C*	0	0
Char - H*	0	0
Char - N*	0	0
Char - S*	0	0
Char - O*	0	0
Char - Ash*	15909.29971	15909.29971
Total, lb/hr	306774	306774
Heat Flow, Btu/hr	-1009794064	-1009794083

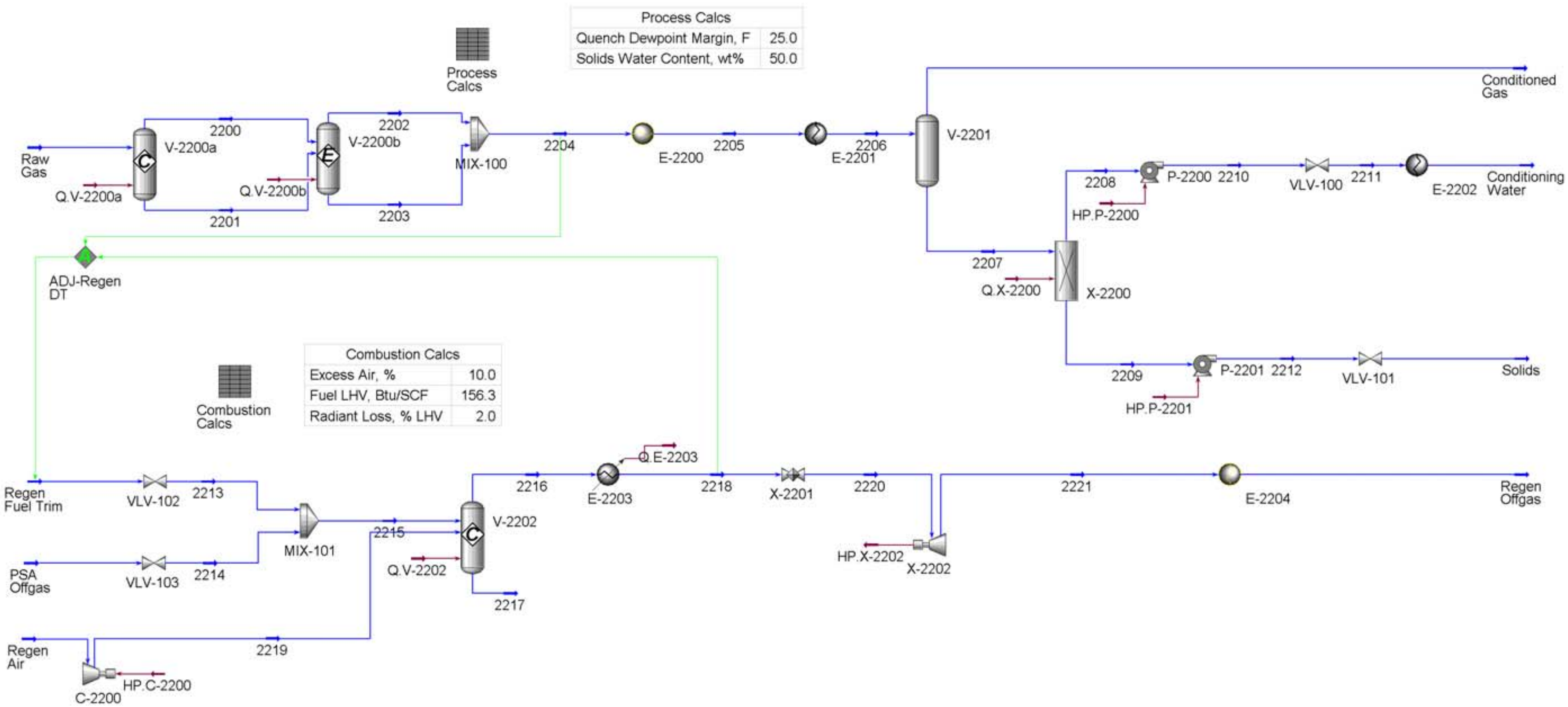

Gasifier Steam
VLV-104
2129
2100
V-2100
Q.V-2100
2102
Prepared Feed
X-2100
HP.X-2100
Combustor Offgas
E-2101
2130
2120
X-2108
HP.X-2108
X-2105
2117
Q.X-2105
2101
Power Calcs
HP.X-2105 227.1 hp
HP.X-2106 106.5 hp
HP.X-2107 70.97 hp
Power Calcs
2118
X-2104
2116
2121
2119
VLV-102
VLV-101
2124
X-2107
Ash
2128
MIX-103
2126
X-2106
2125
MIX-102
2123
Ash Conditioning Water
VLV-103
2127-rec
RCY-2127
2127
X-2103
Q.X-2103
ADJ-CombT2
ADJ-CombT1
2114
V-2101b
2112
V-2101a
Q.V-2101b
Q.V-2101a
2115
2113
2111
2110
Auxiliary Flows
X-2102
2106
Raw Gas
2103
X-2101
2104
2107
2105
Make-Up Sand
MgO
MIX-100
2108-rec
RCY-2108
2108
2109
VLV-100
Combustor Fuel Trim
MIX-101
Combustor Air
HP.C-2100
C-2100

Flowsheet: Gasification (GASI)

Stream	2100	2101	2102	2103	2104	2105	2106	2107	2108	2108-rec	2109	2110	2111	2112	2113
Pressure, psia	25	25	23	23	23	23	23	23	23	23	23	23	23	23	23
Temperature, F	60.06085007	1848.510958	1443.742685	1443.742685	1443.742685	1443.742685	1443.742685	1443.742685	1442.561622	1442.561622	114.0416063	178.338377	1442.561626	1848.513545	1848.513545
Components, lb/hr															
Hydrogen	0	0	2547.905306	2547.905306	0	0	0	0	0	0	0	0	0	0	0
CO	0	0	82512.51202	82512.51202	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	0	0	0	0	0	0	0	0	0	0	0	406202.9434	0	406308.781	0
Oxygen	0	0	0	0	0	0	0	0	0	0	0	124470.6336	0	11315.51214	0
Argon	0	0	0	0	0	0	0	0	0	0	0	6928.795767	0	6928.795767	0
CO2	0	0	40593.2565	40593.2565	0	0	0	0	0	0	0	286.0436313	0	147462.9206	0
H2O	46016.10021	0	149797.7443	149797.7443	0	0	0	0	0	0	0	10742.80151	0	59282.60829	0
H2S	0	0	238.6001794	238.6001794	0	0	0	0	0	0	0	0	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	40.5970779	0
Ammonia	0	0	1821.257595	1821.257595	0	0	0	0	0	0	0	0	0	0	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	17114.06022	17114.06022	0	0	0	0	0	0	0	0	0	0	0
Ethane	0	0	1294.632448	1294.632448	0	0	0	0	0	0	0	0	0	0	0
Ethylene	0	0	8637.613849	8637.613849	0	0	0	0	0	0	0	0	0	0	0
Acetylene	0	0	517.6541506	517.6541506	0	0	0	0	0	0	0	0	0	0	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	0	1712.821378	1712.821378	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	0	0	5138.464135	5138.464135	0	0	0	0	0	0	0	0	0	0	0
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	2898626.081	2898626.081	2898.626081	0	2895727.455	0	2608.763473	2901527.609	2901527.609	0	0	2901527.609	0	2901527.609
Stover*	244848.6001	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	40171.10388	40.17110388	0	40130.93278	0	36.15399349	40167.08677	40167.08677	0	0	40167.08677	0	0
Char - H*	0	0	5432.121337	5.432121337	0	5426.689216	0	4.888909204	5431.578125	5431.578125	0	0	5431.578125	0	0
Char - N*	0	0	105.8499938	0.105849994	0	105.7441438	0	0.095264994	105.8394088	105.8394088	0	0	105.8394088	0	0
Char - S*	0	0	20.32243291	0.020322433	0	20.30211048	0	0.01829019	20.32040067	20.32040067	0	0	20.32040067	0	0
Char - O*	0	0	36991.93333	36.99193333	0	36954.9414	0	33.29274	36988.23414	36988.23413	0	0	36988.23414	0	0
Char - Ash*	15909.29971	143040.6425	158949.9422	158.9499422	0	158790.9922	0	143.054948	158934.0472	158934.0472	0	0	158934.0472	0	158934.0472
Total, lb/hr	306774	3041666.724	3452223.877	315066.8195	0	3137157.057	0	2826.267619	3143174.715	3143174.715	0	548631.2179	3143174.715	631339.2149	3060461.656
Heat Flow, Btu/hr	-1009784109	-16959806055	-18554043521	-1007992706	0	-17546050816	0	-15807252.99	-17581301323	-17581301323	0	-49344664.53	-17581301319	-583842988.7	-17046802959

Stream	2114	2115	2116	2117	2118	2119	2120	2121	2123	2124	2125	2126	2127	2127-rec	2128
Pressure, psia	23	23	23	23	23	23	21	21	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	1848.510958	1848.510958	1848.510958	1848.510958	1848.510958	1848.510958	1848.510958	1848.510958	1848.509927	1848.487251	1848.507659	110	109.9999992	109.9999993	109.9996871
Components, lb/hr															
Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0	0.000381818	0.000381817	0.000381818
CO	0	0	0	0	0	0	0	0	0	0	0	0	0.002696501	0.002696494	0.002696501
Nitrogen	406308.781	0	406308.781	406308.781	0	0	406308.781	0	0	0	0	0	0.000104972	0.000104972	0.000104972
Oxygen	11315.51214	0	11315.51214	11315.51214	0	0	11315.51214	0	0	0	0	0	0	0	0
Argon	6928.795767	0	6928.795767	6928.795767	0	0	6928.795767	0	0	0	0	0	0	0	0
CO2	147462.9206	0	147462.9206	147462.9206	0	0	147462.9206	0	0	0	0	0	6.97362997	6.973609582	6.97362997
H2O	59282.60829	0	59282.60829	59282.60829	0	0	59282.60829	0	0	0	0	0	2078.414929	2078.409204	2078.414929
H2S	0	0	0	0	0	0	0	0	0	0	0	0	0.02388774	0.023887673	0.02388774
SO2	40.5970779	0	40.5970779	40.5970779	0	0	40.5970779	0	0	0	0	0	0	0	0
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0	2.915905296	2.915896946	2.915905296
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0	0	6.15941E-06	6.1594E-06	6.15941E-06
Ethane	0	0	0	0	0	0	0	0	0	0	0	0	1.28493E-06	1.28493E-06	1.28493E-06
Ethylene	0	0	0	0	0	0	0	0	0	0	0	0	8.62693E-06	8.62692E-06	8.62693E-06
Acetylene	0	0	0	0	0	0	0	0	0	0	0	0	1.62824E-05	1.62824E-05	1.62824E-05
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	0	0	0	0	0	0	0	0	0	0	0	8.87514E-08	8.87512E-08	8.87514E-08
Naphthalene	0	0	0	0	0	0	0	0	0	0	0	0	7.40374E-10	7.40372E-10	7.40374E-10
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	2901527.609	2901.527609	290.1527609	0	2611.374848	0	290.1527609	2611.374848	290.1527609	2901.527609	2901.527609	0	0	2901.527609
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	158934.0472	15893.40472	1589.340472	0	14304.06425	0	1589.340472	14304.06425	1589.340472	15893.40472	15893.40472	0	0	15893.40472
Total, lb/hr	631339.2149	3060461.656	650134.1473	633218.7082	0	16915.43909	631339.2149	1879.493233	16915.43909	1879.493233	18794.93233	18794.93233	2088.331568	2088.325814	20883.2639
Heat Flow, Btu/hr	-583843509.5	-17046805344	-670842798.7	-592543438.4	0	-78299360.36	-583844754.7	-8699928.929	-78299365.44	-8699941.929	-86999307.37	-94999268.17	-14118466.92	-14118428.02	-109117731.2

Stream	2129	2130	Ash	Ash Conditioning Water	Combustor Air	Combustor Fuel Trim	Combustor Offgas	Gasifier Steam	Make-Up Sand	MgO	Prepared Feed	Raw Gas			
Pressure, psia	25	14.69594446	14.69594446	14.69594446	14.69594446	274.9981307	14.69594446	54.696	23	23	14.69594446	23			
Temperature, F	346.8014203	1703.452734	110.0003608	109.9999992	90	118.9434271	250	352.4429737	60	60	60.00050878	1443.742685			
Components, lb/hr															
Hydrogen	0	0	0.000381818	0.000381817	0	0	0	0	0	0	0	2547.905306			
CO	0	0	0.002696501	0.002696494	0	0	0	0	0	0	0	82512.51202			
Nitrogen	0	406308.781	0.000104972	0.000104972	406202.9434	0	406308.781	0	0	0	0	0			
Oxygen	0	11315.51214	0	0	124470.6336	0	11315.51214	0	0	0	0	0			
Argon	0	6928.795767	0	0	6928.795767	0	6928.795767	0	0	0	0	0			
CO2	0	147462.9206	6.97362997	6.973609582	286.0436313	0	147462.9206	0	0	0	0	40593.2565			
H2O	103781.6441	59282.60829	2078.414929	2078.409204	10742.80151	0	59282.60829	103781.6441	0	0	46016.10021	149797.7443			
H2S	0	0	0.02388774	0.023887673	0	0	0	0	0	0	0	238.6001794			
SO2	0	40.5970779	0	0	0	0	40.5970779	0	0	0	0	0			
Ammonia	0	0	2.915905296	2.915896946	0	0	0	0	0	0	0	1821.257595			
NO2	0	0	0	0	0	0	0	0	0	0	0	0			
Methane	0	0	6.15941E-06	6.1594E-06	0	0	0	0	0	0	0	17114.06022			
Ethane	0	0	1.28493E-06	1.28493E-06	0	0	0	0	0	0	0	1294.632448			
Ethylene	0	0	8.62693E-06	8.62692E-06	0	0	0	0	0	0	0	8637.613849			
Acetylene	0	0	1.62824E-05	1.62824E-05	0	0	0	0	0	0	0	517.6541506			
Propane	0	0	0	0	0	0	0	0	0	0	0	0			
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0			
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0			
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0			
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0			
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0			
Benzene	0	0	8.87514E-08	8.87512E-08	0	0	0	0	0	0	0	1712.821378			
Naphthalene	0	0	7.40374E-10	7.40372E-10	0	0	0	0	0	0	0	5138.464135			
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0			
Sand*	0	0	2901.527609	0	0	0	0	0	2994.589401	196.8008162	0	289.8626081			
Stover*	0	0	0	0	0	0	0	0	0	0	244848.6001	0			
Char - C*	0	0	0	0	0	0	0	0	0	0	0	4.017110388			
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0.543212134			
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0.010584999			
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0.002032243			
Char - O*	0	0	0	0	0	0	0	0	0	0	0	3.699193333			
Char - Ash*	0	0	15893.40472	0	0	0	0	0	0	0	15909.29971	15.89499422			
Total, lb/hr	103781.6441	631339.2149	20883.2639	2088.325814	548631.2179	0	631339.2149	103781.6441	2994.589401	196.8008162	306774	312240.5518			
Heat Flow, Btu/hr	-584453358	-612866948.3	-109117727.4	-14118428.02	-61228507.77	0	-880130704.1	-584453358	-18244266.19	-1198991.246	-1009794028	-992185452.6			



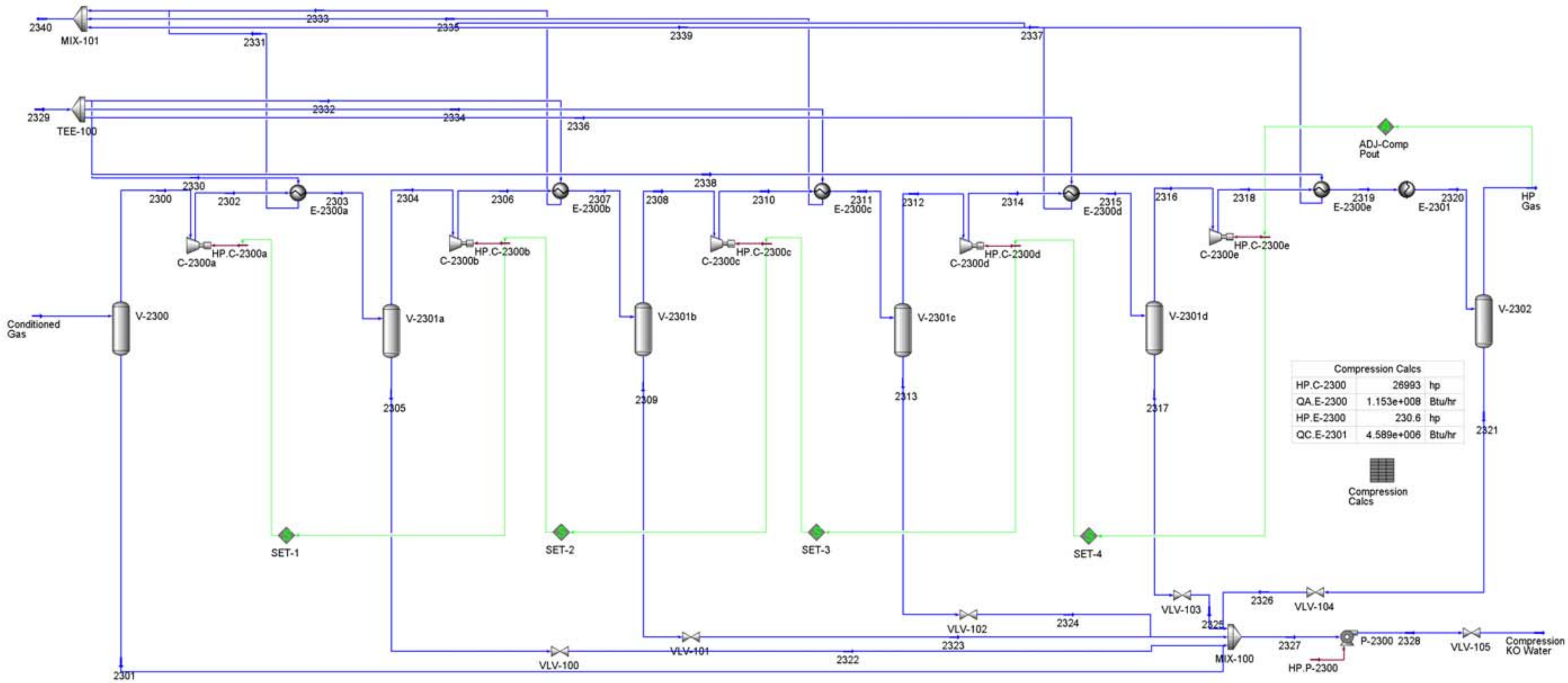
Process Calcs	
Quench Dewpoint Margin, F	25.0
Solids Water Content, wt%	50.0

Combustion Calcs	
Excess Air, %	10.0
Fuel LHV, Btu/SCF	156.3
Radiant Loss, % LHV	2.0

Flowsheet: Conditioning (COND)

Stream	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214
Pressure, psia	20	20	20	20	20	18	18	18	18	18	29.69594446	19.69594446	44.696	21	21
Temperature, F	1443.742681	1443.742681	1443.742681	1443.742681	1443.742681	183.8593257	140	140	140	140	140.015843	140.0413396	140.0644256	114.0009036	109.6758899
Components, lb/hr															
Hydrogen	12297.11249	0	15304.23468	0	15304.23468	15304.23468	15304.23468	0.006976631	0.006976631	0	0.006976631	0.006976631	0	1957.568072	1195.40422
CO	140198.4821	0	98416.63974	0	98416.63974	98416.63974	98416.63974	0.049270817	0.049270817	0	0.049270817	0.049270817	0	12588.48719	3187.383875
Nitrogen	1348.120935	0	1348.120935	0	1348.120935	1348.120935	1348.120935	0.00191806	0.00191806	0	0.00191806	0.00191806	0	172.4374412	493.6974901
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	2.42226E-06	5.6914E-06
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	3.81002E-08	8.95211E-08
CO2	40593.2565	0	106239.3557	0	106239.3557	106239.3557	106239.3557	127.423039	127.423039	0	127.423039	127.423039	0	13529.0579	90226.92175
H2O	112697.2395	0	85825.41138	0	85825.41138	85825.41138	85825.41138	38291.09368	37977.06395	314.0297355	37977.06395	37977.06395	314.0297355	155.9903365	611.5266374
H2S	238.6001794	0	238.6001794	0	238.6001794	238.6001794	238.6001794	0.436479829	0.436479829	0	0.436479829	0.436479829	0	0.604633276	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	182.1257595	0	182.1257595	0	182.1257595	182.1257595	182.1257595	53.27978944	53.27978944	0	53.27978944	53.27978944	0	0.041028498	6.58676E-07
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	3422.812044	0	3422.812044	0	3422.812044	3422.812044	3422.812044	0.000112546	0.000112546	0	0.000112546	0.000112546	0	437.8138044	1253.52776
Ethane	12.94632448	0	12.94632448	0	12.94632448	12.94632448	12.94632448	2.34784E-05	2.34784E-05	0	2.34784E-05	2.34784E-05	0	1.655963724	4.741274519
Ethylene	863.7613849	0	863.7613849	0	863.7613849	863.7613849	863.7613849	0.000157633	0.000157633	0	0.000157633	0.000157633	0	110.4841704	316.3328601
Acetylene	51.76541506	0	51.76541506	0	51.76541506	51.76541506	51.76541506	0.000297514	0.000297514	0	0.000297514	0.000297514	0	6.621291883	18.95775661
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	17.12821378	0	17.12821378	0	17.12821378	17.12821378	17.12821378	1.62168E-06	1.62168E-06	0	1.62168E-06	1.62168E-06	0	2.190877471	6.272817738
Naphthalene	5.138464135	0	5.138464135	0	5.138464135	5.138464135	5.138464135	1.35282E-08	1.35282E-08	0	1.35282E-08	1.35282E-08	0	0.657262875	1.881844272
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	289.8626081	0	289.8626081	289.8626081	289.8626081	289.8626081	289.8626081	0	289.8626081	0	0	289.8626081	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	4.017110388	0	4.017110388	4.017110388	4.017110388	4.017110388	4.017110388	0	4.017110388	0	0	4.017110388	0	0
Char - H*	0	0.543212134	0	0.543212134	0.543212134	0.543212134	0.543212134	0.543212134	0	0.543212134	0	0	0.543212134	0	0
Char - N*	0	0.010584999	0	0.010584999	0.010584999	0.010584999	0.010584999	0.010584999	0	0.010584999	0	0	0.010584999	0	0
Char - S*	0	0.002032243	0	0.002032243	0.002032243	0.002032243	0.002032243	0.002032243	0	0.002032243	0	0	0.002032243	0	0
Char - O*	0	3.699193333	0	3.699193333	3.699193333	3.699193333	3.699193333	3.699193333	0	3.699193333	0	0	3.699193333	0	0
Char - Ash*	0	15.89499422	0	15.89499422	15.89499422	15.89499422	15.89499422	15.89499422	0	15.89499422	0	0	15.89499422	0	0
Total, lb/hr	311928.4894	314.0297355	311928.0402	314.0297355	312242.0699	312242.0699	312242.0699	38786.32148	38158.26201	628.0594709	38158.26201	38158.26201	628.0594709	28963.60997	97316.6483
Heat Flow, Btu/hr	-842652802.8	-1756361.443	-865554486.1	-1756361.443	-867310847.6	-1062686329	-1108014296	-260770581	-256792689.5	-3977891.398	-256790889.8	-256790889.8	-3977844.335	-74602433.47	-357443669.5

