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PNNL-18944

Catalytic Hydrothermal Gasification of Lignin-Rich Biorefinery Residues and Algae

Final Report

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October 2009

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Summary

Funding from the federal government was provided by the Office of the Biomass Program within the Energy Efficiency and Renewable Energy assistant secretariat as part of the Thermochemical Conversion Platform. The funding for the project was initially provided FY2008 with subsequent funding approved for FY2009 but later rescinded for lack of progress.

This report describes the results of the work performed by PNNL using feedstock materials provided by the National Renewable Energy Laboratory, KL Energy and Lignol lignocellulosic ethanol pilot plants. Test results with algae feedstocks provided by Genifuel, which provided in-kind cost share to the project, are also included.

The work conducted during this project involved developing and demonstrating on the bench-scale process technology at PNNL for catalytic hydrothermal gasification of lignin-rich biorefinery residues and algae. A technoeconomic assessment evaluated the use of the technology for energy recovery in a lignocellulosic ethanol plant.

Feedstock Effects

Initial tests in catalytic hydrothermal gasification were performed in a continuous-flow reactor at PNNL. The system required feedstock slurry preparation for pumpable materials in high-pressure feeding systems. Representative feedstocks were provided to PNNL for gasification tests by the participants. The bench-scale tests provided product gas and byproduct materials in sufficient quantity for subsequent analysis and mass and elemental balance. The bench-scale system was used to optimize processing conditions such as temperature, slurry concentration, and residence time. A ruthenium on carbon catalyst was used in all tests.

The lignin-rich feedstocks showed varying levels of processing difficulties related primarily to the physical properties of the lignin (melting and viscosity of liquid intermediates) and also to the apparent slower rate of conversion. Plugging in the feed lines and in the transfer lines was a common problem, which stopped several of the tests. The mineral separation step functioned well in most cases with only a small loss of carbon. High conversion of the lignin materials to gas resulted in low contamination levels in the byproduct water. The gas product showed the expected methane and carbon dioxide content (with higher levels of methane) and only low amounts of hydrogen coproducts with minimal amounts of carbon monoxide or hydrocarbon gas products.

The algae feedstocks were much more reliably processed. High conversions were obtained even with high slurry concentrations. Consistent catalyst operation in these short-term tests suggested good stability and minimal poisoning effects. High methane content in the product gas was noted with significant carbon dioxide captured in the aqueous byproduct in combination with alkali constituents and the ammonia byproduct derived from proteins in the algae. High conversion of algae to gas products was found with low levels of byproduct water contamination and minimal loss of carbon in the mineral separation step.

Techno-Economic Assessment

A modeling effort evaluated the effect of displacing the solids recovery and combustion found in the lignocellulosic ethanol Base Case with catalytic hydrothermal gasification and subsequent power generation in two configurations: a steam boiler with turbine and a combined cycle gas turbine (CCGT). For each case, the wet gasification and power generation configurations were fully integrated into a CHEMCAD process model of the lignocellulosic ethanol Base Case. Capital cost reductions were found in the case with the steam boiler. Assessment of these configurations is preliminary and further efforts are required to determine overall efficiency and an optimized process.

Overall, the wet gasification cases appeared to be competitive with the Base Case. Interestingly, the more expensive power configurations, such as in the Base Case or the Combined Cycle Gas Turbine (CCGT), yielded comparable Minimum Fuel Selling Prices. This was due to the greater power export capability of the Base Case and the wet gasification with CCGT case. The main factor driving the reduced power export capability inherent to the wet gasification cases was that only a portion of the offgas from the wet gasification process was sent to power generation. A certain amount was used as fuel in the wet gasification feed trim pre-heater. This requirement may be optimized by using experimental data that has been gathered, for this report, indicating the optimum solids content of the slurry feedstock.

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Introduction

The purpose of this project was to develop an understanding of catalytic hydrothermal gasification as applied to feedstocks generated in biorefinery applications and algae. PNNL performed bench-scale research efforts to generate process information to optimize the application and to allow scale-up of the technology.

Catalytic Hydrothermal Gasification of biomass provides a highly efficient pathway to medium-Btu fuel gas. This gas product can be used directly in heat and power applications or has potential to be cleaned to pipeline quality gas. As a fuel gas, it could be used in the ethanol biorefinery to displace other energy requirements. As synthetic natural gas, it has potential to displace imported petroleum used in transportation application. Hydrothermal processing utilizes water-based slurries at medium temperatures (300–350°C) and sufficient pressure (2,300-3,000 psia) to maintain the water in the liquid phase. The processing option is particularly applicable to wet biomass feedstocks, such as biorefinery residues or algae.