Stream	2215	2216	2217	2218	2219	2220	2221	Conditioned Gas	Conditioning Water	PSA Offgas	Raw Gas	Regen Air	Regen Fuel Trim	Regen Offgas	Solids
Pressure, psia	21	21	21	21	21	20	14.69594446	18	14.69594446	25	23	14.69594446	274.9981307	14.69594446	34.696
Temperature, F	111.0373042	2755.4704	2755.4704	1643.752531	159.3870902	1643.752574	1536.276952	140	110	110	1443.742681	90	118.9434271	250	140.0850763
Components, lb/hr															
Hydrogen	3152.972293	0	0	0	0	0	0	15304.2277	0.006976631	1195.40422	2547.905306	0	1957.568072	0	0
CO	15775.87106	0	0	0	0	0	0	98416.59047	0.049270817	3187.383875	82512.51202	0	12588.48719	0	0
Nitrogen	666.1349314	152799.9208	0	152799.9208	152133.7521	152799.9208	152799.9208	1348.119017	0.00191806	493.6974901	0	152133.7521	172.4374412	152799.9208	0
Oxygen	8.11366E-06	4237.900932	0	4237.900932	46617.54628	4237.900932	4237.900932	0	0	5.6914E-06	0	46617.54628	2.42226E-06	4237.900932	0
Argon	1.27621E-07	2595.01738	0	2595.01738	2595.017379	2595.01738	2595.01738	0	0	8.95211E-08	0	2595.017379	3.81002E-08	2595.01738	0
CO2	103755.9797	134771.0275	0	134771.0275	107.1309098	134771.0275	134771.0275	106111.9327	127.423039	90226.92175	40593.2565	107.1309098	13529.0579	134771.0275	0
H2O	767.5169739	37349.69699	0	37349.69699	4023.463465	37349.69699	37349.69699	47534.3177	37977.06395	611.5266374	149797.7443	4023.463465	155.9903365	37349.69699	314.0297355
H2S	0.604633276	0	0	0	0	0	0	238.1636996	0.436479829	0	238.6001794	0	0.604633276	0	0
SO2	0	1.136712744	0	1.136712744	0	1.136712744	1.136712744	0	0	0	0	0	0	1.136712744	0
Ammonia	0.041029157	0	0	0	0	0	0	128.84597	53.27978944	6.58676E-07	1821.257595	0	0.041028498	0	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	1691.341564	0	0	0	0	0	0	3422.811931	0.000112546	1253.52776	17114.06022	0	437.8138044	0	0
Ethane	6.397238243	0	0	0	0	0	0	12.94630101	2.34784E-05	4.741274519	1294.632448	0	1.655963724	0	0
Ethylene	426.8170304	0	0	0	0	0	0	863.7612273	0.000157633	316.3328601	8637.613849	0	110.4841704	0	0
Acetylene	25.5790485	0	0	0	0	0	0	51.76511755	0.000297514	18.95775661	517.6541506	0	6.621291883	0	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	8.46369521	0	0	0	0	0	0	17.12821216	1.62168E-06	6.272817738	1712.821378	0	2.190877471	0	0
Naphthalene	2.539107147	0	0	0	0	0	0	5.138464122	1.35282E-08	1.881844272	5138.464135	0	0.657262875	0	0
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	0	0	0	0	0	0	289.8626081	0	0	0	289.8626081
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	4.017110388	0	0	0	4.017110388
Char - H*	0	0	0	0	0	0	0	0	0	0	0.543212134	0	0	0	0.543212134
Char - N*	0	0	0	0	0	0	0	0	0	0	0.010584999	0	0	0	0.010584999
Char - S*	0	0	0	0	0	0	0	0	0	0	0.002032243	0	0	0	0.002032243
Char - O*	0	0	0	0	0	0	0	0	0	0	3.699193333	0	0	0	3.699193333
Char - Ash*	0	0	0	0	0	0	0	0	0	0	15.89499422	0	0	0	15.89499422
Total, lb/hr	126280.2583	331754.7004	0	331754.7004	205476.9102	331754.7004	331754.7004	273455.7485	38158.26201	97316.6483	312240.5518	205476.9102	28963.60997	331754.7004	628.0594709
Heat Flow, Btu/hr	-432046103	-457027469.5	0	-581902075.3	-19439395.61	-581902075.3	-593349799.7	-847243715.4	-257974436.8	-357443669.5	-992185453.2	-22931696.52	-74602433.47	-718575948.4	-3977844.724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MIX-101
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TEE-100
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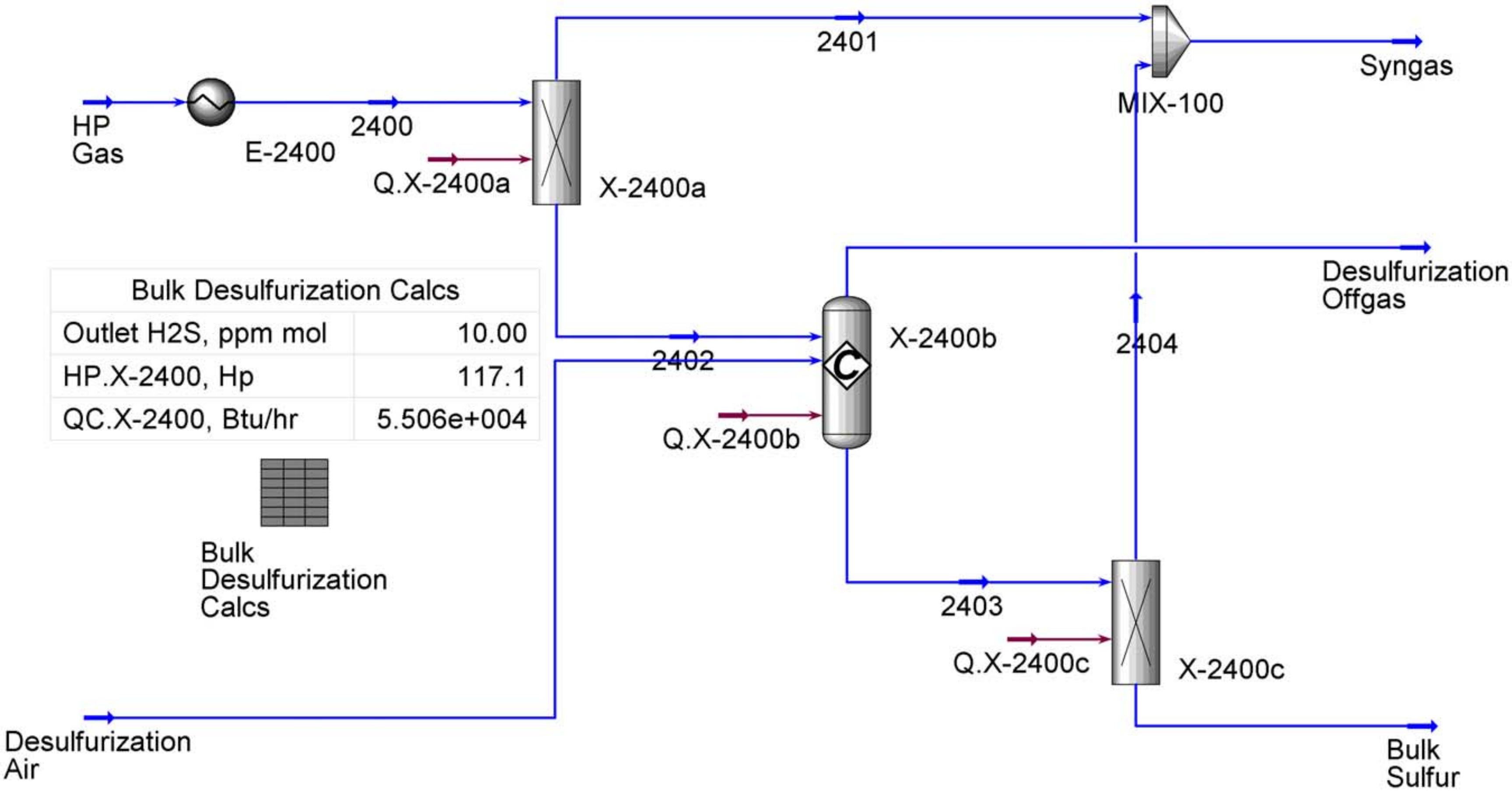
2334
2336
ADJ-Comp Pout
2338
2330
2300
2302
2303
E-2300a
2304
2306
2307
E-2300b
2308
2310
2311
E-2300c
2312
2314
2315
E-2300d
2316
2318
2319
E-2300e
2320
E-2301
HP Gas
HP.C-2300a
C-2300a
HP.C-2300b
C-2300b
HP.C-2300c
C-2300c
HP.C-2300d
C-2300d
HP.C-2300e
C-2300e
Conditioned Gas
V-2300
V-2301a
V-2301b
V-2301c
V-2301d
V-2302
Compression Calcs
HP.C-2300 26993 hp
QA.E-2300 1.153e+008 Btu/hr
HP.E-2300 230.6 hp
QC.E-2301 4.589e+006 Btu/hr
2305
2309
2313
2317
2321
Compression Calcs
SET-1
SET-2
SET-3
SET-4
VLV-103
2326
VLV-104
VLV-102
2324
2325
2323
VLV-101
VLV-100
2322
MIX-100
2327
P-2300
2328
VLV-105
Compression KO Water
HP.P-2300
2301

Flowsheet: Compression (COMP)

Stream	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314
Pressure, psia	18	18	31.10158494	29.10158494	29.10158494	29.10158494	52.14251353	50.14251353	50.14251353	50.14251353	92.06595372	87.06595372	87.06595372	87.06595372	162.1272845
Temperature, F	140	140	251.1346925	140	140	140	259.9252666	140	140	140	265.9901702	140	140	140	269.6083408
Components, lb/hr															
Hydrogen	15304.2277	0	15304.2277	15304.2277	15304.22126	0.006442626	15304.22126	15304.22126	15304.21414	0.007126763	15304.21414	15304.21414	15304.20711	0.007026426	15304.20711
CO	98416.59047	0	98416.59047	98416.59047	98416.54493	0.045538652	98416.54493	98416.54493	98416.49456	0.050413916	98416.49456	98416.49456	98416.44486	0.049695901	98416.44486
Nitrogen	1348.119017	0	1348.119017	1348.119017	1348.117249	0.001768206	1348.117249	1348.117249	1348.115299	0.001950639	1348.115299	1348.115299	1348.113383	0.00191569	1348.113383
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO2	106111.9327	0	106111.9327	106111.9327	106011.3509	100.5817204	106011.3509	106011.3509	105921.9904	89.36063092	105921.9904	105921.9904	105855.8677	66.12266724	105855.8677
H2O	47534.3177	0	47534.3177	47534.3177	27355.38984	20178.92786	27355.38984	27355.38984	15142.41919	12212.97054	15142.41919	15142.41919	8482.11265	6660.30654	8482.11265
H2S	238.1636996	0	238.1636996	238.1636996	237.8384064	0.32529314	237.8384064	237.8384064	237.5642575	0.274148998	237.5642575	237.5642575	237.3673119	0.196945614	237.3673119
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	128.84597	0	128.84597	128.84597	87.90238582	40.94358423	87.90238582	87.90238582	52.70503312	35.19735238	52.70503312	52.70503312	27.69911757	25.00591556	27.69911757
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	3422.811931	0	3422.811931	3422.811931	3422.811863	6.79492E-05	3422.811863	3422.811863	3422.811843	2.19724E-05	3422.811843	3422.811843	3422.811817	2.5694E-05	3422.811817
Ethane	12.94630101	0	12.94630101	12.94630101	12.94630078	2.25391E-07	12.94630078	12.94630078	12.9462915	9.28264E-06	12.9462915	12.9462915	12.94628229	9.21799E-06	12.94628229
Ethylene	863.7612273	0	863.7612273	863.7612273	863.7612231	4.18686E-06	863.7612231	863.7612231	863.7612225	9.63339E-07	863.7612225	863.7612225	863.761198	2.45314E-05	863.761198
Acetylene	51.76511755	0	51.76511755	51.76511755	51.76511597	1.58413E-06	51.76511597	51.76511597	51.76506977	4.62181E-05	51.76506977	51.76506977	51.76506221	7.56221E-06	51.76506221
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	17.12821216	0	17.12821216	17.12821216	17.12821215	7.53836E-09	17.12821215	17.12821215	17.12821216	6.33128E-10	17.12821216	17.12821216	17.12820996	2.2041E-06	17.12820996
Naphthalene	5.138464122	0	5.138464122	5.138464122	5.138464122	2.38223E-12	5.138464122	5.138464122	5.138464124	5.11093E-13	5.138464124	5.138464124	5.138464103	2.09932E-08	5.138464103
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	273455.7485	0	273455.7485	273455.7485	253134.9162	20320.83228	253134.9162	253134.9162	240797.0539	12337.86224	240797.0539	240797.0539	234045.3632	6751.690776	234045.3632
Heat Flow, Btu/hr	-847243715.4	0	-833507533.6	-867929818.6	-731334175.2	-136595643.4	-717597993.5	-743887324.4	-661086155.7	-82801168.76	-647349973.9	-667980785.5	-622748042.5	-45232742.95	-609011860.8

Stream	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329
Pressure, psia	157.1272845	157.1272845	157.1272845	295.0009644	290.0009644	285.0009644	285.0009644	18	18	18	18	18	18	24.69594446	14.76812681
Temperature, F	140	140	140	271.8610175	140	110	110	140.0286465	140.0823908	140.1656076	140.2795636	110.5885511	137.8680841	137.8814749	90
Components, lb/hr															
Hydrogen	15304.20711	15304.19957	0.007545202	15304.19957	15304.19957	15304.19957	0.008224022	0.006442626	0.007126763	0.007026426	0.007545202	0.008224022	0.036365039	0.036365039	0
CO	98416.44486	98416.39167	0.05319677	98416.39167	98416.39167	98416.39167	0.06301952	0.045538652	0.050413916	0.049695901	0.05319677	0.06301952	0.261864759	0.261864759	0
Nitrogen	1348.113383	1348.111338	0.00204509	1348.111338	1348.111338	1348.111338	0.003789561	0.001768206	0.001950639	0.00191569	0.00204509	0.003789561	0.011469187	0.011469187	5794638.903
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1775620.751
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98841.89701
CO2	105855.8677	105809.0752	46.79244181	105809.0752	105809.0752	105809.0752	39.44990504	100.5817204	89.36063092	66.12266724	46.79244181	39.44990504	342.3073654	342.3073654	4080.520785
H2O	8482.11265	4622.030228	3860.082422	4622.030228	4622.030228	4622.030228	3510.861916	20178.92786	12212.97054	6660.30654	3860.082422	3510.861916	46423.14927	46423.14927	153250.1341
H2S	237.3673119	237.2253447	0.141967238	237.2253447	237.2253447	237.2253447	0.133340856	0.32529314	0.274148998	0.196945614	0.141967238	0.133340856	1.071695845	1.071695845	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	27.69911757	11.10953036	16.5895872	11.10953036	11.10953036	11.10953036	10.78878199	40.94358423	35.19735238	25.00591556	16.5895872	10.78878199	128.5252214	128.5252214	0
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	3422.811817	3422.811797	1.98676E-05	3422.811797	3422.811797	3422.811797	2.83285E-05	6.79492E-05	2.19724E-05	2.5694E-05	1.98676E-05	2.83285E-05	0.000163812	0.000163812	0
Ethane	12.94628229	12.94625267	2.96115E-05	12.94625267	12.94625267	12.94625267	1.44201E-07	2.25391E-07	9.28264E-06	9.21799E-06	2.96115E-05	1.44201E-07	4.84818E-05	4.84818E-05	0
Ethylene	863.761198	863.7611525	4.55105E-05	863.7611525	863.7611525	863.7611525	2.92198E-05	4.18686E-06	9.63339E-07	2.45314E-05	4.55105E-05	2.92198E-05	0.000104412	0.000104412	0
Acetylene	51.76506221	51.76504683	1.53818E-05	51.76504683	51.76504683	51.76504683	8.10658E-06	1.58413E-06	4.62181E-05	7.56221E-06	1.53818E-05	8.10658E-06	7.88529E-05	7.88529E-05	0
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	17.12820996	17.12818924	2.07185E-05	17.12818924	17.12818924	17.12818924	6.07516E-09	7.53836E-09	6.33128E-10	2.2041E-06	2.07185E-05	6.07516E-09	2.29368E-05	2.29368E-05	0
Naphthalene	5.138464103	5.1384635	6.02696E-07	5.1384635	5.1384635	5.1384635	9.59418E-06	2.38223E-12	5.11093E-13	2.09932E-08	6.02696E-07	9.59418E-06	1.02179E-05	1.02179E-05	0
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	234045.3632	230121.6938	3923.669337	230121.6938	230121.6938	230121.6938	3561.309053	20320.83228	12337.86224	6751.690776	3923.669337	3561.309053	46895.36368	46895.36368	7826432.205
Heat Flow, Btu/hr	-626829225	-600578018.7	-26251206.26	-586841837	-602995830.2	-607584767.5	-23964886.9	-136595643.4	-82801168.76	-45232742.95	-26251206.26	-23964886.9	-314845648.3	-314844327.3	-873453662.5

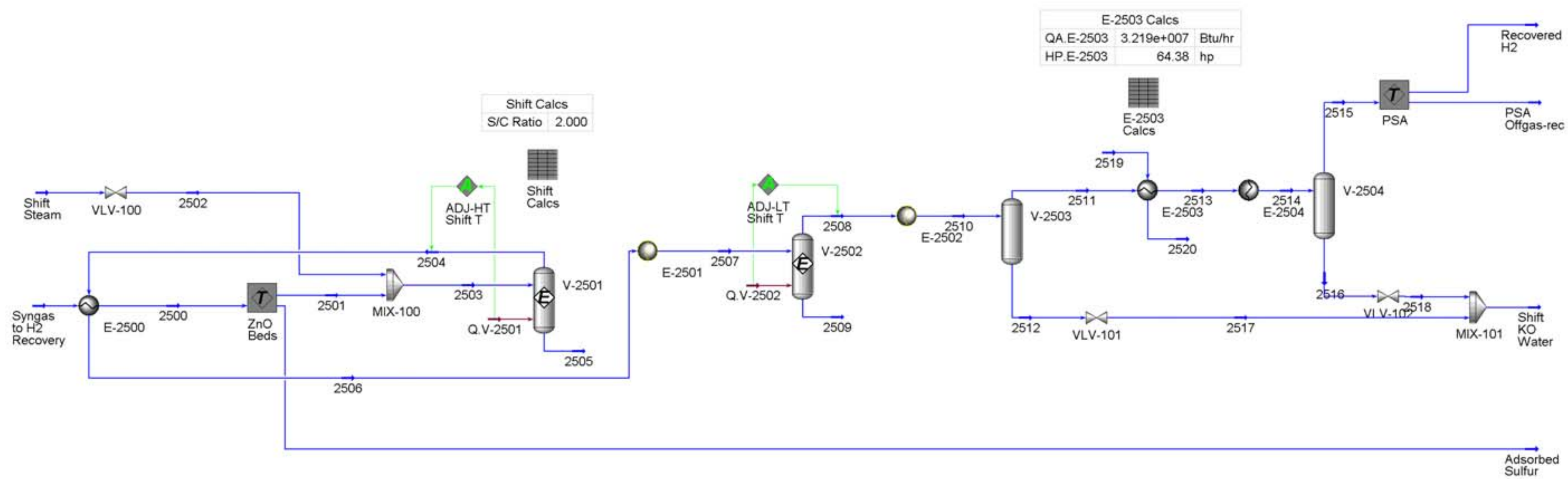
Stream	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	Compression KO Water	Conditioned Gas	HP Gas
Pressure, psia	14.76812681	14.69594446	14.76812681	14.69594446	14.76812681	14.69594446	14.76812681	14.69594446	14.76812681	14.69594446	14.69594446	14.69594446	18	285.0009644
Temperature, F	90	150	90	150	90	150	90	150	90	150	150	137.8959756	140	110
Components, lb/hr														
Hydrogen	0	0	0	0	0	0	0	0	0	0	0	0.036365039	15304.2277	15304.19134
CO	0	0	0	0	0	0	0	0	0	0	0	0.261864759	98416.59047	98416.32865
Nitrogen	1729756.427	1729756.427	1321066.376	1321066.376	1036719.859	1036719.859	895341.1871	895341.1871	811755.0533	811755.0533	5794638.903	0.011469187	1348.119017	1348.107549
Oxygen	530040.1727	530040.1727	404807.4281	404807.4281	317676.6191	317676.6191	274354.6954	274354.6954	248741.8356	248741.8356	1775620.751	0	0	0
Argon	29505.27366	29505.27366	22534.05413	22534.05413	17683.82108	17683.82108	15272.25818	15272.25818	13846.48996	13846.48996	98841.89701	0	0	0
CO2	1218.075392	1218.075392	930.2803673	930.2803673	730.0466873	730.0466873	630.489386	630.489386	571.6289528	571.6289528	4080.520785	342.3073654	106111.9327	105769.6253
H2O	45746.66494	45746.66494	34938.08721	34938.08721	27418.00829	27418.00829	23678.98316	23678.98316	21468.3905	21468.3905	153250.1341	46423.14927	47534.3177	1111.168312
H2S	0	0	0	0	0	0	0	0	0	0	0	1.071695845	238.1636996	237.0920038
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	0	0	0	0	0	0	0	0	0	0	0	128.5252214	128.84597	0.320748371
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0	0.000163812	3422.811931	3422.811769
Ethane	0	0	0	0	0	0	0	0	0	0	0	4.84818E-05	12.94630101	12.94625253
Ethylene	0	0	0	0	0	0	0	0	0	0	0	0.000104412	863.7612273	863.7611233
Acetylene	0	0	0	0	0	0	0	0	0	0	0	7.88529E-05	51.76511755	51.76503872
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	0	0	0	0	0	0	0	0	0	0	2.29368E-05	17.12821216	17.12818923
Naphthalene	0	0	0	0	0	0	0	0	0	0	0	1.02179E-05	5.138464122	5.138453906
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	2336266.613	2336266.613	1784276.226	1784276.226	1400228.355	1400228.355	1209277.613	1209277.613	1096383.398	1096383.398	7826432.205	46895.36368	273455.7485	226560.3848
Heat Flow, Btu/hr	-260734467.1	-226312170	-199130659.2	-172841328.3	-156269747.5	-135638935.9	-134959063.4	-117141699.2	-122359725.3	-106205732.1	-758139865.6	-314844327.3	-847243715.4	-583619880.6



Bulk Desulfurization Calcs	
Outlet H2S, ppm mol	10.00
HP.X-2400, Hp	117.1
QC.X-2400, Btu/hr	5.506e+004

Flowsheet: Bulk Desulfurization (DESU)

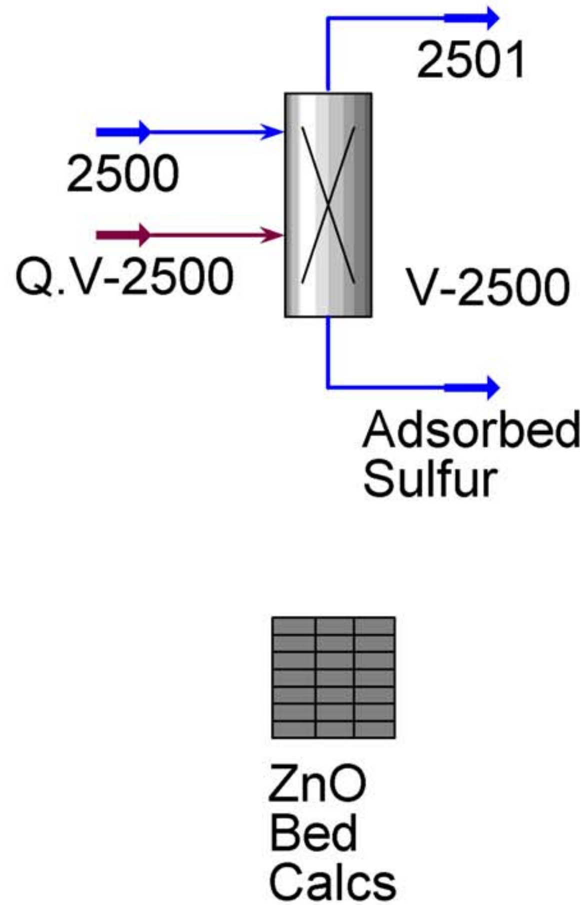
Stream	2400	2401	2402	2403	2404	Bulk Sulfur	Desulfurization Air	Desulfurization Offgas	HP Gas	Syngas
Pressure, psia	280.0009644	275.0009644	14.69594446	14.69594446	275.0009644	14.69594446	14.69594446	14.69594446	285.0009644	275.0009644
Temperature, F	120	120	120	110	120	110	90	110	110	118.9434276
Components, lb/hr										
Hydrogen	15304.19134	15304.19134	0	0	0	0	0	0	15304.19134	15304.19134
CO	98416.32865	98416.32865	0	0	0	0	0	0	98416.32865	98416.32865
Nitrogen	1348.107549	1348.107549	0	0.001488098	0.001488098	0	391.661554	391.6600659	1348.107549	1348.109037
Oxygen	0	0	0	1.89371E-05	1.89371E-05	0	120.014792	10.9104167	0	1.89371E-05
Argon	0	0	0	2.97866E-07	2.97866E-07	0	6.680756408	6.68075611	0	2.97866E-07
CO2	105769.6253	105769.6253	0	5.05593E-05	5.05593E-05	0	0.275803745	0.275753186	105769.6253	105769.6254
H2O	1111.168312	1111.168312	0	108.347053	108.347053	0	10.35822709	24.85654549	1111.168312	1219.515365
H2S	237.0920038	4.726999417	232.3650044	0	0	0	0	0	237.0920038	4.726999417
SO2	0	0	0	0	0	0	0	0	0	0
Ammonia	0.320748371	0.320748371	0	0	0	0	0	0	0.320748371	0.320748371
NO2	0	0	0	0	0	0	0	0	0	0
Methane	3422.811769	3422.811769	0	0	0	0	0	0	3422.811769	3422.811769
Ethane	12.94625253	12.94625253	0	0	0	0	0	0	12.94625253	12.94625253
Ethylene	863.7611233	863.7611233	0	0	0	0	0	0	863.7611233	863.7611233
Acetylene	51.76503872	51.76503872	0	0	0	0	0	0	51.76503872	51.76503872
Propane	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0
Benzene	17.12818923	17.12818923	0	0	0	0	0	0	17.12818923	17.12818923
Naphthalene	5.138453906	5.138453906	0	0	0	0	0	0	5.138453906	5.138453906
S_Rhombic	0	0	0	218.6587811	0	218.6587811	0	0	0	0
Sand*	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	226560.3848	226328.0198	232.3650044	327.007392	108.3486109	218.6587811	528.9911332	434.3835374	226560.3848	226436.3684
Heat Flow, Btu/hr	-582573020.9	-582505728.3	-56883.31911	79861.69642	-733091.8614	814147.876	-59036.62907	-140421.2706	-583619880.6	-583238820.2


E-2503 Calcs
QA.E-2503 3.219e+007 Btu/hr
HP.E-2503 64.38 hp
Shift Calcs
S/C Ratio 2.000
Recovered H2
PSA
PSA Offgas-rec
E-2503 Calcs
2515
2519
V-2504
Shift Steam
VLV-100
2502
ADJ-HT Shift T
Shift Calcs
ADJ-LT Shift T
2508
2510
E-2502
V-2503
2511
E-2503
2513
2514
E-2504
2520
V-2502
2504
V-2501
2507
E-2501
2503
2501
MIX-100
Q.V-2501
Q.V-2502
2509
Syngas to H2 Recovery
E-2500
2500
ZnO Beds
2505
2516
VLV-102
2518
2512
VLV-101
2517
MIX-101
Shift KO Water
2506
Adsorbed Sulfur

Flowsheet: H2 Recovery (H2RE)

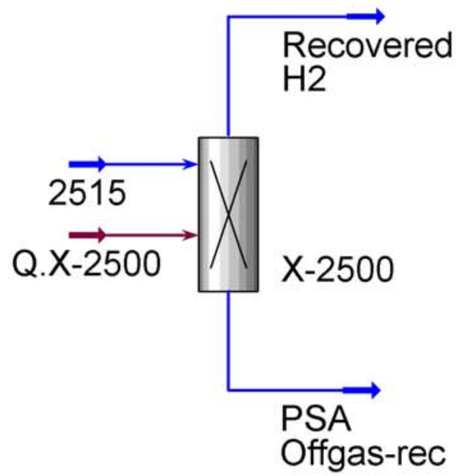
Stream	2500	2501	2502	2503	2504	2505	2506	2507	2508	2509	2510	2511	2512	2513	2514
Pressure, psia	270.0009644	265.0009644	265.0009644	265.0009644	260.0009644	260.0009644	257.5009644	255.0009644	250.0009644	250.0009644	245.0009644	245.0009644	245.0009644	240.0009644	235.0009644
Temperature, F	707	707	647.4773136	681.4909054	863.0626511	863.0626511	508.6304763	392	519.8172099	519.8172099	274.4261532	274.4261532	274.4261532	140	110
Components, lb/hr															
Hydrogen	5604.817326	5604.817326	0	5604.817326	7027.518201	0	7027.518201	7027.518201	7969.414914	0	7969.414914	7969.414914	0	7969.414914	7969.414914
CO	36042.77623	36042.77623	0	36042.77623	16275.34424	0	16275.34424	16275.34424	3188.349849	0	3188.349849	3188.349849	0	3188.349849	3188.349849
Nitrogen	493.7147423	493.7147423	0	493.7147423	493.7147423	0	493.7147423	493.7147423	493.7147423	0	493.7147423	493.7147423	0	493.7147423	493.7147423
Oxygen	6.9353E-06	6.9353E-06	0	6.9353E-06	6.9353E-06	0	6.9353E-06	6.9353E-06	6.9353E-06	0	6.9353E-06	6.9353E-06	0	6.9353E-06	6.9353E-06
Argon	1.09087E-07	1.09087E-07	0	1.09087E-07	1.09087E-07	0	1.09087E-07	1.09087E-07	1.09087E-07	0	1.09087E-07	1.09087E-07	0	1.09087E-07	1.09087E-07
CO2	38735.75647	38735.75647	0	38735.75647	69793.62443	0	69793.62443	69793.62443	90355.43105	0	90355.43105	90355.43105	0	90355.43105	90355.43105
H2O	446.6201899	446.6201899	45914.91934	46361.53953	33648.19597	0	33648.19597	33648.19597	25231.34683	0	25231.34683	25231.34683	0	25231.34683	25231.34683
H2S	1.73115767	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	0.117466907	0.117466907	0	0.117466907	0.117466907	0	0.117466907	0.117466907	0.117466907	0	0.117466907	0.117466907	0	0.117466907	0.117466907
NO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	1253.528153	1253.528153	0	1253.528153	1253.528153	0	1253.528153	1253.528153	1253.528153	0	1253.528153	1253.528153	0	1253.528153	1253.528153
Ethane	4.741275044	4.741275044	0	4.741275044	4.741275044	0	4.741275044	4.741275044	4.741275044	0	4.741275044	4.741275044	0	4.741275044	4.741275044
Ethylene	316.3331665	316.3331665	0	316.3331665	316.3331665	0	316.3331665	316.3331665	316.3331665	0	316.3331665	316.3331665	0	316.3331665	316.3331665
Acetylene	18.9577861	18.9577861	0	18.9577861	18.9577861	0	18.9577861	18.9577861	18.9577861	0	18.9577861	18.9577861	0	18.9577861	18.9577861
Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	6.272815702	6.272815702	0	6.272815702	6.272815702	0	6.272815702	6.272815702	6.272815702	0	6.272815702	6.272815702	0	6.272815702	6.272815702
Naphthalene	1.881843662	1.881843662	0	1.881843662	1.881843662	0	1.881843662	1.881843662	1.881843662	0	1.881843662	1.881843662	0	1.881843662	1.881843662
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stover*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char - Ash*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total, lb/hr	82927.24863	82925.51747	45914.91934	128840.4368	128840.2301	0	128840.2301	128840.2301	128840.0899	0	128840.0899	128840.0899	0	128840.0899	128840.0899
Heat Flow, Btu/hr	-190535670.9	-190535554.9	-252614542.6	-443150097.5	-443150103.3	0	-466212588.1	-473563578	-473563575.7	0	-489091782.7	-489091782.7	0	-521281534.4	-524268807.1

Stream	2515	2516	2517	2518	2519	2520	Adsorbed Sulfur	PSA Offgas-rec	Recovered H2	Shift KO Water	Shift Steam	Syngas to H2 Recovery			
Pressure, psia	235.0009644	235.0009644	14.69594446	14.69594446	14.76812681	14.69594446	265.0009644	25	225.0009644	14.69594446	304.696	275.0009644			
Temperature, F	110	110	211.3194071	110.3166349	90	150	707	110	110.0000002	110.3166349	651.9141016	118.9434276			
Components, lb/hr															
Hydrogen	7969.362032	0.052881953	0	0.052881953	0	0	0	1195.404305	6773.957727	0.052881953	0	5604.817326			
CO	3188.324753	0.025096296	0	0.025096296	0	0	0	3187.383568	0.941184303	0.025096296	0	36042.77623			
Nitrogen	493.6974288	0.017313529	0	0.017313529	1617568.693	1617568.693	0	493.6974288	0	0.017313529	0	493.7147423			
Oxygen	5.6914E-06	1.2439E-06	0	1.2439E-06	495663.075	495663.075	0	5.6914E-06	0	1.2439E-06	0	6.9353E-06			
Argon	8.95211E-08	1.95657E-08	0	1.95657E-08	27591.63441	27591.63441	0	8.95211E-08	0	1.95657E-08	0	1.09087E-07			
CO2	90226.92673	128.5043149	0	128.5043149	1139.074027	1139.074027	0	90226.92673	0	128.5043149	0	38735.75647			
H2O	611.5192468	24619.82758	0	24619.82758	42779.64913	42779.64913	0	611.5192468	0	24619.82758	45914.91934	446.6201899			
H2S	0	0	0	0	0	0	1.73115767	0	0	0	0	1.73115767			
SO2	0	0	0	0	0	0	0	0	0	0	0	0			
Ammonia	6.58625E-07	0.117466249	0	0.117466249	0	0	0	6.58625E-07	0	0.117466249	0	0.117466907			
NO2	0	0	0	0	0	0	0	0	0	0	0	0			
Methane	1253.527938	0.000214867	0	0.000214867	0	0	0	1253.527938	0	0.000214867	0	1253.528153			
Ethane	4.741271808	3.23653E-06	0	3.23653E-06	0	0	0	4.741271808	0	3.23653E-06	0	4.741275044			
Ethylene	316.3329259	0.000240656	0	0.000240656	0	0	0	316.3329259	0	0.000240656	0	316.3331665			
Acetylene	18.95776998	1.61147E-05	0	1.61147E-05	0	0	0	18.95776998	0	1.61147E-05	0	18.9577861			
Propane	0	0	0	0	0	0	0	0	0	0	0	0			
i-Butane	0	0	0	0	0	0	0	0	0	0	0	0			
n-Butane	0	0	0	0	0	0	0	0	0	0	0	0			
i-Pentane	0	0	0	0	0	0	0	0	0	0	0	0			
n-Pentane	0	0	0	0	0	0	0	0	0	0	0	0			
n-Hexane	0	0	0	0	0	0	0	0	0	0	0	0			
Benzene	6.272815702	6.22024E-11	0	6.22024E-11	0	0	0	6.272815702	0	6.22024E-11	0	6.272815702			
Naphthalene	1.881843662	2.58697E-14	0	2.58697E-14	0	0	0	1.881843662	0	2.58697E-14	0	1.881843662			
S_Rhombic	0	0	0	0	0	0	0	0	0	0	0	0			
Sand*	0	0	0	0	0	0	0	0	0	0	0	0			
Stover*	0	0	0	0	0	0	0	0	0	0	0	0			
Char - C*	0	0	0	0	0	0	0	0	0	0	0	0			
Char - H*	0	0	0	0	0	0	0	0	0	0	0	0			
Char - N*	0	0	0	0	0	0	0	0	0	0	0	0			
Char - S*	0	0	0	0	0	0	0	0	0	0	0	0			
Char - O*	0	0	0	0	0	0	0	0	0	0	0	0			
Char - Ash*	0	0	0	0	0	0	0	0	0	0	0	0			
Total, lb/hr	104091.5448	24748.54513	0	24748.54513	2184742.125	2184742.125	1.73115767	97316.64586	6774.898911	24748.54513	45914.91934	82927.24863			
Heat Flow, Btu/hr	-356934118.9	-167334688.3	0	-167334688.3	-243823872.9	-211634121.1	-164.7691217	-357443646	752737.1154	-167334688.3	-252614542.6	-213598155.6			

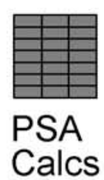

2501
2500
Q.V-2500
V-2500
Adsorbed
Sulfur
ZnO
Bed
Calcs

Flowsheet: ZnO Beds (ZNO)

Stream	2500	2501	Adsorbed Sulfur
Pressure, psia	270.0009644	265.0009644	265.0009644
Temperature, F	707	707	707
Components, lb/hr			
Hydrogen	5604.817326	5604.817326	0
CO	36042.77623	36042.77623	0
Nitrogen	493.7147423	493.7147423	0
Oxygen	6.9353E-06	6.9353E-06	0
Argon	1.09087E-07	1.09087E-07	0
CO2	38735.75647	38735.75647	0
H2O	446.6201899	446.6201899	0
H2S	1.73115767	0	1.73115767
SO2	0	0	0
Ammonia	0.117466907	0.117466907	0
NO2	0	0	0
Methane	1253.528153	1253.528153	0
Ethane	4.741275044	4.741275044	0
Ethylene	316.3331665	316.3331665	0
Acetylene	18.9577861	18.9577861	0
Propane	0	0	0
i-Butane	0	0	0
n-Butane	0	0	0
i-Pentane	0	0	0
n-Pentane	0	0	0
n-Hexane	0	0	0
Benzene	6.272815702	6.272815702	0
Naphthalene	1.881843662	1.881843662	0
S_Rhombic	0	0	0
Sand*	0	0	0
Stover*	0	0	0
Char - C*	0	0	0
Char - H*	0	0	0
Char - N*	0	0	0
Char - S*	0	0	0
Char - O*	0	0	0
Char - Ash*	0	0	0
Total, lb/hr	82927.24863	82925.51747	1.73115767
Heat Flow, Btu/hr	-190535670.9	-190535554.9	-164.7691217

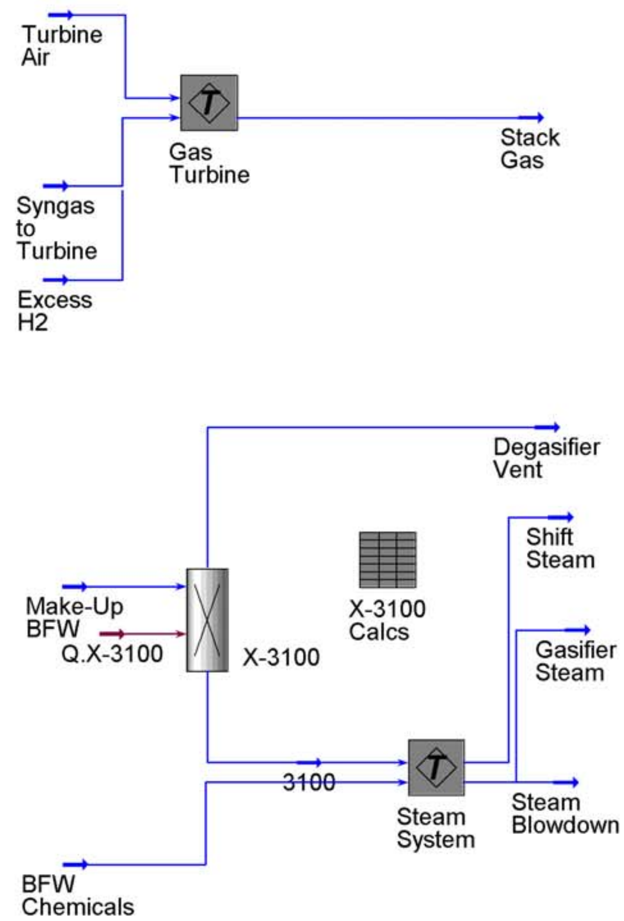


PSA Calcs		
Inlet Flow	57.00	MMSCFD
Inlet H2 Mole Frac	0.6316	
Recovered H2	30.60	MMSCFD



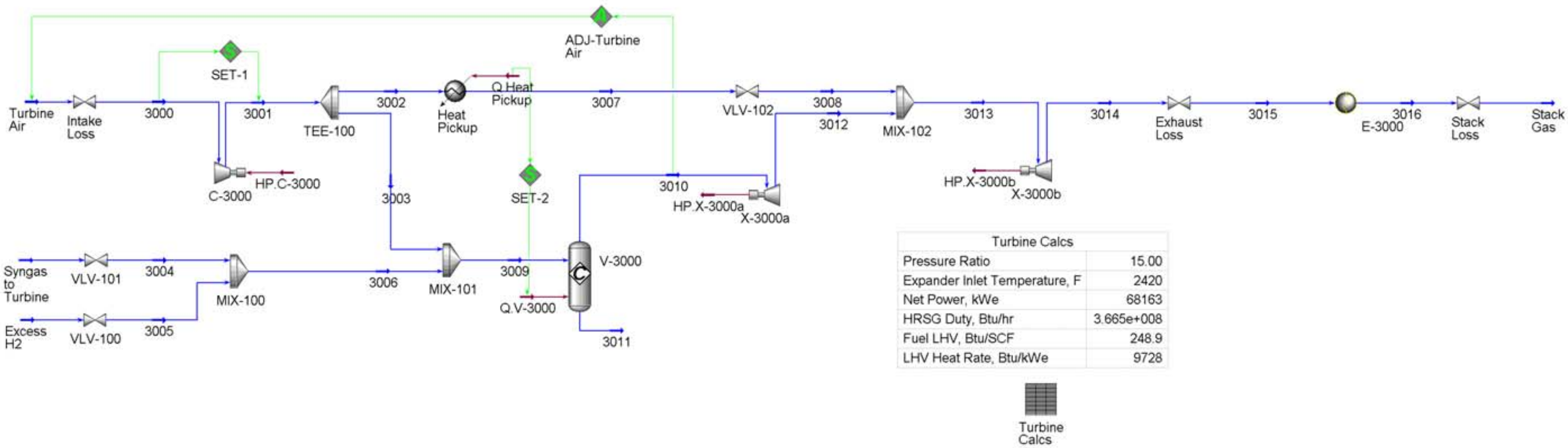
Flowsheet: PSA (PSA)

Stream	2515	PSA Offgas-rec	Recovered H2
Pressure, psia	235.0009644	25	225.0009644
Temperature, F	110	110	110
Components, lb/hr			
Hydrogen	7969.362032	1195.404305	6773.957727
CO	3188.324753	3187.383568	0.941184303
Nitrogen	493.6974288	493.6974288	0
Oxygen	5.6914E-06	5.6914E-06	0
Argon	8.95211E-08	8.95211E-08	0
CO2	90226.92673	90226.92673	0
H2O	611.5192468	611.5192468	0
H2S	0	0	0
SO2	0	0	0
Ammonia	6.58625E-07	6.58625E-07	0
NO2	0	0	0
Methane	1253.527938	1253.527938	0
Ethane	4.741271808	4.741271808	0
Ethylene	316.3329259	316.3329259	0
Acetylene	18.95776998	18.95776998	0
Propane	0	0	0
i-Butane	0	0	0
n-Butane	0	0	0
i-Pentane	0	0	0
n-Pentane	0	0	0
n-Hexane	0	0	0
Benzene	6.272815702	6.272815702	0
Naphthalene	1.881843662	1.881843662	0
S_Rhombic	0	0	0
Sand*	0	0	0
Stover*	0	0	0
Char - C*	0	0	0
Char - H*	0	0	0
Char - N*	0	0	0
Char - S*	0	0	0
Char - O*	0	0	0
Char - Ash*	0	0	0
Total, lb/hr	104091.5448	97316.64586	6774.898911
Heat Flow, Btu/hr	-356934118.9	-357443646	752737.1154


Turbine
Air
Gas
Turbine
Stack
Gas
Syngas
to
Turbine
Excess
H2
Degasifier
Vent
Shift
Steam
Make-Up
BFW
Q.X-3100
X-3100
X-3100
Calcs
Gasifier
Steam
3100
Steam
System
Steam
Blowdown
BFW
Chemicals

Flowsheet: Cogeneration (COGN)

Stream	3100	BFW Chemicals	Degasifier Vent	Excess H2	Gasifier Steam	Make-Up BFW	Shift Steam	Stack Gas	Steam Blowdown	Syngas to Turbine	Turbine Air
Pressure, psia	14.69594446	14.69594446	14.69594446	225.0009644	54.696	14.69594446	304.696	14.69594446	14.69594446	275.0009644	14.69594446
Temperature, F	60	60	60	110.0000002	352.4429737	60	651.9141016	249.9999999	113.2617414	118.9434276	90
Components, lb/hr											
Hydrogen	0	0	0	7.458052767	0	0	0	0	0	7741.805901	0
CO	0	0	0	0.001036234	0	0	0	0	0	49785.06193	0
Nitrogen	0	0	0	0	0	0	0	988058.3758	0	681.9568745	987376.2855
Oxygen	0	0	0	0	0	0	0	204071.4637	0	9.57957E-06	302556.527
Argon	0	0	0	0	0	0	0	16842.1444	0	1.50679E-07	16842.1444
CO2	0	0	0	0	0	0	0	138687.263	0	53504.81392	695.2994869
H2O	164746.3611	5.269273437	0	0	103781.6441	164746.3611	45914.91934	100466.5237	15055.06696	616.906247	26113.02459
H2S	0	0	0	0	0	0	0	0	0	2.391208471	0
SO2	0	0	0	0	0	0	0	4.495480566	0	0	0
Ammonia	0	0	0	0	0	0	0	0	0	0.162254351	0
NO2	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	1731.469749	0
Ethane	0	0	0	0	0	0	0	0	0	6.54901471	0
Ethylene	0	0	0	0	0	0	0	0	0	436.9437634	0
Acetylene	0	0	0	0	0	0	0	0	0	26.18595607	0
Propane	0	0	0	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0	0	0	0
Benzene	0	0	0	0	0	0	0	0	0	8.664496771	0
Naphthalene	0	0	0	0	0	0	0	0	0	2.599347583	0
Total, lb/hr	164746.3611	5.269273437	0	7.459089	103781.6441	164746.3611	45914.91934	1448130.266	15055.06696	114545.5107	1333583.281
Heat Flow, Btu/hr	-1125002385	-35982.2526	0	828.7552694	-584453358	-1125002385	-252614542.6	-1047570176	-101980087.7	-295038244	-148830966.3



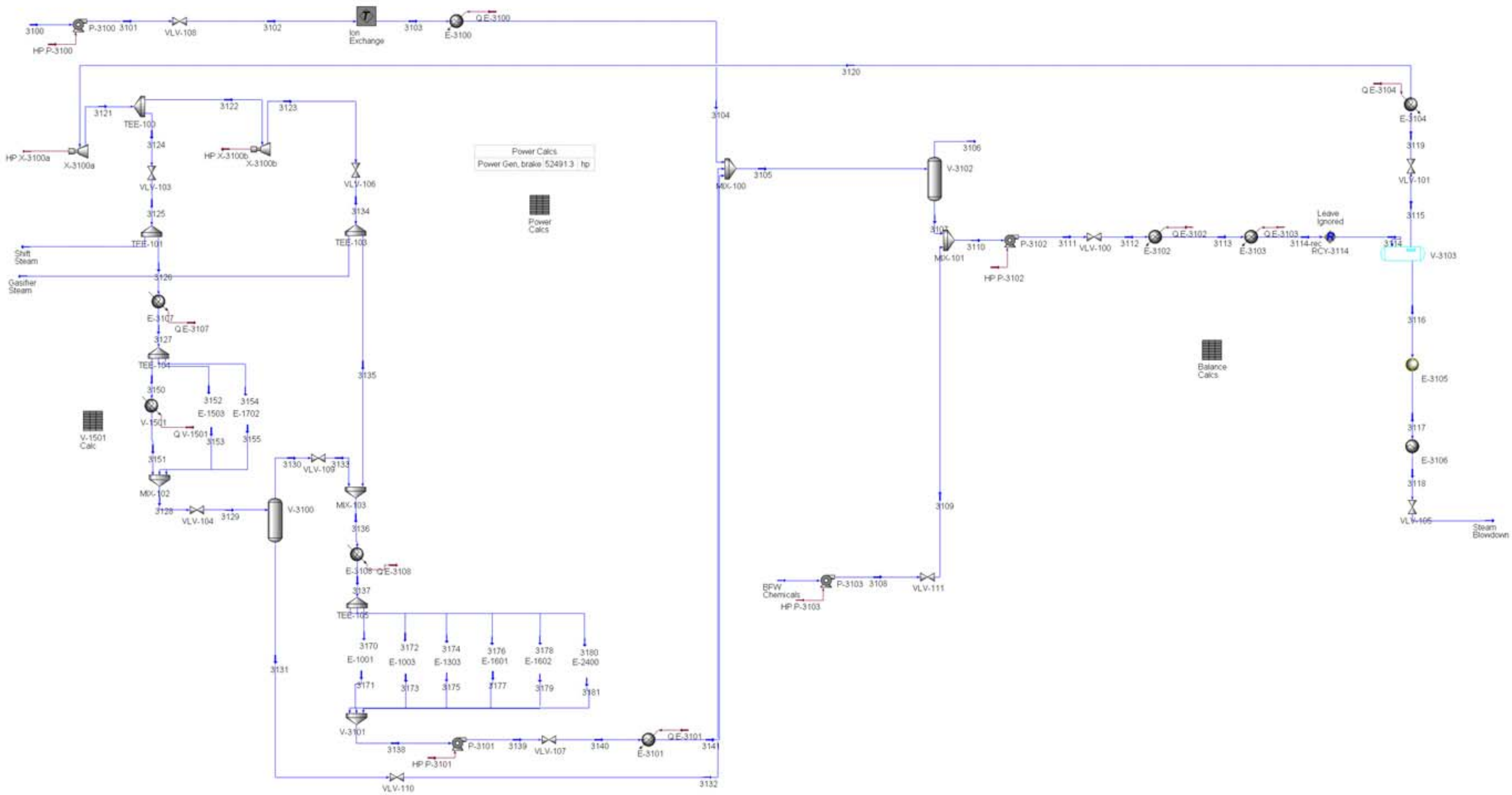
Turbine Calcs	
Pressure Ratio	15.00
Expander Inlet Temperature, F	2420
Net Power, kWe	68163
HRSG Duty, Btu/hr	3.665e+008
Fuel LHV, Btu/SCF	248.9
LHV Heat Rate, Btu/kWe	9728

Flowsheet: Gas Turbine (GAST)