Hydrothermal processing of biomass to gaseous fuels requires expanded process development to take the technology to a scale for industrial demonstration. Technical challenges associated with hydrothermal processing of biomass include the issues associated not only with feeding of high-pressure slurries and pressure let-down, but also defining the properties of the byproducts, which are highly dependent on the feedstock composition; optimization of the gasification process variables; and demonstrating the effectiveness of separation techniques to remove impurities before catalyst poisoning.

Feedstock Effects

Tests in hydrothermal gasification have been performed at PNNL in batch and continuous-flow reactors over the past 30 years. Initial batch tests evaluated the effects of feedstock composition relative to lignin and cellulose composition in wood. Subsequent tests evaluated a range of high-moisture biomass feedstocks in the batch reactor. The technology development then moved to continuous-flow process testing in both a continuous-flow stirred tank reactor and an essentially plug-flow tubular reactor. In these tests, catalyst lifetime was recognized as a significant concern and emphasis shifted to catalyst development using model compounds. Application of the improved catalysts was restarted in 2003 with funding from the Office of the Biomass Program. In engineering development tests in a scaled-up reactor, the issue of mineral precipitation became evident, which required the development of a new processing step for mineral separation to protect the catalyst bed. This improved processing system is demonstrated at the bench-scale in this project using lignin-rich biorefinery residues and algae as biomass feedstocks.

The bench-scale Continuous-flow Reactor System (CRS) was used in these tests to evaluate processing conditions for hydrothermal gasification, such as slurry concentration and residence time with the various feedstocks.

Reactor System Design

The CRS was composed of five major functional subsystems: feed pretreatment and preparation, pumping, preheater/reactor, reaction products separation, and instrumentation and control. The system was based on a throughput of 0.5-10 lb of slurry or solution per hour and was typically operated over a range of 1 to 3 liter/hour. The process flow diagram is shown in **Figure 1.** The modifications implemented for handling minerals and sulfur are indicated in the outline labeled "NEW."

The CRS was designed for obtaining engineering data for the continuous flow hydrothermal gasification process. The system consists of the high-pressure pump feeding system, product recovery system, data acquisition and control system, furnaces, and other equipment required to utilize the 1-liter stirred tank preheater (MAWP 6500 psi @ 800°F) and the 1-liter tubular catalytic reactor (MAWP 10,000 psi @ 72°F, or approximately7500 psi @ 400°C). The feed line, operated at ambient temperature, was ½" 316 SS tubing with 0.049" wall. All process lines at temperature of 200°C or above were ¼" 316 SS tubing with 0.065" wall. The mineral separation and sulfur stripping were done via two 1-liter Parr vessels.

Feed Pretreatment and Preparation --
The feedstock pretreatment and preparation method was designed to ensure a relatively homogeneous feed for the reactor. The feedstocks typically required a milling step in a Union Process Attrition Mill.