Stream	3000	3001	3002	3003	3004	3005	3006	3007
Pressure, psia	14.55157975	218.2736962	218.2736962	218.2736962	218.2736962	218.2736962	218.2736962	218.2736962
Temperature, F	89.99394726	770.6744651	770.6744651	770.6744651	117.8783877	110.0020859	117.8734741	820.6744651
Components, lb/hr								
Hydrogen	0	0	0	0	7741.805901	7.458052767	7749.263953	0
CO	0	0	0	0	49785.06193	0.001036234	49785.06297	0
Nitrogen	987376.2855	987376.2855	136356.665	851019.6205	681.9568745	0	681.9568745	136356.665
Oxygen	302556.527	302556.527	41783.05638	260773.4706	9.57957E-06	0	9.57957E-06	41783.05638
Argon	16842.1444	16842.1444	2325.900141	14516.24425	1.50679E-07	0	1.50679E-07	2325.900141
CO2	695.2994869	695.2994869	96.02085914	599.2786278	53504.81392	0	53504.81392	96.02085914
H2O	26113.02459	26113.02459	3606.208696	22506.8159	616.906247	0	616.906247	3606.208696
H2S	0	0	0	0	2.391208471	0	2.391208471	0
SO2	0	0	0	0	0	0	0	0
Ammonia	0	0	0	0	0.162254351	0	0.162254351	0
NO2	0	0	0	0	0	0	0	0
Methane	0	0	0	0	1731.469749	0	1731.469749	0
Ethane	0	0	0	0	6.54901471	0	6.54901471	0
Ethylene	0	0	0	0	436.9437634	0	436.9437634	0
Acetylene	0	0	0	0	26.18595607	0	26.18595607	0
Propane	0	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0	0
Benzene	0	0	0	0	8.664496771	0	8.664496771	0
Naphthalene	0	0	0	0	2.599347583	0	2.599347583	0
Total, lb/hr	1333583.281	1333583.281	184167.8511	1149415.43	114545.5107	7.459089	114552.9698	184167.8511
Heat Flow, Btu/hr	-148830966.3	81685384.2	11280751.56	70404632.65	-295038244	828.7552694	-295037415.2	13722853.94

Stream	3008	3009	3010	3011	3012	3013	3014
Pressure, psia	23.52783319	218.2736962	206.9936962	206.9936962	23.52783319	23.52783319	15.30949447
Temperature, F	820.677171	671.8908484	2419.98896	2419.98896	1400	1331.901821	1171.885294
Components, lb/hr							
Hydrogen	0	7749.263953	0	0	0	0	0
CO	0	49785.06297	0	0	0	0	0
Nitrogen	136356.665	851701.5773	851701.7108	0	851701.7108	988058.3758	988058.3758
Oxygen	41783.05638	260773.4706	162288.4073	0	162288.4073	204071.4637	204071.4637
Argon	2325.900141	14516.24425	14516.24425	0	14516.24425	16842.1444	16842.1444
CO2	96.02085914	54104.09254	138591.2421	0	138591.2421	138687.263	138687.263
H2O	3606.208696	23123.72214	96860.31503	0	96860.31503	100466.5237	100466.5237
H2S	0	2.391208471	0	0	0	0	0
SO2	0	0	4.495480566	0	4.495480566	4.495480566	4.495480566
Ammonia	0	0.162254351	0	0	0	0	0
NO2	0	0	0	0	0	0	0
Methane	0	1731.469749	0	0	0	0	0
Ethane	0	6.54901471	0	0	0	0	0
Ethylene	0	436.9437634	0	0	0	0	0
Acetylene	0	26.18595607	0	0	0	0	0
Propane	0	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0	0
Benzene	0	8.664496771	0	0	0	0	0
Naphthalene	0	2.599347583	0	0	0	0	0
Total, lb/hr	184167.8511	1263968.4	1263962.415	0	1263962.415	1448130.266	1448130.266
Heat Flow, Btu/hr	13722853.94	-224632782.6	-227074884.9	0	-627314637.1	-613591783.1	-681106406.8

Stream	3015	3016	Excess H2	Stack Gas	Syngas to Turbine	Turbine Air
Pressure, psia	14.9485827	14.76812681	225.0009644	14.69594446	275.0009644	14.69594446
Temperature, F	1171.885564	250.002848	110.0000004	250	118.9434276	90
Components, lb/hr						
Hydrogen	0	0	7.458052767	0	7741.805901	0
CO	0	0	0.001036234	0	49785.06193	0
Nitrogen	988058.3758	988058.3758	0	988058.3758	681.9568745	987376.2855
Oxygen	204071.4637	204071.4637	0	204071.4637	9.57957E-06	302556.527
Argon	16842.1444	16842.1444	0	16842.1444	1.50679E-07	16842.1444
CO2	138687.263	138687.263	0	138687.263	53504.81392	695.2994869
H2O	100466.5237	100466.5237	0	100466.5237	616.906247	26113.02459
H2S	0	0	0	0	2.391208471	0
SO2	4.495480566	4.495480566	0	4.495480566	0	0
Ammonia	0	0	0	0	0.162254351	0
NO2	0	0	0	0	0	0
Methane	0	0	0	0	1731.469749	0
Ethane	0	0	0	0	6.54901471	0
Ethylene	0	0	0	0	436.9437634	0
Acetylene	0	0	0	0	26.18595607	0
Propane	0	0	0	0	0	0
i-Butane	0	0	0	0	0	0
n-Butane	0	0	0	0	0	0
i-Pentane	0	0	0	0	0	0
n-Pentane	0	0	0	0	0	0
n-Hexane	0	0	0	0	0	0
Benzene	0	0	0	0	8.664496771	0
Naphthalene	0	0	0	0	2.599347583	0
Total, lb/hr	1448130.266	1448130.266	7.459089	1448130.266	114545.5107	1333583.281
Heat Flow, Btu/hr	-681106406.8	-1047570176	828.7552694	-1047570176	-295038244	-148830966.3


Power Calcs
Power Gen, brake 52491.3 hp
Ion Exchange
Shift Steam
Gasifier Steam
BFW Chemicals
Steam Blowdown
Balance Calcs
V-1501 Calc
Leave Ignored

Flowsheet: Steam System (STEM)

Stream	3100	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114
Pressure, psia	14.69594446	84.696	74.696	69.696	64.696	64.696	64.696	64.696	74.696	64.696	64.696	1334.696	1284.696	1279.696	1279.696
Temperature, F	60	60.07864882	60.10698891	60.12115847	297.6656079	297.6674276	297.6674276	297.6674276	60.06740358	60.09574455	297.6658002	300.6850129	300.776451	575.3922046	575.3938389
Components, lb/hr															
H2O	164746.3611	164746.3611	164746.3611	164746.3611	164746.3611	752748.0788	0	752748.0788	5.269273437	5.269273437	752753.3481	752753.3481	752753.3481	752753.3481	752753.3481
Total, lb/hr	164746.3611	164746.3611	164746.3611	164746.3611	164746.3611	752748.0788	0	752748.0788	5.269273437	5.269273437	752753.3481	752753.3481	752753.3481	752753.3481	752753.3481
Heat Flow, Btu/hr	-1123365012	-1123319380	-1123319380	-1123319380	-1083945191	-4952688622	0	-4952688622	-35928.63163	-35928.63163	-4952724550	-4948612004	-4948612004	-4715145935	-4273622098

Stream	3114-rec	3115	3116	3117	3118	3119	3120	3121	3122	3123	3124	3125	3126	3127	3128
Pressure, psia	1279.696	1279.696	1279.696	1274.696	1269.696	1269.696	1264.696	314.696	314.696	64.696	314.696	304.696	304.696	304.696	299.696
Temperature, F	575.3938389	575.3938389	575.3938389	200	110	574.3831292	1000	653.0887284	653.0887284	356.0979782	653.0887284	651.9141016	651.9141016	418.7744946	417.2517896
Components, lb/hr															
H2O	752753.3481	737698.2811	15055.06696	15055.06696	15055.06696	737698.2811	737698.2811	737698.2811	148263.4644	148263.4644	589434.8167	589434.8167	543519.8973	543519.8973	543519.8973
Total, lb/hr	752753.3481	737698.2811	15055.06696	15055.06696	15055.06696	737698.2811	737698.2811	737698.2811	148263.4644	148263.4644	589434.8167	589434.8167	543519.8973	543519.8973	543519.8973
Heat Flow, Btu/hr	-4273622098	-4179319214	-94302884.5	-100505531.3	-101856080	-4179319214	-3945992646	-4059849354	-815953277.5	-835657277.6	-3243896076	-3243896076	-2991207870	-3067359289	-3507263336

Stream	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138	3139	3140	3141	3150	3151
Pressure, psia	64.696	64.696	64.696	64.696	54.696	54.696	54.696	54.696	54.696	49.696	79.696	69.696	64.696	304.696	299.696
Temperature, F	297.6685343	297.6685343	297.6685343	297.6646205	292.7413949	352.4429737	352.4429737	314.5699238	286.7221265	280.6313062	280.6994453	280.7184115	297.6656079	418.7744946	417.2517896
Components, lb/hr															
H2O	543519.8973	75452.1594	468067.738	468067.738	75452.1594	148263.4644	44481.82033	119933.9797	119933.9797	119933.9797	119933.9797	119933.9797	119933.9797	-83807.9257	-83807.9257
Total, lb/hr	543519.8973	75452.1594	468067.738	468067.738	75452.1594	148263.4644	44481.82033	119933.9797	119933.9797	119933.9797	119933.9797	119933.9797	119933.9797	-83807.9257	-83807.9257
Heat Flow, Btu/hr	-3507263336	-427622983.7	-3079640353	-3079640353	-427622983.7	-835657277.6	-250712857.8	-678335841.4	-680109624.4	-791201378.2	-791186042.4	-791186042.4	-789103077.6	472970760.8	540801664.4

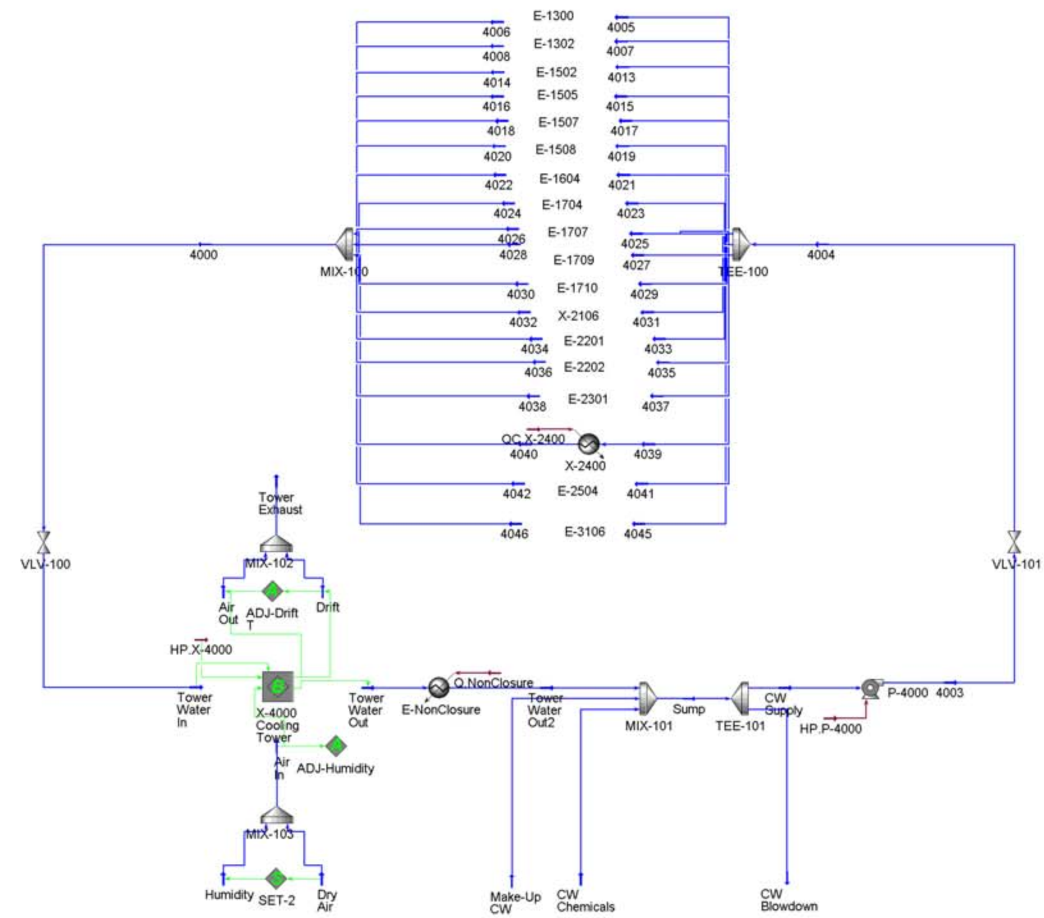
Stream	3152	3153	3154	3155	3170	3171	3172	3173	3174	3175	3176	3177	3178	3179	3180
Pressure, psia	304.696	299.696	304.696	299.696	54.696	49.696	54.696	49.696	54.696	49.696	54.696	49.696	54.696	49.696	54.696
Temperature, F	418.7744946	417.2517896	418.7744946	417.2517896	286.7221265	280.6313062	286.7221265	280.6313062	286.7221265	280.6313062	286.7221265	280.6313062	286.7221265	280.6313062	286.7221265
Components, lb/hr															
H2O	550350.2854	550350.2854	76977.53762	76977.53762	20180.37366	20180.37366	1748.024942	1748.024942	8014.596116	8014.596116	14755.13127	14755.13127	74105.67038	74105.67038	1130.183357
Total, lb/hr	550350.2854	550350.2854	76977.53762	76977.53762	20180.37366	20180.37366	1748.024942	1748.024942	8014.596116	8014.596116	14755.13127	14755.13127	74105.67038	74105.67038	1130.183357
Heat Flow, Btu/hr	-3105906643	-3551338944	-434423406	-496726056.9	-114436845.9	-133129405.8	-9912525.12	-11531675.56	-45448370.57	-52872084.35	-83671923.59	-97339221.33	-420231028.5	-488873200.6	-6408930.815

Stream	3181	BFW Chemicals	Gasifier Steam	Shift Steam	Steam Blowdown										
Pressure, psia	49.696	14.69594446	54.696	304.696	14.69594446										
Temperature, F	280.6313062	60	352.4429737	651.9141016	113.2617414										
Components, lb/hr															
H2O	1130.183357	5.269273437	103781.6441	45914.91934	15055.06696										
Total, lb/hr	1130.183357	5.269273437	103781.6441	45914.91934	15055.06696										
Heat Flow, Btu/hr	-7455790.525	-35929.88261	-584944419.8	-252688206.5	-101856080										

Calcs		
Total Duty	5.068e+008	Btu/hr
L/G	1.000	
NTU	1.333	
z	18.30	ft
Fan Power, Brake	2638	hp

Calcs

WARNING: Proper execution of several user variables and the spreadsheet Calcs depends upon the non-numeric stream names (e.g. Tower Water In). The codes should be updated if the stream names are changed.



Flowsheet: Cooling Water (CW)

Stream	4000	4003	4004	4005	4006	4007	4008	4013	4014	4015	4016	4017	4018	4019	4020
Pressure, psia	59.69594446	74.69594446	64.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446
Temperature, F	110	89.97299816	90	90	110	90	110	90	110	90	110	90	110	90	110
Components, lb/hr															
Nitrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2O	24605243.1	24605243.1	24605243.1	394254.0531	394254.0531	874858.4417	874858.4417	641318.5876	641318.5876	11198241.04	11198241.04	569354.8231	569354.8231	147357.5437	147357.5437
Total, lb/hr	24605243.1	24605243.1	24605243.1	394254.0531	394254.0531	874858.4417	874858.4417	641318.5876	641318.5876	11198241.04	11198241.04	569354.8231	569354.8231	147357.5437	147357.5437
Heat Flow, Btu/hr	-1.66751E+11	-1.67258E+11	-1.67258E+11	-2679998623	-2671877944	-5946976070	-5928956103	-4359455326	-4346245716	-76121653885	-75890997226	-3870271288	-3858543957	-1001684095	-998648886.1

Stream	4021	4022	4023	4024	4025	4026	4027	4028	4029	4030	4031	4032	4033	4034	4035
Pressure, psia	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446
Temperature, F	90	110	90	110	90	110	90	110	90	110	90	110	90	110	90
Components, lb/hr															
Nitrogen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2O	72106.46176	72106.46176	3912110.431	3912110.431	3281689.642	3281689.642	333719.5351	333719.5351	97671.43674	97671.43674	388393.6053	388393.6053	2200645.352	2200645.352	57460.4888
Total, lb/hr	72106.46176	72106.46176	3912110.431	3912110.431	3281689.642	3281689.642	333719.5351	333719.5351	97671.43674	97671.43674	388393.6053	388393.6053	2200645.352	2200645.352	57460.4888
Heat Flow, Btu/hr	-490154043.3	-488668824.8	-26593133246	-26512553241	-22307757277	-22240162414	-2268506532	-2261632717	-663935637.2	-661923842	-2640161386	-2632161418	-14959203253	-14913875285	-390595935.9

Stream	4036	4037	4038	4039	4040	4041	4042	4045	4046	Air In	Air Out	CW Blowdown	CW Chemicals	CW Supply	Drift
Pressure, psia	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	64.69594446	59.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446
Temperature, F	110	90	110	90	110	90	110	90	110	90	102.3209411	89.90452349	60	89.90452349	97.17346386
Components, lb/hr															
Nitrogen	0	0	0	0	0	0	0	0	0	18581404.37	18581404.37	0	0	0	0
Oxygen	0	0	0	0	0	0	0	0	0	5693802.104	5693802.104	0	0	0	0
Argon	0	0	0	0	0	0	0	0	0	316951.8045	316951.8045	0	0	0	0
CO2	0	0	0	0	0	0	0	0	0	13084.81995	13084.81995	0	0	0	0
H2O	57460.4888	222790.1264	222790.1264	2672.894528	2672.894528	145030.2786	145030.2786	65568.35189	65568.35189	491420.2177	938375.702	111738.8711	4.921048619	24605243.1	49210.48619
Total, lb/hr	57460.4888	222790.1264	222790.1264	2672.894528	2672.894528	145030.2786	145030.2786	65568.35189	65568.35189	25096663.31	25543618.8	111738.8711	4.921048619	24605243.1	49210.48619
Heat Flow, Btu/hr	-389412389	-1514447923	-1509858986	-18169384.94	-18114329.78	-985864175.1	-982876902.4	-445710301.3	-444359751.9	-2800845440	-5291495434	-759587489.2	-33604.33209	-1.67264E+11	-334158417.5

Stream	Dry Air	Humidity	Make-Up CW	Sump	Tower Exhaust	Tower Water In	Tower Water Out	Tower Water Out2							
Pressure, psia	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446	14.69594446							
Temperature, F	176.7746739	90	135.7095251	89.90452349	97.34600798	110.118818	88.74817027	88.74817027							
Components, lb/hr															
Nitrogen	18581404.37	0	0	0	18581404.37	0	0	0							
Oxygen	5693802.104	0	0	0	5693802.104	0	0	0							
Argon	316951.8045	0	0	0	316951.8045	0	0	0							
CO2	13084.81995	0	0	0	13084.81995	0	0	0							
H2O	0	491420.2177	607899.9205	24716981.97	987586.1882	24605243.1	24109077.12	24109077.12							
Total, lb/hr	24605243.1	491420.2177	607899.9205	24716981.97	25592829.28	24605243.1	24109077.12	24109077.12							
Heat Flow, Btu/hr	539722118.9	-3340567558	-4103707287	-1.68023E+11	-5625653852	-1.66751E+11	-1.63919E+11	-1.63919E+11							

Appendix F
Detailed Description of Base Case Economic Model

This appendix provides a detailed discussion of the economic model developed for the base case. Table 1 summarizes the material balance, net power export and other important assumptions and results for the economic model. The base case material balance was developed for a plant capacity of 100 MMgal/yr ethanol (denatured), with starch hydrolyzate and corn steep water supplied by an across the fence wet milling, a corn stover gasification unit to supply hydrogen and a gas turbine+bottoming cycle to provide steam and power.

Capital costs, operating costs, and revenues from the process material and energy balances. These costs and revenues were combined into discounted cash flow calculations to evaluate project-level economics on a 100% equity basis. Traditional single parameter sensitivity and Monte Carlo analysis were used to identify economic drivers. Each of these areas of the economic model will be discussed in detail in this appendix.

Capital Costs

Table 2 summaries the capital cost estimate. Capital costs are divided into three categories: Fixed Capital, Working Capital, and Start-up.

Fixed Capital – Fixed capital is estimated at $297.3 MM, or roughly $2.97 per annual gallon of capacity. The design basis uses both a conventional ethanol feedstock (e.g. starch hydrolyzate) and a less conventional lignocellulosic feed (e.g. corn stover). Projected fixed capital requirements for lignocellulosic based ethanol facilities are typically higher than for conventional corn dry mills.

A typical corn dry mill of equivalent capacity would require $1.00-1.50 of fixed capital per annual gallon of capacity based on our survey of recent plant announcements in (1). In contrast, the goal case reported in (2) for a grassroots direct fermentation facility using corn stover as the feedstock estimates fixed capital at $2.85 per gallon of annual capacity, with actual state of technology projections being much higher. The projected capital cost for the base case appears to be reasonable, after considering that infrastructure for processing lignocellulosic feeds is included in the model.

Standard factoring methods were used to construct the fixed capital estimate. The following basic methodology was used for process areas excluding the Feed Handling, Gasifier, and Conditioning sections of the Gasification and H2 Recovery area: 1) Size the individual pieces of process equipment using the process model material and energy balance as the basis, 2) Estimate the purchased equipment cost for each piece of equipment based on its size and a Chemical Engineering Index of 450 to adjust for any variances in the year of estimation, 3) Apply an installation factor, adjusted as needed based on the equipment type, to estimate the direct installed costs, 4) Apply additional factors to estimate indirect costs and project contingencies.

Direct installed costs for the Feed Handling, Gasifier, and Conditioning sections of the Gasification and H2 Recovery area were based on (3), using the power law:

$$\frac{\$_1}{\$_2} = \left(\frac{Capacity_1}{Capacity_2}\right)^n$$

with n = 0.7 to adjust for the difference in plant capacity. This area of the plant contains highly integrated and specialized process equipment, which for preliminary cost estimations, are more accurately estimated as a system rather than being built-up from individual pieces of equipment.

Table 3 presents the detailed fixed capital estimate. Each individual piece of equipment is identified with a tag number and name, a brief description of the equipment along with its size is given, the design temperature and pressure plus the materials of construction are stated, and the purchased equipment cost, installation factor and direct installed costs are presented. The purchased equipment costs were generated from a variety of sources. The software package Preliminary Design and Quotation Service (PDQS Inc., Gates Mills, OH) was used for estimating the purchase cost of many individual pieces of equipment, with supplemental sources such as vendor quotes from previous projects used for the rest.

Figure 1 divides the fixed capital estimate into directs, various indirect and contingency categories. Direct fixed capital is responsible for 71% of the total fixed capital. Figure 1 also shows the distribution of direct fixed capital by major process area. The direct fixed capital is nearly evenly divided across four categories: Fermentation and Recovery, Gasification and H2 Recovery, Utilities, and all other areas. One consequence of this nearly even distribution is that future process development efforts aimed at reducing capital costs for any one section of the plant will have a muted impact on process economics.

Working Capital – This category represents the amount of cash on-hand required to maintain an ongoing business. A crude estimate, based on 45 days of revenue, gives a working capital requirement of $19.7MM.

Start-Up Costs – This category represents the cost, beyond contingency, required to bring the plant up to full production in the first few years of operation. Start-up costs were estimated at 5% of fixed capital, or $14.9MM. In actual practice, start-up costs are allocated as both capital and operating expenses. In this estimate, they are identified in the capital summary as a part of the project's capital budget, but treated as an operating expense in the cash flow calculations.

Operating Costs

Table 4 summarizes the plant level operating cost estimate. Operating costs are divided into two categories: Variable costs, and Fixed Costs.

Variable Costs – Variable costs are proportional to the actual production rate. They can further divided into categories such as raw materials, catalysts, disposal, operating labor, etc. Table 4 shows that variable costs are dominated by the raw material costs for starch hydrolyzate, stover, and light steep water. None of these items are standard items of commerce, so some discussion is needed to justify the prices shown in Table 4.

We assumed a starch hydrolyzate price of $0.05 per lb (dry) in the base case economic model. The actual price of starch hydrolyzate would be set by a contractual agreement with the host corn wet mill. This agreement would most likely transfer commodity risk from the wet mill to the ethanol facility via a formula that takes into account fluctuations in corn and related wet mill co-product prices. The formula would also include a fixed margin to account for other processing costs and provide a financial return to the wet mill.

We have compiled cash costs for corn, unrefined corn oil, corn gluten meal, and corn gluten feed over the time period 1990-2004 (Chicago, IL basis) using data published in (4,5). Figure 2 shows that net corn (nominal basis), defined as the cost of corn less the value of the non-starch co-products using the actual reported prices without adjustments for inflation, was fairly constant over this time period with the exception of the Midwest drought year of 1996. Net corn ranged from $0.0179 to $0.1011 per lb of starch hydrolyzate (dry), with an average value of $0.0375. Thus, the assumed transfer price of $0.05 per lb (dry) used in our base case economic model would allow the mill a reasonable margin during an average year.

We assumed a price of $30 per metric ton (dry) for corn stover. The projected price of corn stover has been studied extensively by the U.S. Department of Energy and its subcontractors. The $30 per metric ton (dry) value used in our study is typical.

We assumed a light steep water price of $130 per US ton (dry). Like starch hydrolyzate, the actual price would be set by a contractual agreement with the host corn wet mill. This value for light steep water was arrived at by valuing the protein content. Soybean meal, a good proxy for the value of protein, typically sells for about $150 per US and contains ~ 44 wt% protein. The $130 per US ton (dry) results after adjustment for the lower protein content of light steep water.

Fixed Costs – Fixed costs are defined as operating costs that are incurred independent of the actual production rate for the plant. Supervision, maintenance, plant overhead, depreciation, property taxes and insurance fall into this category. Standard factors, shown in Table 4, were used to estimate these fixed costs. Depreciation and maintenance are the two largest fixed operating costs categories, both of which are factored off of plant fixed capital.

Revenues

Table 5 shows that ethanol sales is the major revenue stream for the plant, followed by electricity sales then steep water return sales. We have compiled rack prices for denatured fuel grade ethanol, Midwest basis, over the time period 1990-2004 (6,7). The monthly data are plotted in Figure 3. Fuel ethanol prices have varied from $0.90-$1.78 per gallon (denatured), with an average price of $1.24 per gallon (denatured) over this time period. We used the average price in the base case model.

Electricity markets have undergone significant deregulation in the past decade. The value of electricity depends upon many factors such as: time of day, geographic location, potential for green power credits, etc. The base case model assumes electricity sales are priced at an average of $0.05 per kWhr.

The value of steep water return was estimated from its protein content. The $125 per US ton (dry) value used in the base case economic model was arrived at in the same manner as that used to value light steep water. In actual practice, the value of steep water return will be set by contract with the corn wet mill host.

The process model assumes the ammonia nitrogen in light steep water is converted into cell mass during fermentation, thus the plant is a net producer of protein. The net protein revenue (i.e. the revenue from steep water return less costs for light steep water) under the assumptions used in the model is $0.0624 per gallon of ethanol (denatured).

Discounted Cash Flows

Discounted cash flow calculations use the time value of money concept to combine capital costs, operating costs, and revenues into one or more performance measures. The calculations can be done using either market pricing or rational pricing for the revenues, the choice of which depends upon the objectives of the analysis. Our base case model uses both market and rational price methods.

Market based pricing is commonly used in the private sector to evaluate the profitability of a potential project. In this method, a market analysis is used to establish the value of the products, the revenues are calculated using these market prices, and the cash flows for the project are then discounted at the corporate cost of capital. Our model uses a discount rate of 7% real with a 2% inflation rate, giving a 9% nominal discount rate which is within the range of values typically used in the private sector. The project is considered acceptable if the net present value (NPV) of the discounted cash flows is positive, or if the internal rate of return (IRR) is higher than the discount rate. In actual practice, the project is not accepted unless it is shown to be much more successful than the minimum requirement. Hurdle rates for the internal rate of return of 15-30% are often required to justify the increased risk of the project vs. other safer investments. These higher hurdle rates are also used by the corporation to limit, to a manageable number, the number of projects that are being pursued at any given time.

Rational pricing methods are commonly used in research environments. In this method, the assumed selling price for the product is not related to its market value. Rather, the assumed selling price is determined iteratively by requiring a zero net present value for the project when the cash flows are discounted at a given rate. The National Renewable Energy Laboratory, a leader in the field of bioethanol research, typically uses rational pricing with after tax cash flows discounted at 10% nominal in their analyses (2). This discount rate is low compared to typical corporate hurdle rates, but reflects the assumption that bioethanol will someday be a mature business. We have adopted the same discount rate (10% nominal, after tax) in our rational pricing method.

Table 6 presents the cash flow calculations. Other pertinent assumptions used in the discounted cash flows: 1) Two years of construction, 2) First operating year at 64% of nameplate capacity, second operating year at 85% of nameplate capacity, followed by twenty-three years of operation at 100% of nameplate capacity, 3) 100% equity investment, 4) Zero terminal value except for return of working capital, 5) Depreciation using 10 year MACRS, 6) Corporate overheads at 2% of revenues, and 7) Combined state and federal income tax rate of 37%. A summary of results for the discounted case flow calculations for the base case is:

Market Pricing	
Net Present Value, $MM (After-tax, 9% Nominal)	-6.64
Internal Rate of Return (After-tax)	8.7%
Rational Ethanol Price, $/gal (denatured)	1.29

The base case, as currently formulated, is not justifiable on an economic basis. Recommendations on means to improve the economic projections are discussed in Task 3 of the main body of this report.

Figure 4 presents the cost breakdown using Year 6 as the proof year. Net cash cost, defined as the price at which ethanol can be sold while maintaining the plant at cash flow breakeven, is $0.84 per gallon ethanol (denatured). This is a significant measure since it defines the plant's competitive position within the existing industry. Ethanol prices have not dipped below $0.90 per gallon (denatured) over the past 15 years, suggesting that this plant would most likely always be cash flow positive and would continue to operate during periods of depressed ethanol prices.

Net feed, defined as the difference between the cost of starch hydrolyzate+stover+light steep water less the revenues from electricity+steep water return, is $0.43 per gallon of ethanol (denature) and is the largest single cost component. Strategies to lower this cost component (e.g. replace starch hydrolyzate with biomass hydrolyzate) would make the most impact on improving overall process economics.

Sensitivity

A series of sensitivity studies were conducted in which a single variable (e.g. fixed capital) was allowed to vary from its base value and the economic performance was re-evaluated with all parameters held constant. The purpose of these sensitivity studies is to point out areas that would have the most impact for improvements in the technology and its implementation.

Figure 5 shows the sensitivity of internal rate of return and rational ethanol price with respect to variations in fixed capital. Included in this sensitivity are secondary affects of variation in fixed capital on operating costs since several items (e.g. maintenance, property taxes) were assumed to be a factor of fixed capital. While variations in fixed capital do influence these performance measures, the effect is somewhat muted since feedstock and other non-capital related costs are significant economic drivers. For example, fixed capital would have to drop by about one-third to raise the after tax internal rate of return to 15.0% (nominal).

Figure 6 shows the sensitivity of internal rate of return and rational ethanol price with respect to variations in starch hydrolyzate real price. The performance measures are sensitive to the cost of fermentable substrate. Attractive economic performance occurs for starch hydrolyzate prices below ~ $0.02 per lb (dry); negative performance measures occur for starch hydrolyzte prices above ~ $0.08 per lb (dry). As stated earlier, starch hydrolyzate prices would most likely be set by a contract formula based on net corn plus a margin. The vertical lines on Figure 6 are the net corn values of starch hydrolyzate without margin at several selected values of corn prices. It is unlikely that contractual negotiations with the host corn wet mill would lead to starch hydrolyzate prices in the range of $0.02 per lb (dry), suggesting that other low-cost fermentable sugar sources such as biomass hydrolyzates be pursued.

Figure 7 shows the sensitivity of internal rate of return and rational ethanol price with respect to variations in stover price. Attractive economic performance occurs for stover prices below ~$10 per metric ton (dry); negative performance measures occur for stover prices above ~$55 per metric ton (dry). These results suggest that investigation of lower-cost gasifier feedstocks would be an area of profitable R&D effort, especially when combined with other improvement efforts.

Figure 8 shows the sensitivity of internal rate of return and rational ethanol price with respect to variations in ethanol sales price. The internal rate of return is strongly affected by ethanol market price while, by definition, the rational ethanol price is not affected by ethanol market price. Historically, ethanol prices are correlated with gasoline prices, which in turn are correlated with crude oil prices. Recent prices for crude oil have exceeded $50 per barrel; gasoline and fuel ethanol have been strong. At the time of this writing, rack prices for fuel ethanol are about $1.70 per gallon. A plant could easily be justified under these price conditions. However, as shown earlier in Figure 3, fuel ethanol prices are quite volatile. It would have been quite difficult to justify an ethanol facility using the pricing environment of 1998-1999 and in early 2002.

Figure 9 shows the sensitivity of internal rate of return and rational ethanol price with respect to variations in electricity sales price. Attractive economic performance occurs for average electricity prices greater than ~$0.10 per kWhr. As mentioned earlier, electricity prices are functions of many variables. Locations with a high average electricity price and/or green power credit programs (e.g. California) would have an advantage during site selection.

Figure 10 shows the sensitivity of internal rate of return and rational ethanol price with respect to variations in steep water return price. The performance measures are somewhat insensitive to variations in steep water return price.

Figure 11 shows the sensitivity of rational ethanol price with respect to variations in discount rate. If the discount rate were raised to a typical hurdle rate of 15% (nominal, after tax), the rational ethanol price would rise from $1.29 to $1.54 per gallon of ethanol (denatured) to reflect the higher value placed on capital.

Monte Carlo

Single parameter sensitivity analysis is useful for directing areas of future research, however, it often fails to convey the financial risks of the project. In the Monte Carlo method, a probability distribution is assigned to each key input variable, a random number sequence is then used to define values for these key input variables, and the output variables from the model are tabulated. The resulting distributions display the range of likely results when more than one input variable is changed at a time.

Figure 12 summarizes the assumed probability distributions for the key input variables, and displays the resulting distributions for after tax internal rate of return and net present value. According to the shaded areas of the NPV chart, there is a 56.62% chance that the project will have a negative net present value under the assumptions used in the Monte Carlo analysis. The IRR of the project is slightly below the discount rate (8.7% vs. 9.0%), so the prediction that there is a significant chance of a negative net present value for this project is not surprising. Monte Carlo analyses, such as this one, are often used to justify the risk premium required when setting corporate policies on acceptable hurdle rates.

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Table 1 - Design Summary

Material Balance

In

	lb/hr
BFW Chemicals	5
CO2	634
Combustor Air	548,631
CW Chemicals	5
Desulfurization Air	529
Dry Air	24,605,243
Fresh CaCO3	-129
Fresh Solvent	162
Fresh TBA	33
Fresh Water	1,128,875
Humidity	491,420
Inert Gas	24
Inhibitors	5
Light Steep Water	349,708
Lime	2,130
Make-Up Sand	2,995
MgO	197
Minerals	1,032
Natural Gasoline	3,209
Reductant	187
Regen Air	205,477
Starch Hydrolyzate	368,335
Stover	306,774
Turbine Air	1,333,583
Total	29,349,065

Out

	lb/hr
Adsorbed Sulfur	2
Ash	20,883
Bulk Sulfur	219
Combustor Offgas	631,339
Denatured EtOH	79,280
Desulfurization Offgas	434
Regen Offgas	331,755
Solids	628
Stack Gas	1,448,130
Steep Water Return	563,547
Tower Exhaust	25,592,829
Vents	107
Water Out	679,891
Total	29,349,045

Utilities

Net Power Export, kWe	62,524

Other

Operating Hours per Year	8330
Denatured EtOH, MMgal/yr	100.0
Stover, Metric Ton/d (dry)	2,839
Starch Hydrolyzate, wt% DS	30.0%
Stover, wt% Water	15.0%
Light Steep Water, wt% DS	6.0%
Steep Water Return, wt% DS	6.0%
Nat. Gasoline Density, lb/ft3	42.0

Table 2 - Capital Summary

(Factored Estimate)

Fixed Capital

		Basis	$MM
Directs	Feed Prep	Discrete Estimates	3.4
	Fermentation	Discrete Estimates	11.1
	Pre-Concentration	Discrete Estimates	5.5
	Acidification	Discrete Estimates	7.3
	Extraction	Discrete Estimates	6.3
	Esterification+Fractionation	Discrete Estimates	13.6
	Water Management	Discrete Estimates	8.9
	Hydrogenolysis	Discrete Estimates	15.4
	Denaturing	Discrete Estimates	1.6
	Feed Handling	Discrete Estimates	5.0
	Gasification	Discrete Estimates	22.5
	Conditioning	Discrete Estimates	8.8
	Compression	Discrete Estimates	10.7
	Bulk Desulfurization	Discrete Estimates	1.3
	H2 Recovery	Discrete Estimates	10.1
	Gas Turbine	Discrete Estimates	36.4
	Steam System	Discrete Estimates	10.3
	Cooling Water	Discrete Estimates	2.9
	Other Utilities	Allocation	5.0
	Other OSBL	Allocation	25.0
		Total Directs	211.2
Indirects	Home Office	5% of Directs	10.6
	Outside Engineering	8% of Directs	16.9
	Construction Expense	10% of Directs	21.1
	Contractor's Fee	5% of Directs	10.6
		Indirects	59.1
Contingency	Fixed Capital w/o Contingency		270.3
	Contingency	10% of Directs+Indirects	27.0
		Fixed Capital	297.3

Total Capital

	Fixed Capital		297.3
	Working Capital	45 Days of Revenue	19.7
	Start-up	5% of Fixed Capital	14.9
		Total Capital	331.9
		Fixed Capital, $/Annual Gal	2.97
		Lange Factor, Uncorrected for Skids	2.38

Table 3 - Detailed Fixed Capital

(Factored Estimate)

Area	Tag	Name	Description	Design T, F	Design P, psig	Materials of Construction	Purchased Equipment, $ (CE Index = 450)	Installation Factor, Directs	Direct Installed Cost, $
Feed Prep	A-1001	Mineral Solution Tank Agitator	Turbine, 5 Hp			CS	30,877	1.20	37,052
	A-1002	Reductant Tank Agitator	Turbine, 2.5 Hp			CS	21,260	1.20	25,512
	A-1005	CaCO3 Slurry Tank Agitator	Turbine, 300 Hp			CS	292,412	1.20	350,894
	E-1000	Heat Sterilizer Cross Exchanger	Shell & Tube, 32057 ft2 (NEU)	400	Shell: 100 Tube: 100	CS	397,441	2.60	1,033,347
	E-1001	Heat Sterilzer Trim Heater	Shell & Tube, 2869 ft2 (NEU)	400	Shell: 100 Tube: 100	CS	61,767	2.60	160,594
	E-1002	Sugars-Broth Cross Exchanger	Shell & Tube, 11464 ft2 (NEU)	400	Shell: 50 Tube: 50	CS	168,229	2.60	437,395
	E-1003	Sugars Trim Heater	Shell & Tube, 63 ft2 (NEU)	400	Shell: 100 Tube: 50	CS	7,634	2.60	19,848
	F-1000	Filter Sterilizer	Cartridge (Spared)	400	50	CS	88,976	2.75	244,684
	P-1000	Starch Hydrolyzate Pump	801 gpm @ 75' TDH, Centrifugal (Spared)			CS	14,526	2.65	38,494
	P-1001	Mineral Solution Pump	19 gpm @ 64' TDH, Centrifugal (Spared)			CS	5,028	2.65	13,324
	P-1002	Reductant Pump	3 gpm @ 64 ' TDH, Centrifugal (Spared)			CS	4,866	2.65	12,895
	P-1003	Fermentation Water Pump	1877 gpm @ 68' TDH, Centrifugal (Spared)			CS	23,204	2.65	61,491
	P-1004	Light Steep Water Pump	708 gpm @ 133' TDH, Centrifugal (Spared)			CS	15,394	2.65	40,794
	P-1005	CaCO3 Slurry Pump	238 gpm @ 92' TDH, Centrifugal (Spared)			CS	7,168	2.65	18,995
	T-1000	Starch Hydrolyzate Tank	Atmospheric Tank, 1 @ 200,000 gal			CS	119,663	1.65	197,444
	T-1001	Mineral Solution Tank	Atmospheric Tank, 1 @ 10,000 gal			CS	31,059	1.65	51,247
	T-1002	Reductant Tank	Atmospheric Tank, 1 @ 5,000 gal			CS	17,245	1.65	28,454
	T-1003	Fermentation Water Tank	Atmospheric Tank, 1 @ 450,000 gal			CS	213,800	1.65	352,770
	T-1004	Light Steep Water Tank	Atmospheric Tank, 1 @ 170,000 gal			CS	103,403	1.65	170,615
	T-1005	CaCO3 Slurry Tank	Atmospheric Tank, 1 @ 60,000 gal			CS	59,868	1.65	98,782
	X-1000	Sterilizer	Trombone Pipe, Included in piping costs			CS	0	2.75	0
						Subtotal	1,683,820	Subtotal	3,394,633
Fermentation	T-1100	Fermentor	Atmospheric Tank, 10 @ 1,000,000 gal			CS	6,070,860	1.65	10,016,919
	P-1100	Cell Mass Pump	82 gpm @ 212' TDH, Centrifugal (Spared)			CS	7,548	2.65	20,002
	X-1100	Clarifier	4064 gpm			CS	500,000	2.10	1,050,000
	X-1101	Homogenizer	Included in Above			CS	0	2.75	0
						Subtotal	6,578,408	Subtotal	11,086,921
Pre-Concentration	P-1201	Permeate Pump	1555 gpm @ 24' TDH, Centrifugal (Spared)			CS	18,944	2.65	50,202
	T-1200	Clarified Broth Tank	Atmospheric Tank, 1 @ 1,000,000 gal			CS	607,086	1.65	1,001,692
	T-1201	Permeate Tank	Atmospheric Tank, 1 @ 375,000 gal			CS	209,938	1.65	346,398
	X-1200	Reverse Osmosis Unit	22,799 m2			CS	1,644,207	2.50	4,110,518
						Subtotal	2,480,175	Subtotal	5,508,809
Acidification	C-1300	Rich Stripping Gas Blower	5376 Hp			CS	1,369,541	1.40	1,917,357
	C-1301	Lean Stripping Gas Blower	1940 Hp			CS	605,860	1.40	848,204
	E-1300	Broth Cooler	Shell & Tube, 6795 ft2 (BEM)	400	Shell: 50 Tube: 100	CS	101,100	2.60	262,860
	E-1301	Lean Stripping Gas Air Cooler	Forced Draft Air Fin, 9942 ft2 (Bare)	400	50	CS	214,514	2.60	557,736
	E-1302	Lean Stripping Gas Water Cooler	Shell & Tube, 6919 ft2 (BEM)	400	Shell: 50 Tube: 100	CS	103,892	2.60	270,119
	E-1303	Wash Water Heater	Shell & Tube, 527 ft2 (NEU)	400	Shell: 50 Tube: 100	CS	21,791	2.60	56,657
	P-1300	TBA Pump	928 gpm @ 60' TDH, Centrifugal (Spared)			CS	14,528	2.65	38,499
	T-1300	TBA Tank	Atmospheric Tank, 1 @ 225,000 gal			CS	119,663	1.65	197,444
	V-1300	Rich Stripping Gas KO Drum	21'0" ID x 15"6" TT, Vertical w/ Pad	400	50	CS	124,744	2.75	343,046
	V-1301	Lean Stripping Gas KO Drum	17'6" ID x 13'6" TT, Vertical w/ Pad	400	50	CS	95,523	2.75	262,688
	V-1302	Acidifier	22'0" ID x 38'0" TT, 10 Trays	400	50	CS	353,032	2.10	741,367
	V-1303	Lime Scrubber	24'0" ID x 48'0" TT, Packed	400	50	CS	531,600	2.10	1,116,360
	X-1300	Filter	Rotary Drum, 12'0" ID x 20'0" TT			CS	296,173	2.40	710,815
						Subtotal	3,951,961	Subtotal	7,323,153
Extraction	P-1400	Aqueous Feed Pump	3366 gpm @ 24' TDH, Centrifugal (Spared)			CS	23,876	2.65	63,271
	P-1401	Solvent Feed Pump	2604 gpm @ 29' TDH, Centrifugal (Spared)			CS	24,544	2.65	65,042
	T-1400	Aqueous Feed Tank	Atmospheric Tank, 1 @ 800,000 gal			CS	408,168	1.65	673,477
	T-1401	Solvent Feed Tank	Atmospheric Tank, 1 @ 625,000 gal			CS	304,362	1.65	502,197
	V-1400	Extractor	RDC, 9 Theoretical Stages	400	50	CS	2,380,952	2.10	5,000,000
						Subtotal	3,141,902	Subtotal	6,303,988
Esterification+Fractionation	E-1500	Extract-TBA Cross Exchanger	Shell & Tube, 4448 ft2 (NEU)	400	Shell: 50 Tube: 100	CS	84,552	2.60	219,835

	E-1501	Extract-Bottoms Cross Exchanger	Shell & Tube, 15870 ft2 (NEU)	400	Shell: 100 Tube: 100	CS	219,311	2.60	570,209
	E-1502	Bottoms Cooler	Shell & Tube, 1592 ft2 (BEM)	400	Shell: 100 Tube: 100	CS	34,364	2.60	89,346
	E-1503	Esterifier Reboiler	Shell & Tube, 47683 ft2 (NEU)	400	Shell: 100 Tube: 350	CS	585,666	2.60	1,522,732
	E-1504	TBA Splitter Reboiler	Shell & Tube, 56440 ft2 (NEU)	400	Shell: 100 Tube: FV/50	CS	660,112	2.60	1,716,291
	E-1505	TBA Splitter Condenser	Shell & Tube, 36772 ft2 (BEM)	400	Shell: FV/50 Tube: 100	CS	424,949	2.60	1,104,867
	E-1506	Esterifier Overhead Air Cooler	Forced Draft Air Fin, 23532 ft2 (Bare)	400	100	CS	500,752	2.20	1,101,654
	E-1507	Esterifier Overhead Water Cooler	Shell & Tube, 4752 ft2 (BEM)	400	Shell: 50 Tube: 100	CS	76,141	2.60	197,967
	E-1508	TBA Cooler	Shell & Tube, 1699 ft2 (BEM)	400	Shell: 50 Tube: 100	CS	35,320	2.60	91,832
	P-1500	Extract Feed Pump	3987 gpm @ 112' TDH, Centrifugal (Spared)			CS	39,930	2.65	105,815
	P-1501	Extract Water Pump	179 gpm @ 36' TDH, Centrifugal (Spared)			CS	6,066	2.65	16,075
	P-1502	Ester Pump	2094 gpm @ 69' TDH, Centrifugal (Spared)			CS	27,062	2.65	71,714
	P-1503	TBA Pump	1004 gpm @ 109' TDH, Centrifugal (Spared)			CS	21,802	2.65	57,775
	T-1500	Extract Tank	Atmospheric Tank, 1 @ 1,000,000			CS	607,086	1.65	1,001,692
	V-1500	Esterifier Column	4 @ 13'0" ID x 44'0" TT, 14 Bubble Cap Trays	400	50	CS	927,724	2.10	1,948,220
	V-1501	Esterifier Reactor	Included in V-1500	400	50	CS	0	2.75	0
	V-1502	Esterifier Overhead Drum	11'6" ID x 34'6" TT, Horizontal	400	50	CS	65,158	2.75	179,185
	V-1503	TBA Splitter	2 @ 29'6" ID x 56'0" TT, Packed	400	FV/50	CS	1,646,608	2.10	3,457,877
	V-1504	TBA Splitter Reflux Drum	11'6" ID x 34'6" TT, Horizontal	400	FV/50	CS	65,158	2.75	179,185
						Subtotal	6,027,761	Subtotal	13,632,271
Water Management	A-1600	Water Stripper Feed Tank Agitator	Turbine, 150 Hp			CS	144,560	1.20	173,472
	E-1600	Feed-Bottoms Cross Exchanger	Shell & Tube, 90372 ft2 (NEU)	400	Shell: 100 Tube: 100	CS	1,026,876	2.60	2,669,878
	E-1601	Feed Trim Heater	Shell & Tube, 2186 ft2 (NEU)	400	Shell: 100 Tube: 100	CS	52,534	2.60	136,588
	E-1602	Water Stripper Reboiler	Shell & Tube, 16439 ft2 (NEU)	400	Shell: 100 Tube: 100	CS	226,961	2.60	590,099
	E-1603	Water Stripper Overhead Air Cooler	Forced Draft Air Fin, 12838 ft2 (Bare)	400	100	CS	276,654	2.20	608,639
	E-1604	Water Stripper Overhead Water Cooler	Shell & Tube, 602 ft2 (BEM)	400	Shell: 50 Tube: 100	CS	19,272	2.60	50,107
	P-1600	Water Stripper Feed Pump	2492 gpm @ 82' TDH, Centrifugal (Spared)			CS	32,916	2.65	87,227
	P-1601	Stripped Water Pump	2406 gpm @ 70' TDH, Centrifugal (Spared)			CS	30,290	2.65	80,269
	P-1602	Permeate Pump	579 gpm @ 24' TDH, Centrifugal (Spared)			CS	10,534	2.65	27,915
	P-1603	Solvent Pump	34 gpm @ 29' TDH, Centrifugal (Spared)			CS	4,890	2.65	12,959
	T-1600	Water Stripper Feed Tank	Atmospheric Tank, 1 @ 600,000 gal			CS	317,474	1.65	523,832
	T-1601	Stripped Water Tank	Atmospheric Tank, 1 @ 600,000 gal			CS	317,474	1.65	523,832
	T-1602	Permeate Tank	Atmospheric Tank, 1 @ 140,000 gal			CS	97,827	1.65	161,415
	V-1600	Water Stripper	9'0" ID x 41'0" TT, 14 Trays	400	50	CS	130,700	2.10	274,470
	V-1601	Water Stripper Reflux Drum	5'0" ID x 15'0" TT, Horizontal	400	50	CS	14,158	2.75	38,935
	X-1600	Reverse Osmosis Unit	6202 m2			CS	1,165,311	2.50	2,913,278
						Subtotal	3,868,431	Subtotal	8,872,913
Hydrogenolysis	C-1700	Recycle Compressor	2275 Hp, Centrifugal			CS	688,387	1.50	1,032,581
	C-1701	Vacuum Pump	4 Hp, Liquid Ring			CS	22,693	1.10	24,962
	C-1702	Refrigeration Compressor	349 Hp, Centrifugal, Included in X-1700			CS	0	1.50	0
	E-1701	Feed-Crude Product Cross Exchanger	Shell & Tube, 81439 ft2 (NEU)	450	Shell: 250 Tube: 250	CS	983,014	2.60	2,555,836
	E-1702	Feed Trim Heater	Shell & Tube, 8415 ft2 (NEU)	450	Shell: 350 Tube: 250	CS	143,139	2.60	372,161
	E-1703	Ethanol Splitter Reboiler	Shell & Tube, 8456 ft2 (NEU)	450	Shell: 250 Tube: FV/50	CS	135,405	2.60	352,053
	E-1704	Product Cooler	Shell & Tube, 17644 ft2 (NEU)	400	Shell: 100 Tube: 250	CS	250,057	2.60	650,148
	E-1705	LP KO Drum Knockback Condenser	Shell & Tube, 8 ft2 (NEU)	400	Shell: 50 Tube: 50	CS	7,068	2.60	18,377
	E-1706	Crude Product-Bottoms Cross Exchanger	Shell & Tube, 31346 ft2 (NEU)	400	Shell: 50 Tube: FV/50	CS	387,035	2.60	1,006,291
	E-1707	Ethanol Splitter Condenser	Shell & Tube, 52524 ft2 (BEM)	400	Shell: FV/50 Tube: 100	CS	586,799	2.60	1,525,677
	E-1708	Ethanol Splitter Knockback Condenser	Shell & Tube, 96 ft2 (NEU)	400	Shell: 50 Tube: FV/50	CS	7,953	2.60	20,678
	E-1709	Bottoms Cooler	Shell & Tube, 4225 ft2 (BEM)	400	Shell: 50 Tube: 100	CS	69,816	2.60	181,522
	E-1710	Refrigerant Cooler	Shell & Tube, 1109 ft2 (BEM), Included in X-1700	400	Shell: 300 Tube: 100	CS	0	2.60	0
	P-1700	Ester Feed Pump	2094 gpm @ 570' TDH, Centrifugal (Spared)			CS	44,260	2.65	117,289
	P-1701	Neat EtOH Pump	196 gpm @ 64' TDH, Centrifugal (Spared)			CS	6,284	2.65	16,653
	P-1702	Bottoms Pump	2046 gpm @ 94' TDH, Centrifugal (Spared)			CS	32,916	2.65	87,227
	T-1700	Ester Feed Tank	Atmospheric Tank, 1 @ 500,000 gal			CS	240,516	1.65	396,851
	V-1700	Hydrogenolysis Reactor	2 @ 13'0" ID x 39'0" TT, Vertical	450	250	CS	450,696	2.75	1,239,414
	V-1700	Initial Catalyst Charge for V-1700	9765 ft3 Reduced CuO/ZnO			CS	2,831,850	1.10	3,115,035
	V-1701	HP KO Drum	11'0" ID X 33'0" TT, Vertical w/ Pad	400	250	CS	146,959	2.75	404,137
	V-1702	LP KO Drum	11'0" ID X 33'0" TT, Vertical w/ Pad	400	50	CS	62,359	2.75	171,487
	V-1703	Ethanol Splitter	18'0" ID x 42'0" TT, Packed	400	FV/50	CS	322,107	2.10	676,425
	V-1704	Ethanol Splitter Reflux Drum	8'0" ID x 24'0" TT, Horizontal	400	FV/50	CS	38,995	2.75	107,236
	V-1705	Refrigerant Receiver	Included in X-1700	400	300	CS	0	2.75	0
	V-1706	Refrigerant KO Drum	Included in X-1700	400	50	CS	0	2.75	0
	X-1700	Refrigeration Skid	94 tons @ -31 F, Propane Refrigerant			CS	915,834	1.50	1,373,751
						Subtotal	8,374,142	Subtotal	15,445,792