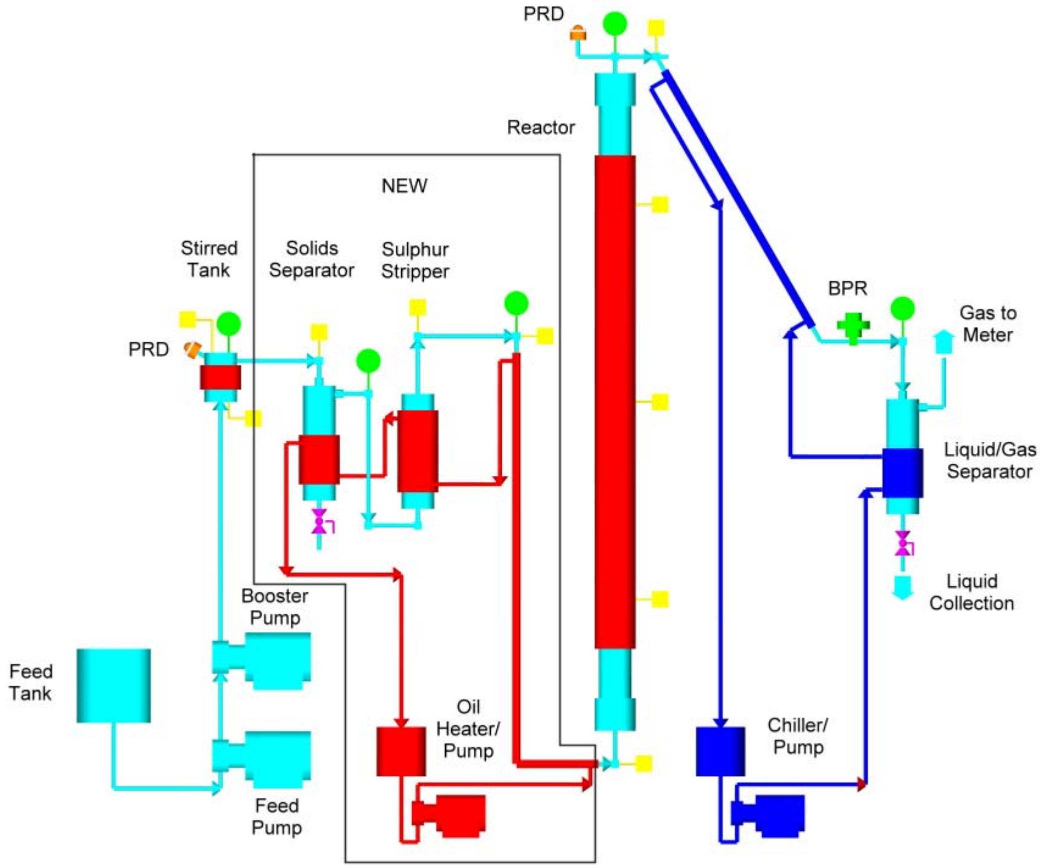

Figure 1. Process Flow Schematic of the Bench-Scale Continuous-Flow Reactor System (CRS)

Pumping --

The pumping subsystem was designed to operate at feed pressures up to 6000 psig and flow rates between 0.2 and 4.0 liter/hour. This system consists of a modified Isco 500D pump. The modification was the addition of a larger bore valve package in the unit that controls the feeding from one cylinder or the other. The valve package purchased consisted of four 3/8-inch air-actuated (6000 psi rated) ball valves with 3/8-inch stainless steel (SS) tubing connections installed on the Isco dual pump package. The valves and tubing were configured to fill and empty the pumps based on controller commands. We also installed oversize caps on the barrels that accommodate 3/8-inch NPT fittings. The large bore head, valve, and tubing allowed us to suction and pump the viscous slurries while still allowing the pump to operate at 3500 psi max. System piping included 0.5-inch (0.065-wall) 304 tubing SS on the outlet of the pump. Pump inlet piping was 0.5-inch (0.035 wall) 304 SS tubing. All valves and valve trim (except the pressure-control valve) were also made of SS. Using the Isco pump, the feeding rates were measured directly by the screw drive of the positive displacement syringe pump.

Pre-Heater/Reactor --

As tested, the preheater was a 1-liter 316 SS vessel equipped with a Carberry-type rotating basket. The preheater functioned as a continuous-flow, stirred-tank reactor (CSTR) in which the feedstock was brought to the reaction temperature.

Following heatup it was possible to separate mineral matter from the process stream and then strip reduced sulfur components. We used an in-line system to protect a catalyst bed in the tubular reactor from mineral deposits. In the process of heat up, the organics in the biomass were pyrolyzed and liquefied while certain inorganic components, such as calcium phosphates, formed and precipitated as solids. We placed a vessel in the process line between the preheater and the reactor to capture and remove the solids following heat-up to reaction temperature. The design of the separator was a simple dip leg vessel wherein the solids fell to the bottom of a vessel and the liquids passed overhead through a filter to the reactor. The solids could be removed by batch from the bottom of the vessel as they built up over time. In later tests we bypassed the tubular reactor and used only the CSTR. We included the solids removal vessel in order that the oil/water separation was more easily attained.

The gasification reactor was a 1-inch ID X 72-inch-long 304 SS tube. The vessel had a maximum allowable working pressure of 10,000 psig at 22°C, which was derated to 5200 psig at 450°C. The vessel had bolted-closure endcaps with metal o-rings on each end. The reactor furnace was a 6-kWe resistance heater split into three separately controllable zones. The pressure was controlled with a dome-loaded diaphragm back-pressure regulator.

Reaction Products Separation --
Product gases and water were vented via a dome-loaded back-pressure regulator (BPR). The off gas was cooled by another chilled heat exchanger to further remove any entrained water, the liquid is accumulated in a weighed tank, and the off-gas is measured by a wet test meter and analyzed by a gas chromatograph. Pressure transducers on each vessel recorded pressures and noted pressure drops due to restriction and plugging. Each vessel and most transfer lines were also monitored for temperature. Three rupture discs protected the system.

Instrumentation and Control --
The data acquisition and control system used in the CRS was a hybrid computer-based system employing discrete data acquisition devices and single-loop process controllers communicating to a central computer. The computer was used during experiments to monitor the process, calibrate instruments, and record data for later analysis. The data acquisition/control system regulated the furnaces and recorded the process parameters and offered off-normal warnings and auto-shut down. LabVIEW was used to coordinate these activities. Non-control sensors such as thermocouples and pressure transducers were monitored via the data acquisition unit.