Denaturing	F-1800	Product Filter	Cartridge (Spared)	400	50	CS	18,940	2.75	52,085
	P-1800	Neat EtOH Pump	196 gpm @ 30' TDH, Centrifugal (Spared)			CS	6,066	2.65	16,075
	P-1801	Natural Gasoline Pump	10 gpm @ 34' TDH, Centrifugal (Spared)			CS	4,866	2.65	12,895
	P-1802	Inhibitors Pump	100 gphr @ 29' TDH, Metering (Spared)			CS	6,712	2.65	17,787
	P-1803	Denatured EtOH Pump	206 gpm @ 45' TDH, Centrifugal (Spared)			CS	6,624	2.65	17,554
	T-1800	Neat EtOH Tank	Atmospheric Tank, 1 @ 300,000 gal			CS	138,478	1.65	228,489
	T-1801	Natural Gasoline Tank	Atmospheric Tank, 1 @ 30,000 gal			CS	45,034	1.65	74,306
	T-1802	Inhibitors Tank	Atmospheric Tank, 1 @ 500 gal			CS	6,947	1.65	11,463
	T-1803	Denatured EtOH Tank	Atmospheric Tank, 5 @ 300,000 gal			CS	692,390	1.65	1,142,444
						Subtotal	926,057	Subtotal	1,573,096
Feed Handling	X-2000	Area Allocation	Area Allocation			CS	2,956,672	1.69	5,000,000
						Subtotal	2,956,672	Subtotal	5,000,000
Gasification	C-2100	Combustor Air Blower	Included in X-2109				0		0
	E-2101	Combustor Offgas Heat Recovery	Included in X-2109				0		0
	V-2100	Gasifier	Included in X-2109				0		0
	V-2101	Combustor	Included in X-2109				0		0
	X-2100	Feeder	Included in X-2109				0		0
	X-2101	Gasifier Primary Cyclone	Included in X-2109				0		0
	X-2102	Gasifier Secondary Cyclone	Included in X-2109				0		0
	X-2103	Combustor Primary Cyclone	Included in X-2109				0		0
	X-2104	Combustor Secondary Cyclone	Included in X-2109				0		0
	X-2105	Electrostatic Precipitator	Included in X-2109				0		0
	X-2106	Ash Cooler	Included in X-2109				0		0
	X-2107	Ash Blender	Included in X-2109				0		0
	X-2108	Combustor Offgas Expander	Included in X-2109				0		0
	X-2109	Area Allocation	Area Allocation				13,318,408	1.69	22,522,633
						Subtotal	13,318,408	Subtotal	22,522,633
Conditioning	C-2200	Regenerator Air Blower	Included in X-2203				0		0
	E-2200	Conditioned Gas Heat Recovery	Included in X-2203				0		0
	E-2201	Conditioned Gas Water Cooler	Included in X-2203				0		0
	E-2202	Conditioning Water Cooler	Included in X-2203				0		0
	E-2203	Included in V-2202	Included in X-2203				0		0
	E-2204	Regen Offgas Heat Recovery	Included in X-2203				0		0
	P-2200	Conditioning Water Pump	Included in X-2203				0		0
	P-2201	Solids Pump	Included in X-2203				0		0
	V-2200	Tar Reformer	Included in X-2203				0		0
	V-2200	Initial Catalyst Charge for V-2200	Included in X-2203				0		0
	V-2201	KO Drum	Included in X-2203				0		0
	V-2202	Regenerator	Included in X-2203				0		0
	X-2200	Clarifier	Included in X-2203				0		0
	X-2201	Electrostatic Precipitator	Included in X-2203				0		0
	X-2202	Regen Offgas Expander	Included in X-2203				0		0
	X-2203	Area Allocation	Area Allocation				5,207,300	1.69	8,806,016
						Subtotal	5,207,300	Subtotal	8,806,016
Compression	V-2300	Syngas Compressor Suction Drum	16'0" ID x 13'0" TT, Vertical w/ Pad	400	50	CS	85,028	2.75	233,827
	C-2300	Syngas Compressor	26,993 Hp (Brake), Centrifgual			CS	4,979,416	1.50	7,469,124
	E-2300	Syngas Compressor Air Cooler	Forced Draft Air Fin, 41515 ft2 (Bare)	400	350	CS	885,074	2.20	1,947,163
	E-2301	Syngas Compressor Water Cooler	Shell & Tube, 1826 ft2 (BEM)	400	Shell: 350 Tube: 100	CS	36,667	2.60	95,334
	P-2300	Compression KO Water Pump	100 gpm @ 16' TDH, Centrifugal (Spared)			CS	5,362	2.65	14,209
	V-2301a	Syngas Compressor Interstage Drum	13'6" ID x 11'6" TT, Vertical w/ Pad	400	50	CS	64,359	2.75	176,987
	V-2301b	Syngas Compressor Interstage Drum	11'6" ID x 10'6" TT, Vertical w/ Pad	400	100	CS	69,224	2.75	190,366
	V-2301c	Syngas Compressor Interstage Drum	10'0" ID x 10'0" TT, Vertical w/ Pad	400	150	CS	67,185	2.75	184,759
	V-2301d	Syngas Compressor Interstage Drum	9'0" ID x 9'6" TT, Vertical w/ Pad	400	200	CS	60,683	2.75	166,878
	V-2302	HP Gas KO Drum	8'0" ID x 9'6" TT, Vertical w/ Pad	400	350	CS	71,500	2.75	196,625
						Subtotal	6,324,498	Subtotal	10,675,273
Bulk Desulfurization	E-2400	Bulk Desulfuration Preheater	Shell & Tube, 50 ft2 (NEU)	400	Shell: 100 Tube: 350	CS	8,143	2.60	21,172
	X-2400	Bulk Desulfurization Unit	LO-CAT II				1,000,000	1.30	1,300,000
						Subtotal	1,008,143	Subtotal	1,321,172

H2 Recovery	E-2500	Preheater	Shell & Tube, 1821 ft2 (NEU)	900	Shell: 300 Tube: 350	CS	47,781	2.60	124,231
	E-2501	Heat Recovery	Shell & Tube, 1460 ft2 (NEU)	550	Shell: 300 Tube: 1450	CS	42,880	2.60	111,488
	E-2502	Heat Recovery	Shell & Tube, 3000 ft2 (NEU)	550	Shell: 300 Tube: 1450	CS	73,218	2.60	190,367
	E-2503	Air Cooler	Forced Draft Air Fin, 6565 ft2 (Bare)	400	300	CS	141,959	2.20	312,310
	E-2504	Water Cooler	Shell & Tube, 1192 ft2 (BEM)	400	Shell: 300 Tube: 100	CS	28,947	2.60	75,262
	V-2500	ZnO Bed	2 @ 5'0" ID x 15'0" TT, Vertical	750	350	CS	87,976	2.75	241,934
	V-2500	Initial Charge for V-2500	450 ft3 ZnO			CS	121,500	1.10	133,650
	V-2501	HT Shift Reactor	8'6" ID x 25'6" TT, Vertical	900	350	CS	181,125	2.75	498,094
	V-2501	Initial Charge for V-2501	1447.5 ft3 Cr Promoted Fe Oxide			CS	419,775	1.10	461,753
	V-2502	LT Shift Reactor	7'6" ID x 22'6" TT, Vertical	550	300	CS	82,097	2.75	225,767
	V-2502	Initial Charge for V-2502	965 ft3 Reduced Cu			CS	279,850	1.10	307,835
	V-2503	KO Drum	6'6" ID x 9'0" TT, Vertical w/ Pad	400	300	CS	47,964	2.75	131,901
	V-2504	KO Drum	5'6" ID x 9'6" TT, Vertical w/ Pad	400	300	CS	44,378	2.75	122,040
	X-2500	PSA Unit	57 MMSCFD Feed @ 63% H2, Polybed w/ 85% Yield			CS	5,140,572	1.40	7,196,801
						Subtotal	6,740,022	Subtotal	10,133,431
Gas Turbine	E-3000	Heat Recovery	HRSG, 366.5 MMBtu/hr			CS	5,758,467	1.70	9,789,394
	X-3001	Gas Turbine	68163 kWe, Includes Generator and Auxiliaries			CS	20,448,900	1.30	26,583,570
						Subtotal	26,207,367	Subtotal	36,372,964
Steam System	E-3100	Degasifier Preheater	Included in Heat Recovery			CS	0		0
	E-3101	Degasifier Preheater	Included in Heat Recovery			CS	0		0
	E-3102	BFW Preheater	Included in Heat Recovery			CS	0		0
	E-3103	Steam Generation	Included in Heat Recovery			CS	0		0
	E-3104	Superheater	Included in Heat Recovery			CS	0		0
	E-3105	Blowdown Cross Exchanger	Included in Heat Recovery			CS	0		0
	E-3106	Blowdown Cooler	Shell & Tube, 290 ft2 (BEM)	400	Shell: 1450 Tube: 100	CS	11,142	2.60	28,969
	E-3107	Desuperheater	Included in piping factors			CS	0		0
	E-3108	Desuperheater	Included in piping factors			CS	0		0
	P-3100	Make-Up Pump	329 gpm @ 162' TDH, Centrifugal (Spared)			CS	10,164	2.65	26,935
	P-3101	Condensate Pump	258 gpm @ 75' TDH, Centrifugal (Spared)			CS	7,914	2.65	20,972
	P-3102	BFW Pump	1636 gpm @ 3193' TDH, Multistage Centrifugal (Spared)			CS	276,982	2.65	734,002
	P-3103	BFW Chemicals Pump	100 gphr @ 139' TDH, Metering (Spared)			CS	6,712	2.65	17,787
	V-3100	LP Steam Drum	8'6" ID x 25'6" TT, Vertical w/ Pad	400	100	CS	61,679	2.75	169,617
	V-3102	Degasifier	17'0" ID x 51'0" TT, 5 Trays, Vertical			CS	184,304	1.65	304,102
	V-3103	HP Steam Drum	10'6" ID x 31'6" TT, Horizontal	600	1450	CS	687,707	2.75	1,891,194
	X-3100	Steam Turbine	39.2 MWe, Non-condensing			CS	4,660,667	1.50	6,991,001
	X-3101	Ion Exchange Unit	330 gpm			CS	84,375	1.60	135,000
						Subtotal	5,991,646	Subtotal	10,319,579
Cooling Water	P-4000	CW Circulation Pump	49045 gpm @ 138' TDH, Centrifugal (Spared)			CS	43,986	2.65	116,563
	X-4000	CW Tower	507MMBtu/hr			CS	2,300,810	1.20	2,760,972
						Subtotal	2,344,796	Subtotal	2,877,535
Other Utilities	X-5000	Other Utilities	Allocation				2,956,672	1.69	5,000,000
						Subtotal	2,956,672	Subtotal	5,000,000
Other OSBL	X-6000	Additional Tank Farm	Allocation				5,913,344	1.69	10,000,000
	X-7000	Pipe Racks	Allocation				5,913,344	1.69	10,000,000
	X-8000	Buildings	Allocation				2,956,672	1.69	5,000,000
						Subtotal	14,783,360	Subtotal	25,000,000
							124,871,541	**Total**	211,170,177

Table 4 - Operating Costs

(Plant Level)

	$/Unit	Unit/hr	$/hr	$/yr	$/gal Denatured EtOH
Variable					
Raw Materials					
Starch Hydrolyzate, lb(dry)	0.05	110500.4338	5,525.02	46,023,431	0.4602
Stover, metric ton(dry)	30	118.2779344	3,548.34	29,557,656	0.2956
Light Steep Water, US Ton(dry)	130	10.49124576	1,363.86	11,360,970	0.1136
Natural Gasoline, gal	1.00	571.6109716	571.61	4,761,519	0.0476
Inert Gas, US ton	100	0.012220409	1.22	10,180	0.0001
CO2, US ton	100	0.316876863	31.69	263,958	0.0026
Fresh Solvent, lb	0.70	162	113.16	942,651	0.0094
Fresh TBA, lb	1.43	33	46.52	387,524	0.0039
Lime, US ton	100	1.064990336	106.50	887,137	0.0089
Minerals, US Ton	100	0.516122925	51.61	429,930	0.0043
Reductant, lb	0.305	187	57.09	475,590	0.0048
Fresh Water, 1000 gal	1.00	135.3297046	135.33	1,127,296	0.0113
Make-Up Sand, US ton	175	1.4972947	262.03	2,182,681	0.0218
MgO, US Ton	365	0.098400408	35.92	299,182	0.0030
Inhibitors, lb	1.00	5	5.44	45,348	0.0005
CW Chemicals, lb	1.00	5	4.92	40,992	0.0004
BFW Chemicals, lb	1.40	5	7.38	61,450	0.0006
		Subtotal	11,867.65	98,857,496	0.9886
Catalysts					
Hydrogenolysis			74.79	623,007	0.0062
Tar Reforming			3.00	25,000	0.0003
Chelated Iron Solution, metric ton S	150	0.099182073	14.88	123,928	0.0012
ZnO			16.04	133,650	0.0013
HT Shift			11.09	92,351	0.0009
LT Shift			7.39	61,567	0.0006
		Subtotal	127.19	1,059,502	0.0106
Disposal					
Ash, US ton	20.00	10.44163195	208.83	1,739,576	0.0174
Adsorbed Sulfur, US ton	Included in ZnO Purchased Cost		0.00	0	0.0000
Bulk Sulfur	Stockpiled		0.00	0	0.0000
Solids, US ton	20.00	0.314029735	6.28	52,317	0.0005
Water Out, 1000 gal	1.50	81.5054685	122.26	1,018,411	0.0102
Steep Water Return	0	-	0.00	0	0.0000
Fresh CaCO3	0	-	0.00	0	0.0000
		Subtotal	337.37	2,810,304	0.0281
Operating Labor w/ Overheads	30	10	300.00	2,499,000	0.0250
Other @ 0.5% of Fixed Capital per year			178.47	1,486,638	0.0149
		Subtotal	478.47	3,985,638	0.0399
		Variable Costs	12,810.68	106,712,940	1.0671

Fixed	Factor	Basis	$/hr	$/yr	$/gal Denatured EtOH
Supervision w/ Overheads	80000	1 per 5 operators/hr	19.21	160,000	0.0016
Maintenance Labor w/ Overheads	0.0125	Fixed Capital	446.17	3,716,595	0.0372
Maintenance Supplies	0.025	Fixed Capital	892.34	7,433,190	0.0743
Plant Overhead	0.6	Labor w/ Overheads	459.23	3,825,357	0.0383
Property Taxes, Insurance, etc.	0.02	Fixed Capital	713.87	5,946,552	0.0595
Depreciation	0.1	Fixed Capital	3,569.36	29,732,761	0.2973
		Fixed Costs	6,100.17	50,814,455	0.5082
		Cash Costs	15,341.49	127,794,635	1.2780
		Operating Costs	18,910.85	157,527,396	1.5753

Table 5 - Revenue Summary

(Real, 100% Capacity)

Product	Price, $/Unit	Volume, Unit/yr		Revenue, $MM/yr	Revenue, $/gal Denatured EtOH	Portion of Total Revenue
Denatured EtOH, gal	1.24	99,998,734		124.0	1.2400	74.0%
Electricity Export, kWe	0.05	520,822,216		26.0	0.2604	15.5%
Steep Water Return, US Ton (dry)	125	140,830		17.6	0.1760	10.5%
			Total	167.6	1.6765	100.0%

Table 6- Cash Flows

Dollar Amounts in Millions

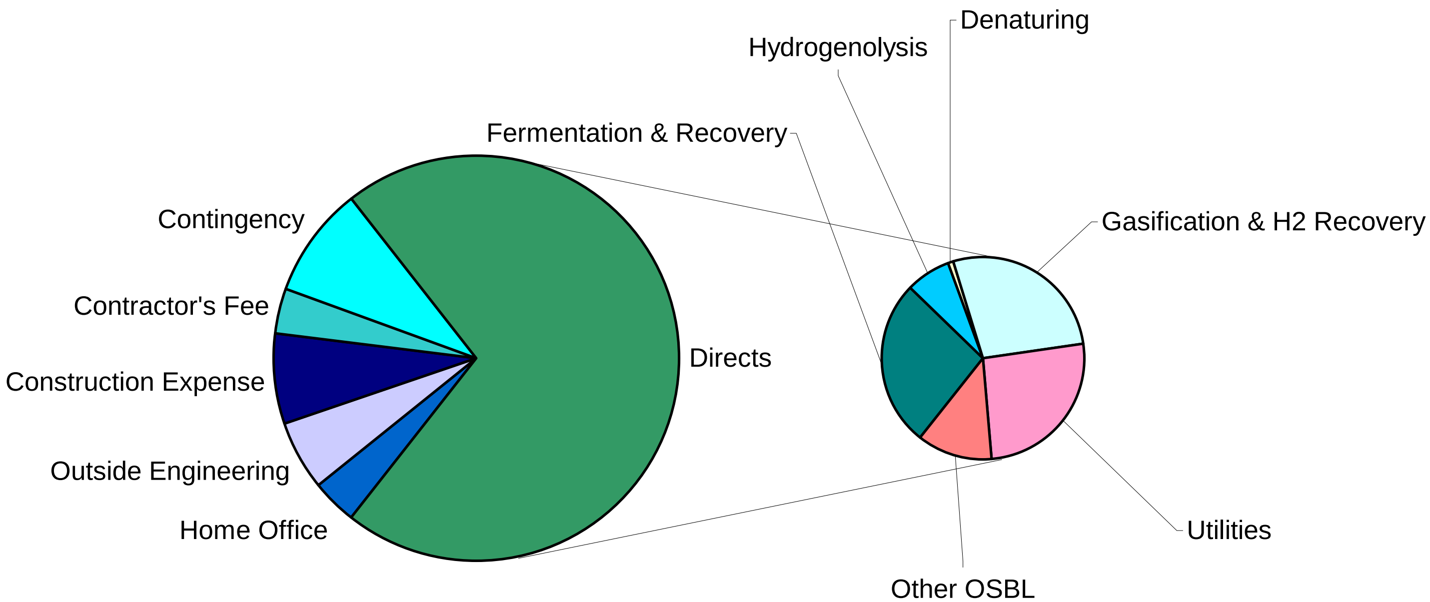
Year		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	Inflation Factor (2%/yr)	1.000	1.020	1.040	1.061	1.082	1.104	1.126	1.149	1.172	1.195	1.219	1.243	1.268	1.294	1.319	1.346	1.373	1.400	1.428	1.457	1.486	1.516	1.546	1.577	1.608	1.641	1.673
	Operating Rate, % of Nameplate	0	0	64	85	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Revenues																												
	Denatured EtOH, MMGal	0	0	64.0	85.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Denatured EtOH Real Price, $/gal	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24	1.24
	Denatured EtOH Nominal Price, $/gal	1.24	1.26	1.29	1.32	1.34	1.37	1.40	1.42	1.45	1.48	1.51	1.54	1.57	1.60	1.64	1.67	1.70	1.74	1.77	1.81	1.84	1.88	1.92	1.96	1.99	2.03	2.08
	Denatured EtOH Revenues	0	0	82.57	111.85	134.22	136.90	139.64	142.44	145.28	148.19	151.15	154.18	157.26	160.41	163.61	166.89	170.22	173.63	177.10	180.64	184.26	187.94	191.70	195.53	199.44	203.43	207.50
	Electricity Export, kWe	0.0E+00	0.0E+00	3.3E+08	4.4E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08	5.2E+08
	Electricity Export Real Price, $/kWe	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500
	Electricity Export Nominal Price, $/kWe	0.0500	0.0510	0.0520	0.0531	0.0541	0.0552	0.0563	0.0574	0.0586	0.0598	0.0609	0.0622	0.0634	0.0647	0.0660	0.0673	0.0686	0.0700	0.0714	0.0728	0.0743	0.0758	0.0773	0.0788	0.0804	0.0820	0.0837
	Electricity Export Revenues	0	0	17.34	23.49	28.19	28.75	29.33	29.91	30.51	31.12	31.74	32.38	33.03	33.69	34.36	35.05	35.75	36.46	37.19	37.94	38.70	39.47	40.26	41.06	41.89	42.72	43.58
	Steep Water Return, US Ton (dry)	0	0	90,131	119,706	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830	140,830
	Steep Water Return Real Price, $/US Ton (dry)	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00	125.00
	Steep Water Return Nomial Price, $/US Ton (dry)	125.00	127.50	130.05	132.65	135.30	138.01	140.77	143.59	146.46	149.39	152.37	155.42	158.53	161.70	164.93	168.23	171.60	175.03	178.53	182.10	185.74	189.46	193.25	197.11	201.05	205.08	209.18
	Steep Water Return Revenues	0	0	11.72	15.88	19.05	19.44	19.82	20.22	20.63	21.04	21.46	21.89	22.33	22.77	23.23	23.69	24.17	24.65	25.14	25.65	26.16	26.68	27.22	27.76	28.31	28.88	29.46
	Nominal Revenues	0	0	111.63	151.22	181.46	185.09	188.79	192.57	196.42	200.35	204.36	208.44	212.61	216.86	221.20	225.63	230.14	234.74	239.44	244.22	249.11	254.09	259.17	264.36	269.64	275.04	280.54
Capital Expenditures																												
	Fixed Capital	-148.66	-151.64																									
	Changes to Working Capital	0	0	-13.75	-4.88	-3.73	-0.45	-0.46	-0.47	-0.47	-0.48	-0.49	-0.50	-0.51	-0.52	-0.53	-0.55	-0.56	-0.57	-0.58	-0.59	-0.60	-0.61	-0.63	-0.64	-0.65	-0.66	-0.68
	Start-up Costs			-15.47																								
	Terminal Value																											34.56
Operating Costs																												
	Starch Hydrolyzate	0	0	-30.64	-41.51	-49.82	-50.81	-51.83	-52.87	-53.92	-55.00	-56.10	-57.22	-58.37	-59.54	-60.73	-61.94	-63.18	-64.44	-65.73	-67.05	-68.39	-69.76	-71.15	-72.57	-74.03	-75.51	-77.02
	Stover	0	0	-19.68	-26.66	-31.99	-32.63	-33.29	-33.95	-34.63	-35.32	-36.03	-36.75	-37.49	-38.24	-39.00	-39.78	-40.58	-41.39	-42.22	-43.06	-43.92	-44.80	-45.70	-46.61	-47.54	-48.49	-49.46
	Light Steep Water	0	0	-7.56	-10.25	-12.30	-12.54	-12.79	-13.05	-13.31	-13.58	-13.85	-14.13	-14.41	-14.70	-14.99	-15.29	-15.60	-15.91	-16.23	-16.55	-16.88	-17.22	-17.56	-17.92	-18.27	-18.64	-19.01
	Other Variable	0	0	-13.16	-17.83	-21.40	-21.83	-22.27	-22.71	-23.16	-23.63	-24.10	-24.58	-25.07	-25.58	-26.09	-26.61	-27.14	-27.68	-28.24	-28.80	-29.38	-29.97	-30.57	-31.18	-31.80	-32.44	-33.08
	Fixed Costs Less Depreciation	0	0	-21.93	-22.37	-22.82	-23.28	-23.74	-24.22	-24.70	-25.19	-25.70	-26.21	-26.74	-27.27	-27.82	-28.37	-28.94	-29.52	-30.11	-30.71	-31.33	-31.95	-32.59	-33.24	-33.91	-34.59	-35.28
	Depreciation w/ 10 yr MACRS	0	0	-29.73	-53.52	-42.82	-34.25	-27.41	-21.91	-19.47	-19.47	-19.50	-19.47	-9.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Corporate Overheads	0	0	-2.23	-3.02	-3.63	-3.70	-3.78	-3.85	-3.93	-4.01	-4.09	-4.17	-4.25	-4.34	-4.42	-4.51	-4.60	-4.69	-4.79	-4.88	-4.98	-5.08	-5.18	-5.29	-5.39	-5.50	-5.61
	Income Taxes	0	0	10.65	8.86	1.23	-2.24	-5.06	-7.40	-8.62	-8.93	-9.24	-9.58	-13.52	-17.47	-17.82	-18.17	-18.54	-18.91	-19.29	-19.67	-20.07	-20.47	-20.88	-21.29	-21.72	-22.15	-22.60
	Cost of Manufacture at Corporate Level	0	0	-114.30	-166.31	-183.55	-181.29	-180.17	-179.96	-181.75	-185.14	-188.62	-192.12	-189.60	-187.12	-190.86	-194.68	-198.57	-202.55	-206.60	-210.73	-214.94	-219.24	-223.63	-228.10	-232.66	-237.32	-242.06
Profitability																												
Before Tax:	Nominal Net Cash From Operations	0	0	16.40	29.56	39.50	40.29	41.10	41.92	42.76	43.62	44.49	45.38	46.29	47.21	48.16	49.12	50.10	51.10	52.13	53.17	54.23	55.32	56.42	57.55	58.70	59.88	61.07
	Nominal Cash Flows	-148.66	-151.64	-12.81	24.69	35.78	39.85	40.64	41.46	42.29	43.13	43.99	44.87	45.77	46.69	47.62	48.57	49.54	50.54	51.55	52.58	53.63	54.70	55.80	56.91	58.05	59.21	94.96
	Cumulative Nominal Cash	-148.66	-300.30	-313.12	-288.43	-252.65	-212.80	-172.16	-130.70	-88.42	-45.28	-1.29	43.58	89.36	136.04	183.66	232.24	281.78	332.32	383.87	436.44	490.07	544.77	600.57	657.48	715.53	774.74	869.70
	NPV @ 9% Nominal	54.27																										
	PI @ 9% Nominal	0.21																										
	IRR	10.8%																										
After Tax:	Nominal Net Cash From Operations	0	0	27.06	38.43	40.73	38.06	36.04	34.52	34.14	34.68	35.24	35.79	32.77	29.74	30.34	30.94	31.56	32.19	32.84	33.50	34.17	34.85	35.55	36.26	36.98	37.72	38.48
	Nominal Cash Flows	-148.66	-151.64	-2.16	33.55	37.00	37.61	35.58	34.05	33.67	34.20	34.75	35.29	32.25	29.22	29.80	30.40	31.01	31.63	32.26	32.91	33.56	34.23	34.92	35.62	36.33	37.06	72.36
	Cumulative Nominal Cash	-148.66	-300.30	-302.46	-268.91	-231.91	-194.30	-158.72	-124.66	-90.99	-56.79	-22.04	13.25	45.50	74.72	104.53	134.92	165.93	197.56	229.82	262.73	296.29	330.52	365.44	401.06	437.39	474.45	546.81
	NPV @ 9% Nominal	-6.64																										
	PI @ 9% Nominal	-0.03																										
	IRR	8.7%																										

Sensitivity Analysis

Update Sensitivities

Fixed Capital, $MM	297.33	150.00	200.00	275.00	350.00	450.00	600.00
Before Tax IRR	10.8%	23.7%	17.8%	12.1%	8.1%	3.9%	-1.5%
After Tax IRR	8.7%	18.6%	14.2%	9.8%	6.6%	3.2%	-1.3%
Rational Denatured EtOH Real Price, $/gal	1.29	0.99	1.10	1.25	1.40	1.61	1.91
Starch Hydrolyzate Real Price, $/lb (dry)	0.050	0.010	0.030	0.050	0.075	0.100	0.150
Before Tax IRR	10.8%	20.7%	16.1%	10.8%	2.0%		
After Tax IRR	8.7%	16.5%	12.9%	8.7%	1.6%		
Rational Denatured EtOH Real Price, $/gal	1.29	0.91	1.10	1.29	1.53	1.77	2.25
Stover Real Price, $/metric Ton (dry)	30	10	20	30	40	50	60
Before Tax IRR	10.8%	16.4%	13.7%	10.8%	7.5%	3.6%	
After Tax IRR	8.7%	13.1%	11.0%	8.7%	6.1%	2.9%	-1.6%
Rational Denatured EtOH Real Price, $/gal	1.29	1.09	1.19	1.29	1.40	1.50	1.60
Denatured Ethanol Real Price, $/gal	1.24	0.95	1.00	1.25	1.50	1.75	2.00
Before Tax IRR	10.8%	-1.2%	1.7%	11.1%	17.8%	23.5%	28.8%
After Tax IRR	8.7%	-1.0%	1.4%	9.0%	14.2%	18.5%	22.4%
Rational Denatured EtOH Real Price, $/gal	1.29	1.29	1.29	1.29	1.29	1.29	1.29
Electricity Real Price, $/kWe	0.05	0.02	0.03	0.04	0.06	0.07	0.10
Before Tax IRR	10.8%	5.5%	7.4%	9.2%	12.3%	13.8%	17.8%
After Tax IRR	8.7%	4.4%	6.0%	7.4%	9.9%	11.1%	14.2%
Rational Denatured EtOH Real Price, $/gal	1.29	1.45	1.40	1.35	1.24	1.19	1.03
Steep Water Return, $/US Ton (dry)	125	0	50	100	130	150	200
Before Tax IRR	10.8%	4.7%	7.4%	9.7%	11.0%	11.8%	13.8%
After Tax IRR	8.7%	3.8%	6.0%	7.9%	8.9%	9.6%	11.1%
Rational Denatured EtOH Real Price, $/gal	1.29	1.47	1.40	1.33	1.29	1.26	1.19
Discount Rate	10%	5%	10%	15%	20%	25%	30%
Rational Denatured EtOH Real Price, $/gal	1.29	1.10	1.29	1.54	1.84	2.18	2.55

Figure 1 – Fixed Capital Breakdown
(Directs Re-grouped by Major Process Area)



		$MM	Directs, %	Fixed Capital, %
Directs	Fermentation & Recovery	56.1	26.6%	18.9%
	Hydrogenolysis	15.4	7.3%	5.2%
	Denaturing	1.6	0.7%	0.5%
	Gasification & H2 Recovery	58.5	27.7%	19.7%
	Utilities	54.6	25.8%	18.4%
	Other OSBL	25.0	11.8%	8.4%
	Directs	211.2	100.0%	71.0%
Indirects	Home Office	10.6		3.6%
	Outside Engineering	16.9		5.7%
	Construction Expense	21.1		7.1%
	Contractor's Fee	10.6		3.6%
	Indirects	59.1		19.9%
	Contingency	27.0		9.1%
	Fixed Capital	297.3		100.0%

Figure 2 - Historic Contribution of Net Corn to Transfer Price of Starch Hydrolyzate

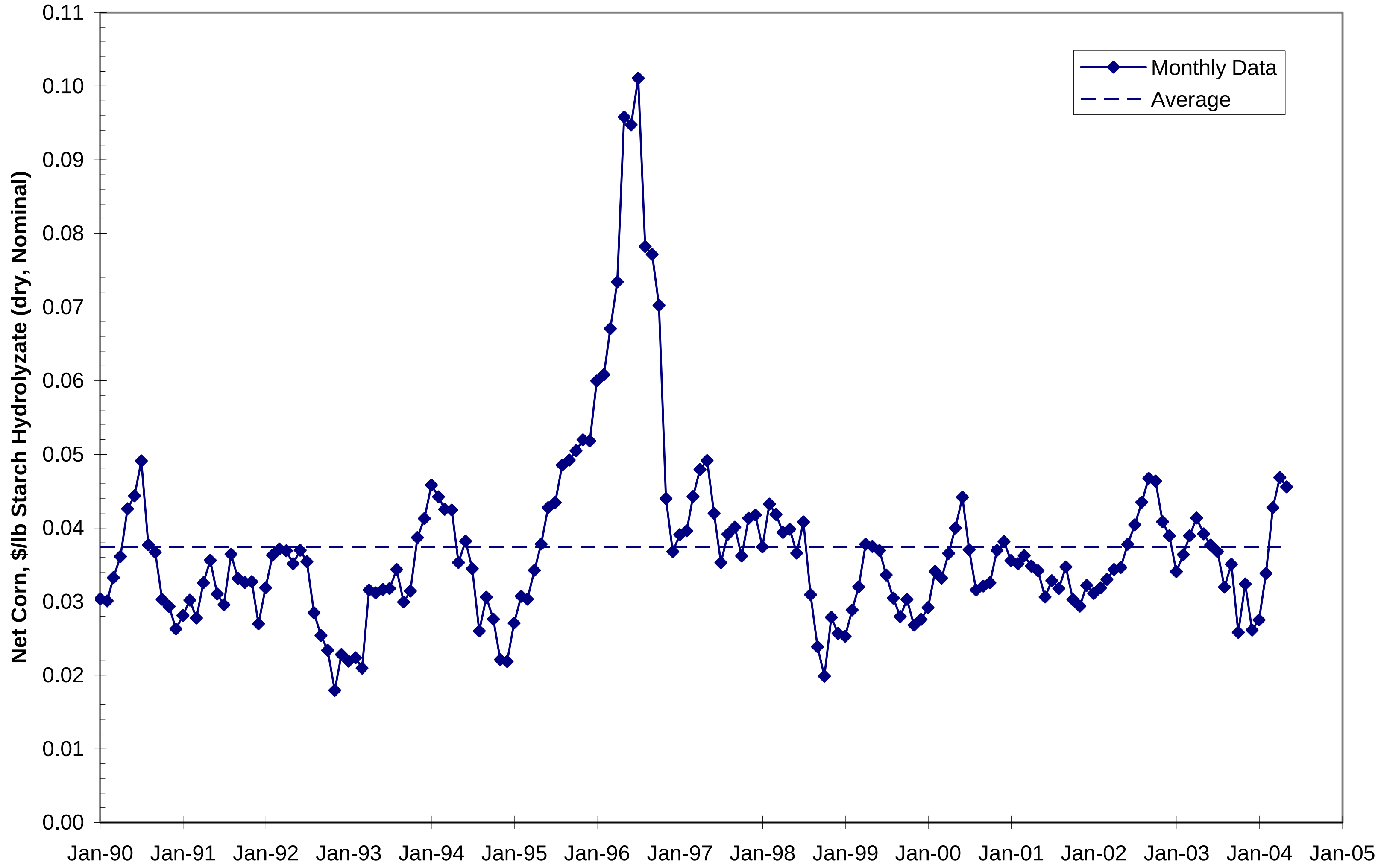


Figure 3 - Historical Prices for Fuel Ethanol

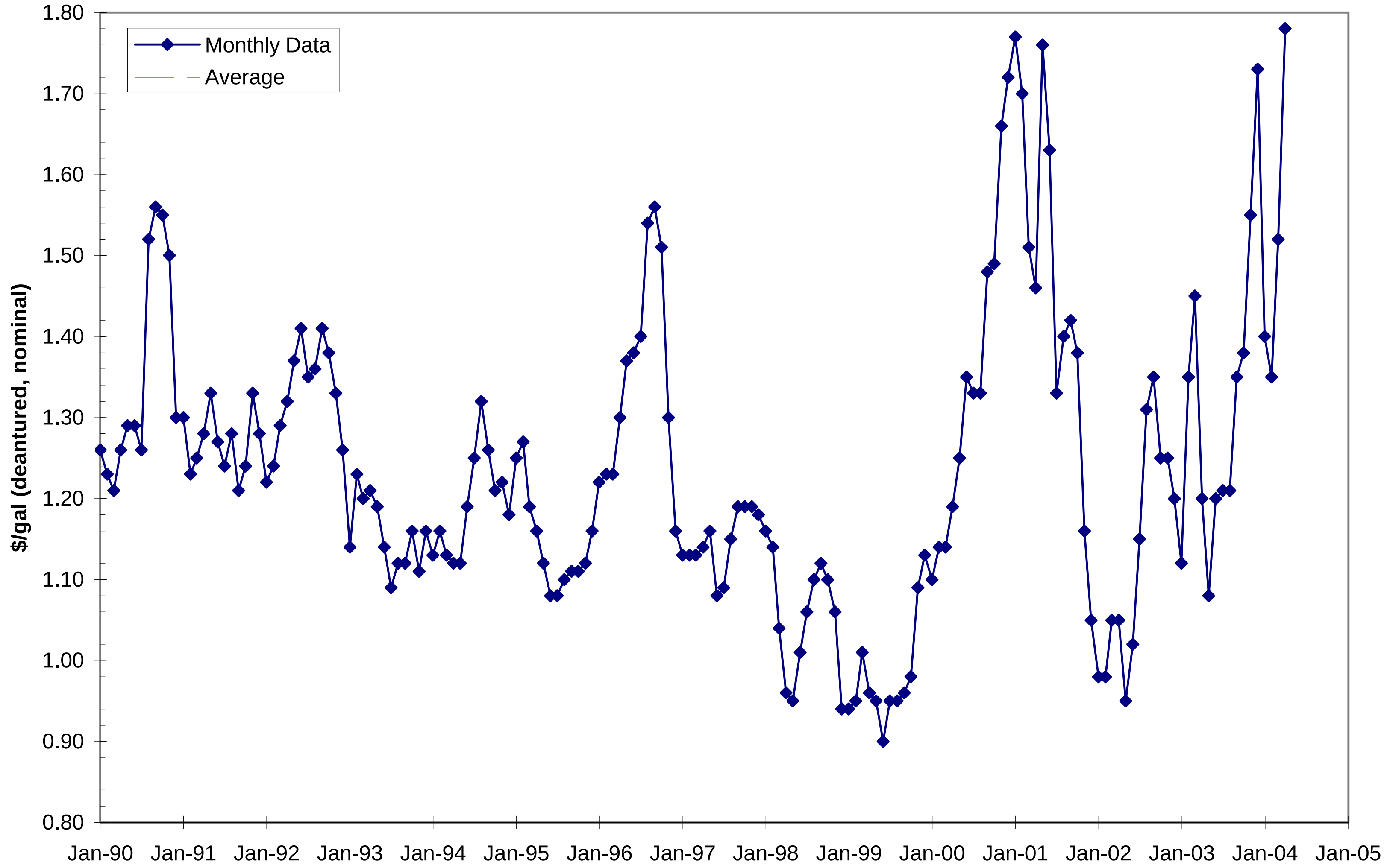
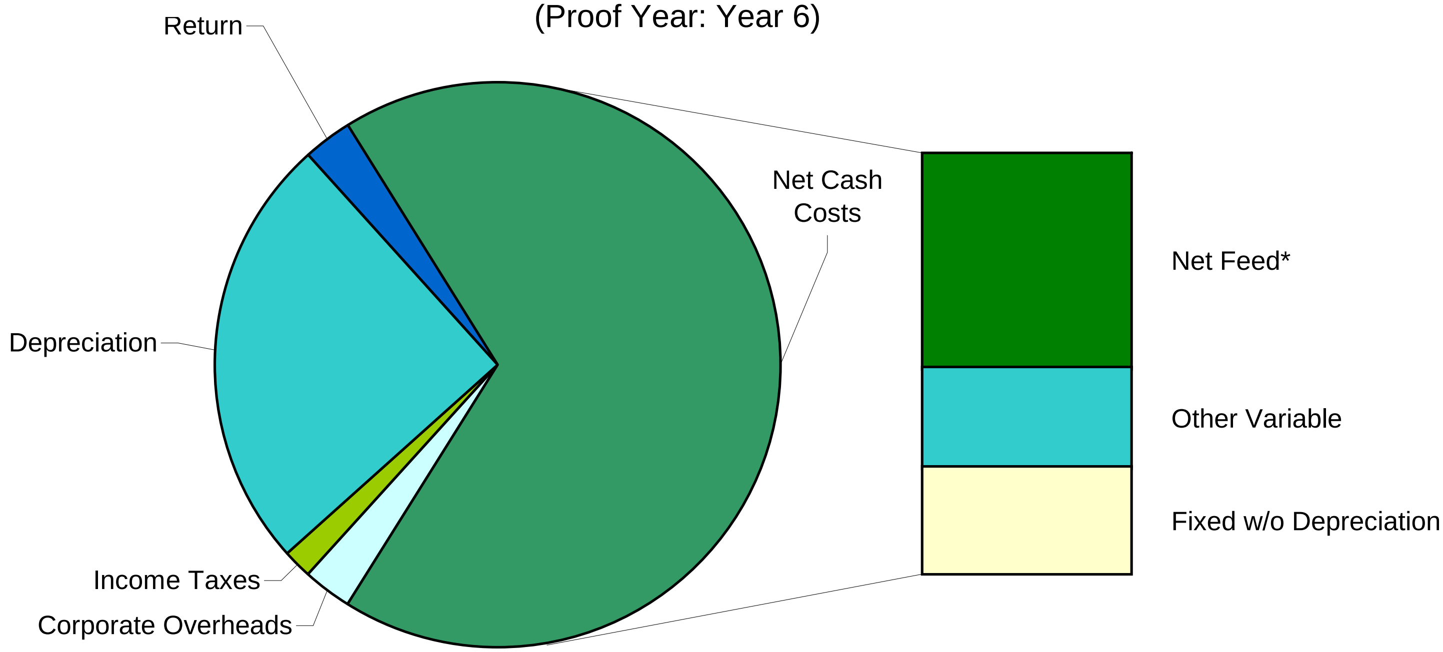


Figure 4 – Cost Breakdown
(Proof Year: Year 6)



Category	Denatured EtOH, $/gal (Real)	%
Net Feed*	0.43	34.9%
Other Variable	0.20	15.9%
Fixed w/o Depreciation	0.21	17.0%
Corporate Overheads	0.03	2.7%
Income Taxes	0.02	1.6%
Depreciation	0.31	25.0%
Return	0.03	2.8%
Market Price	1.24	100.0%
Rational Price	1.29	
Net Cash Costs	0.84	

*Cost of Starch Hydrolyzate+Stover+Light Steep Water
Less Revenues from Electricity+Steep Water Return

Figure 5 - Sensitivity wrt Fixed Capital

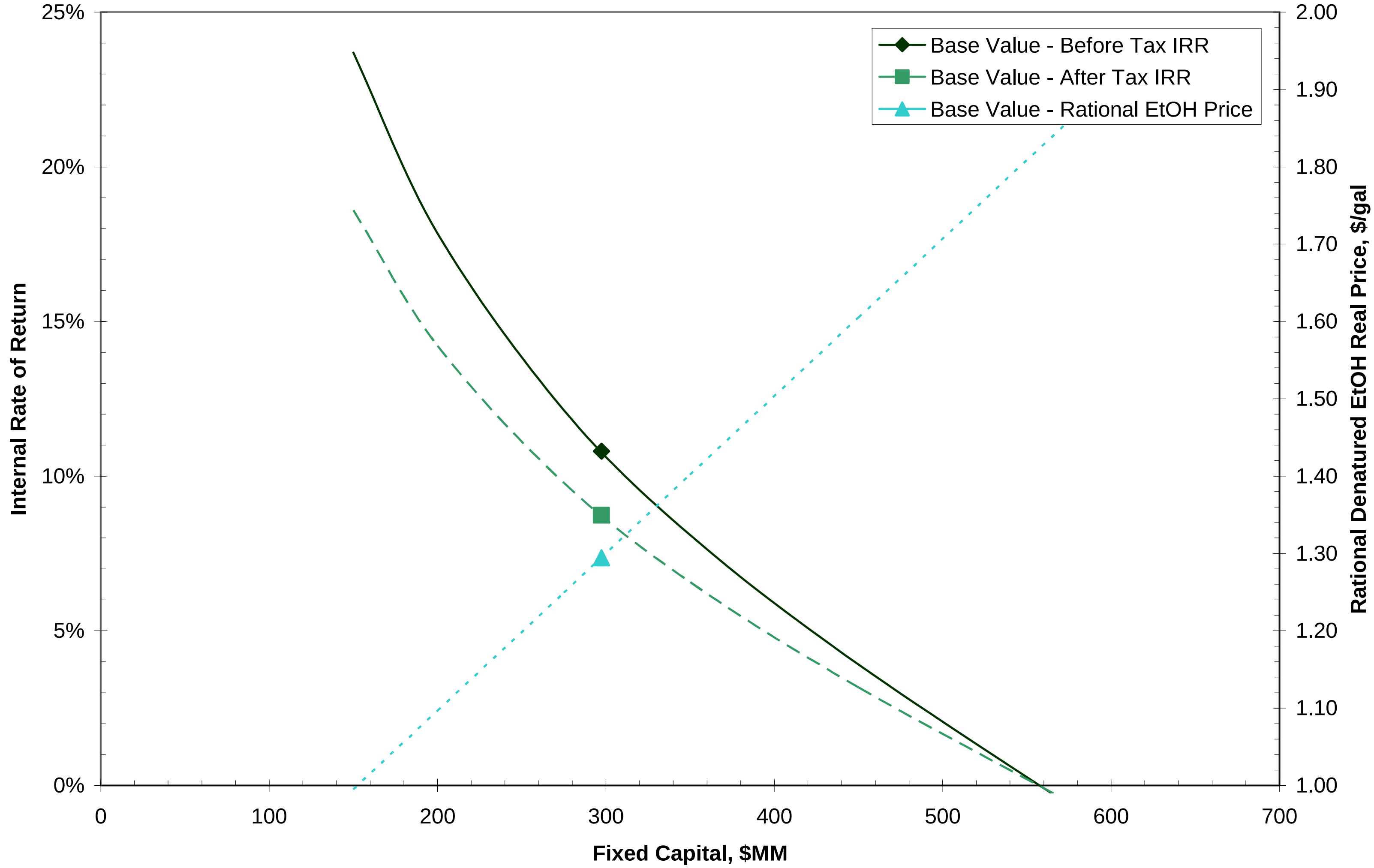


Figure 6 - Sensitivity wrt Starch Hydrolyzate Price

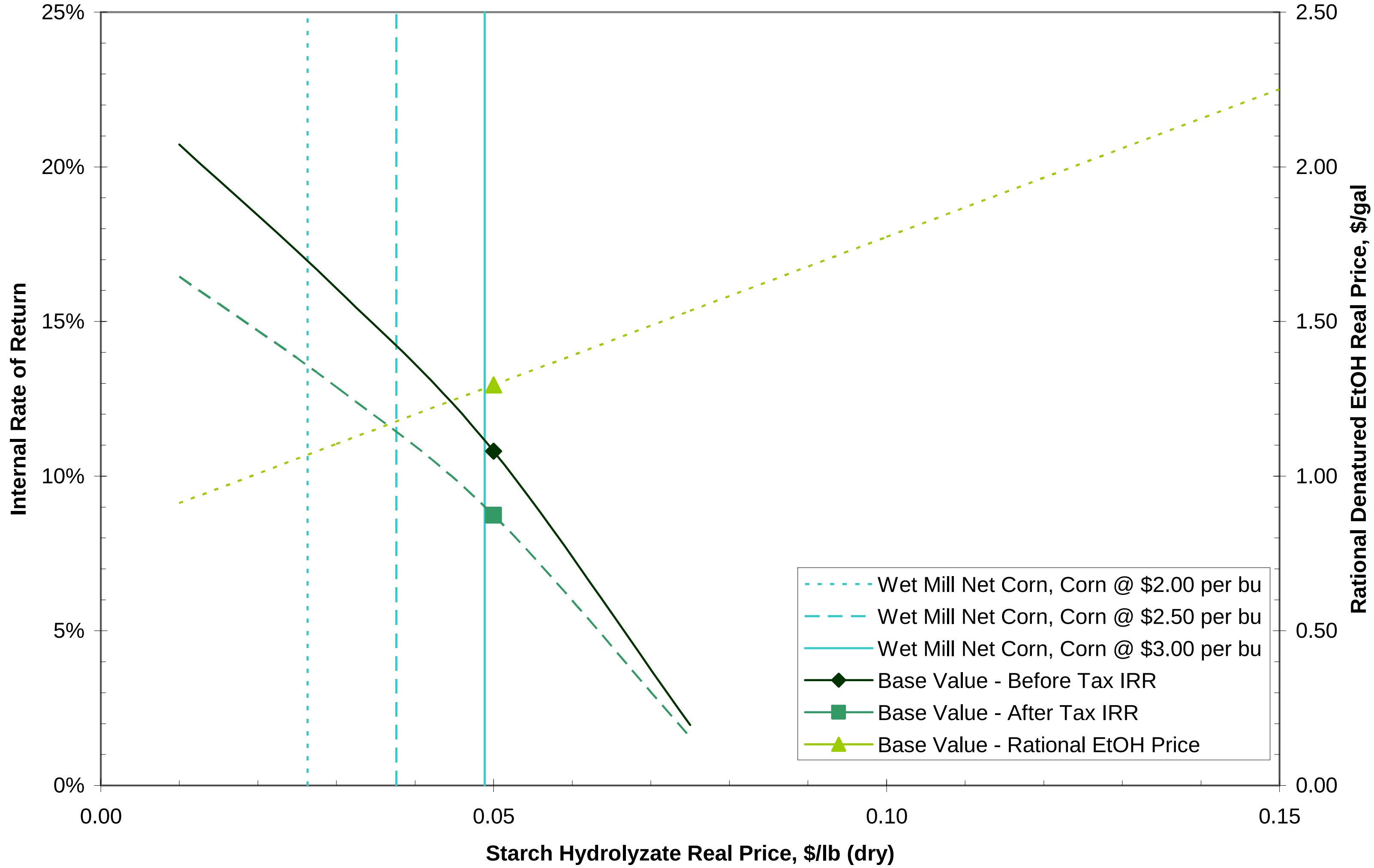


Figure 7 - Sensitivity wrt Stover Price

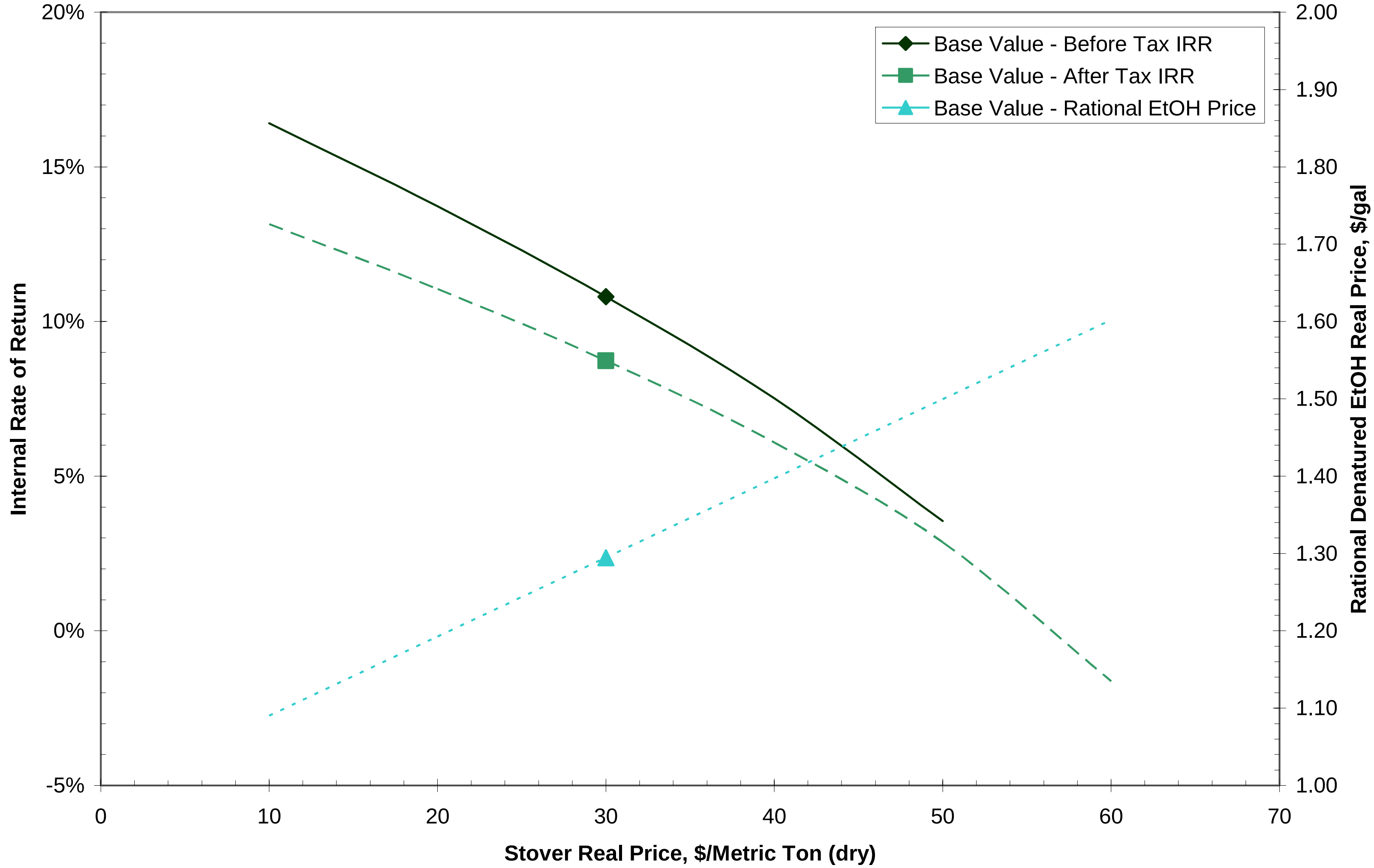


Figure 8 - Sensitivity wrt Denatured EtOH Price

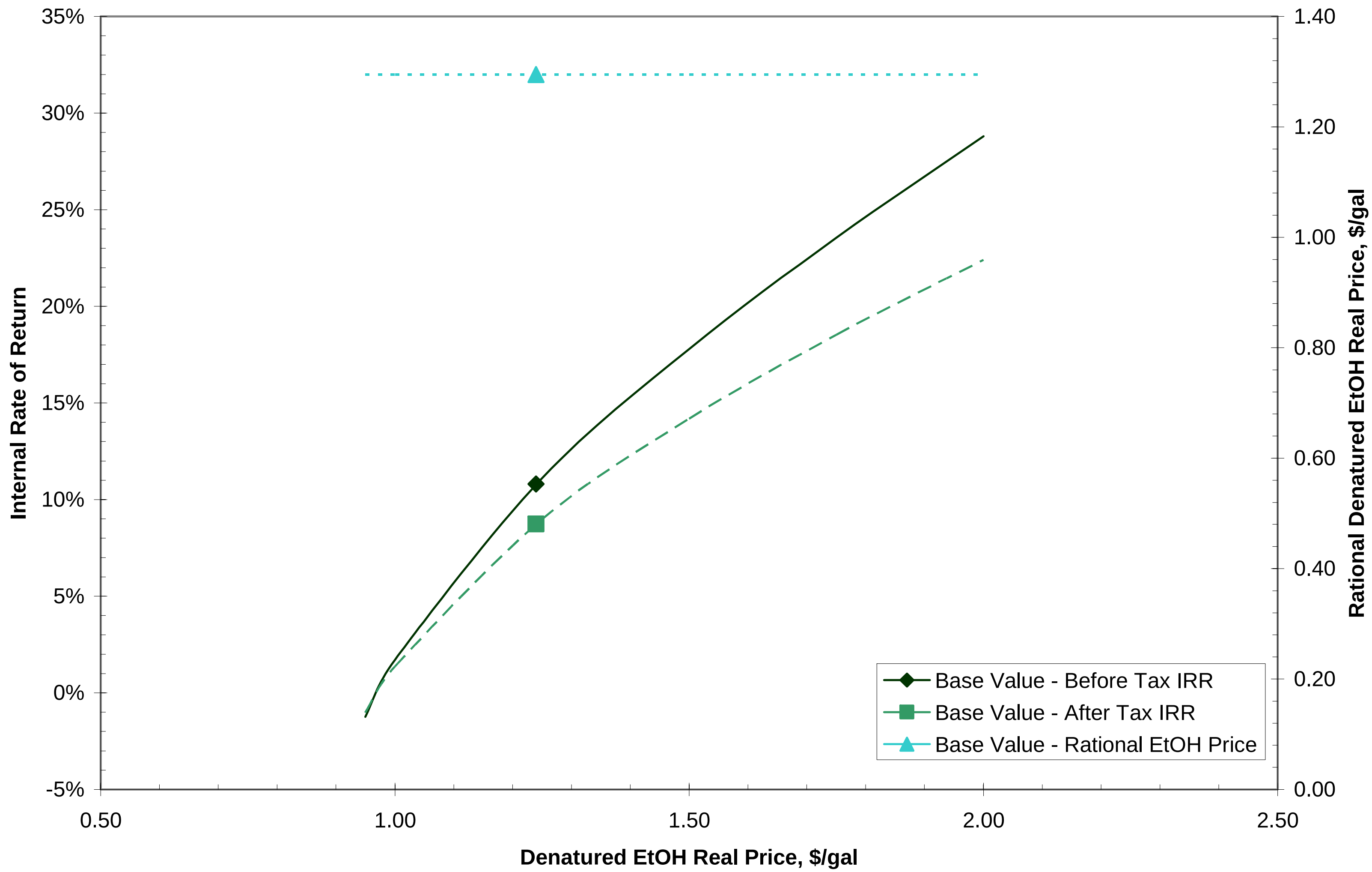


Figure 9 - Sensitivity wrt Electricity Price

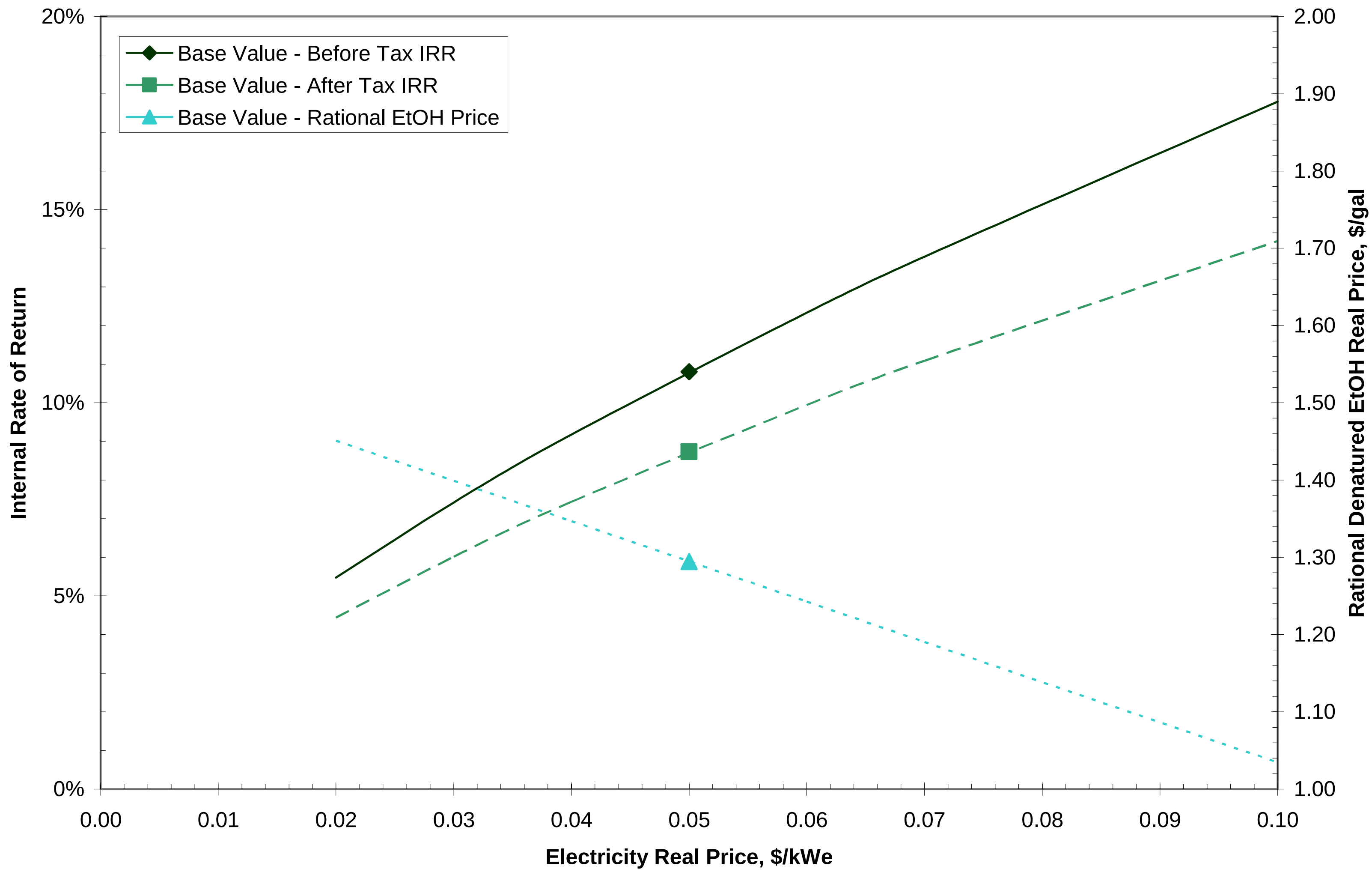


Figure 10 - Sensitivity wrt Steep Water Return Price
(Light Steep Water Price Constant at $130 per US Ton (dry))

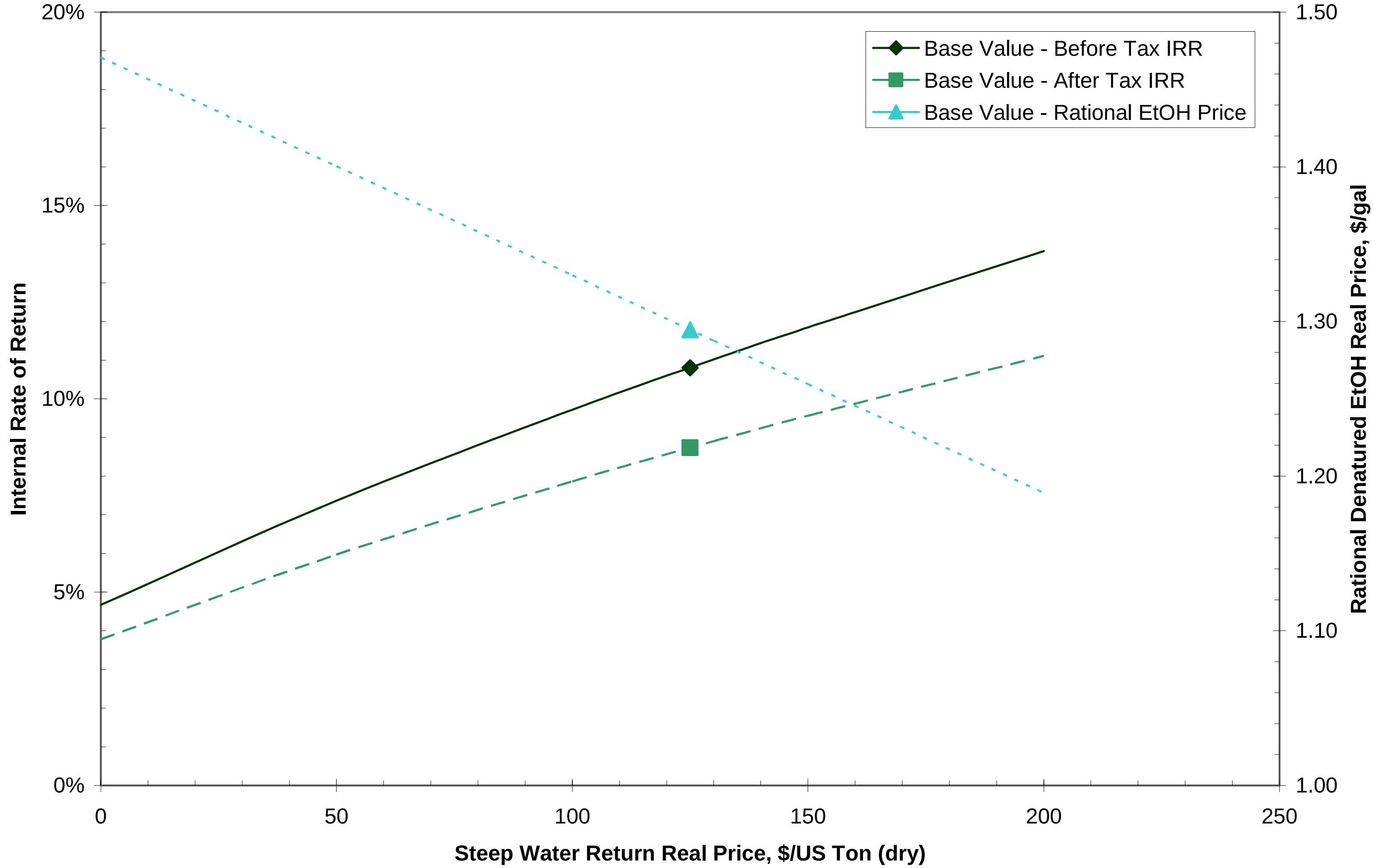


Figure 11 - Sensitivity wrt Discount Rate

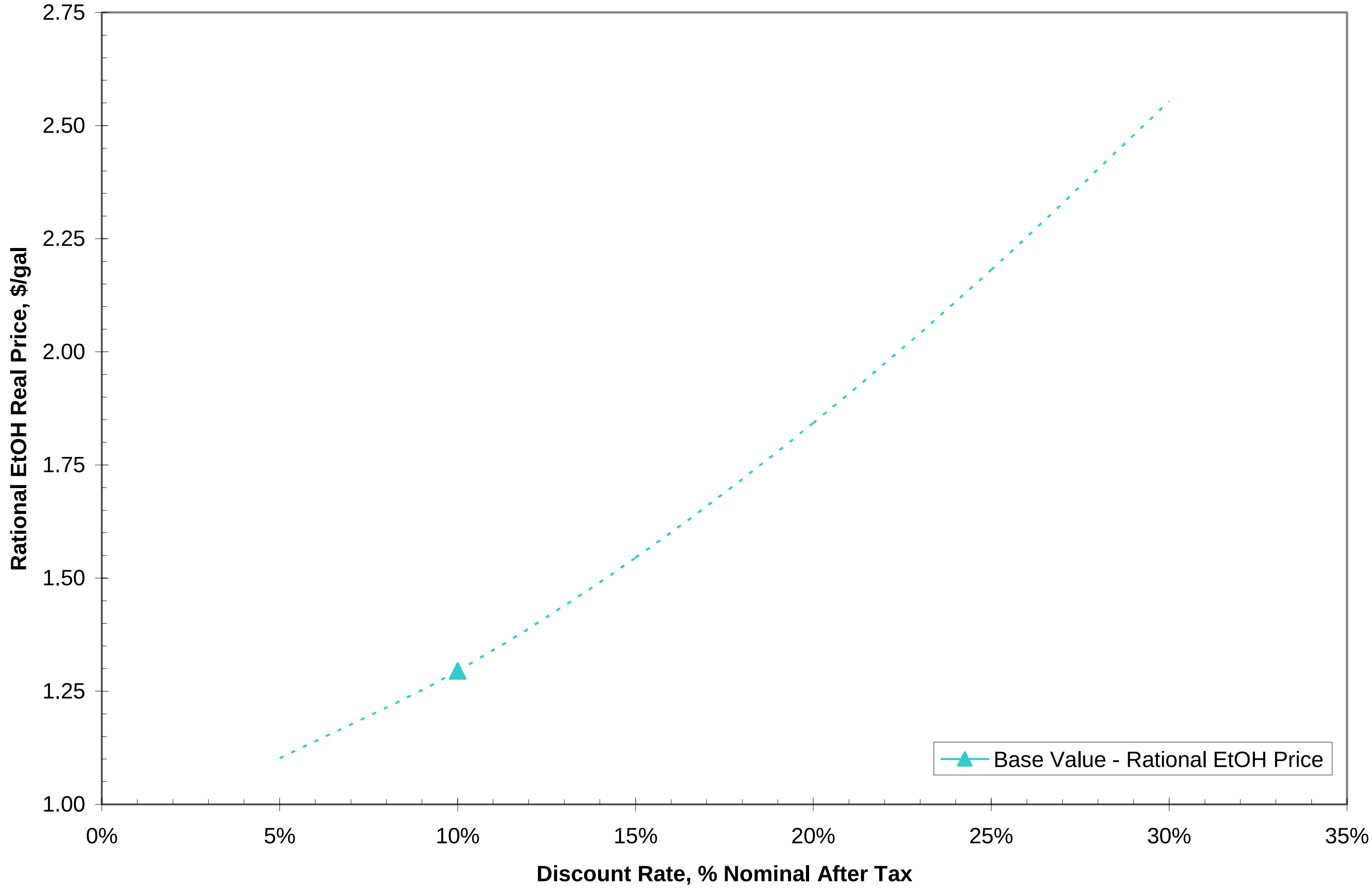


Figure 12 - Monte Carlo Summary

Monte Carlo Variables

	Distribution	Base Value	Units
Operating Rate, Year 3	Normal (Mean 64, Std Dev = 6.4)	64	% of Nameplate
Operating Rate, Year 4	Normal (Mean 85, Std Dev = 8.5)	85	% of Nameplate
Operating Rate, other years	Normal (Mean 100, Std Dev = 10, Truncated @110)	100	% of Nameplate
Denatured Ethanol	Triangle (Min: 0.90, Likeliest: 1.24, Max: 1.70)	1.24	$/gal
Electricity Export	Triangle (Min: 0.02, Likeliest: 0.05, Max: 0.07)	0.05	$/kW
Steep Water Return	Triangle (Min: 50, Likeliest: 125, Max: 300) Correlation with Light Steep Water = 0.8	125	$/US Ton (dry)
Fixed Capital	Triangle (-50% to +50% of Base Value)	297.3	$MM
Start-up Costs	Triangle (-50% to +50% of Base Value)	14.9	$MM
Starch Hydrolyzate	Triangle (Min: 0.03, Likeliest: 0.05, Max: 0.10)	0.0500	$/lb (dry)
Stover	Triangle (Min: 10, Likeliest: 30, Max: 50)	30	$/Metric Ton (dry)
Light Steep Water	Triangle (Min: 50, Likeliest: 130, Max: 200)	130	$/US Ton (dry)
Other Variable	Triangle (-50% to +50% of Base Value)	19.77	$MM/yr
Fixed w/o Depreciation	Triangle (-50% to +50% of Base Value)	21.08	$MM/yr
Corporate Overheads	Triangle (Min:0.5%, Likeliest:2%, Max:3%)	2	% of Revenue
Income Taxes	Triangle (Min:33%,Likeliest:37%,Max:39%)	37	% Rate

Result Summary