Bench-Scale tests

An initial collection of tests were performed with biomass feedstocks to demonstrate the bench-scale mineral separation system. These tests were performed with wet biomass feedstocks other than the lignin-rich biorefinery residues. The results with a corn ethanol stillage and a starch-extracted wheat millfeed were summarized earlier in a preprint in the Petroleum Division of the American Chemical Society and presented at the national meeting in April of 2008.[1] From those tests we concluded that the

[1] DC Elliott, TR Hart, GG Neuenschwander, Catalytic Hydrothermal Gasification Of Biomass For The Production Of Hydrogen-Containing Feedstock (Methane). *Prepr. Pap.-Am. Chem. Soc., Div. Pet. Chem.* **2008,** 53 *(1), 73-74*

wet gasification of biomass had been demonstrated in a continuous-feed, fixed-bed catalytic reactor system at bench-scale with a solids separation system to protect the catalyst bed from poisoning and fouling. The short-term runs suggested a pathway to longer term operation. The inorganic components in the feedstocks were effectively removed by the solids separation system and prevented from poisoning and fouling or plugging the catalyst bed. Sulfur trapping was not as effective in those tests, and alternate trap materials should be tested. Aqueous effluents with low residual COD (as low as 100 ppm) and a product gas containing methane and carbon dioxide had been produced from fermentation stillage from corn ethanol production and wheat millfeed following starch extraction. The results suggested that continuous-flow processing of actual biomass feedstocks, which have mineral and sulfide containing components, could be accomplished without fouling or poisoning the catalyst bed. The product gas from the process was a clean methane-containing stream.

In this project a total of 11 separate process tests were performed. These tests are summarized in **Table 1** and include processing at various flow rates and slurry concentrations. The feedstocks include solid residues (various purities of lignin) from lignocellulosic ethanol production at NREL, KL Energy and Lignol as well as several algae feedstocks provided by Genifuel. Although extensive effort was expending in interactions with IOGEN, Mascoma and Verenium, no residue samples from their lignocellulosic ethanol processes could be obtained, typically as a result of intellectual property concerns on the part of the ethanol producers. Biomass conversion was measured both by carbon conversion to gas and by COD (chemical oxygen demand) reduction. Gas analysis was performed by gas chromatography.

Table 1. List of Process Tests

source	date	Type	biomass	TOS h	Feed rate, L/h	slurry conc, wt%	effluent COD, ppm	gas yield L/g DS
NREL	4/22/09	SSF residue	corn stover	8	1.5	8.84	150	0.57
Lignol	7/2/09	lignin product	aspen	0.4	1.2	21.9	NA	NA
Lignol	7/8/09	lignin product	aspen	2	1.2	17.24	75	NA
Lignol	7/2/09	lignin product	aspen	0.1	1.2	17.1	NA	NA
Lignol	7/2/09	lignin product	aspen	1	1.2	12.7	0	NA
KL Energy	6/17/09	lignin byproduct	pine	5	1.2	8.7	530	0.53
KL Energy	6/17/09	lignin byproduct	pine	10.3	1.5	6.55	0-19875	0.57
Genifuel	11/11/08	wild mix w/spirulina	algae	3.5	1.5	22.2	1600	0.10
Genifuel	11/12/08	Spirulina	algae	4.8	1.4	21.6	10830	0.61
Genifuel	11/19/08	Spirulina	algae	8.5	1.0	22.4	10410	0.55
Genifuel	8/18/09	SLC mix	algae	11.2	1.5	8.05	457	0.57

NREL SSF Gasification --

A single test was performed using SSF (simultaneous saccharification and fermentation) residue produced in the lignocellulosic ethanol pilot plant at the National Renewable Energy Laboratory from corn stover. Dewatered solids were provided and this material was mixed with additional water to process through our wet mill to make the feed slurry. The test was performed at our standard processing conditions of nominally 350°C and 3000 psig. The Ru/C gasification catalyst was used with a pelletized Raney nickel sulfur scrubbing bed. The solids separation step was required at 2 to 4 hour intervals. Consistent operation was witnessed throughout. The process results are presented in **Table 2** as an average of the two data sets included in the Appendix.

Table 2. Process Results with NREL Feedstock

Process Parameters		**Process Results**	
Preheater temp	340	gas yield	0.57
Tubular temp	331-352-349	Gas Composition	
System Pressure	2940	methane	52.1
LHSV, L/L cat @ temp/h	1.9	carbon dioxide	45.1
Feed Composition		hydrogen	1.9
Carbon	43.4	ethane	0.4
Hydrogen	5.0	carbon monoxide	0
Nitrogen	1.4	carbon conversion to gas	71
Oxygen	30.7	carbon lost with solids	12
Sulfur	0.2	COD reduction	99.9
ash	18.3	mass balance	97
Feed dry solids	8.84	carbon balance	84

Lignol Lignin Gasification --
Four tests were attempted using lignin residue produced in the lignocellulosic ethanol pilot plant at Lignol in British Columbia from aspen. The process used by Lignol produced a more purified lignin byproduct. Dewatered solids were provided and this material was mixed with additional water to process through our wet mill to make the feed slurry. The feed slurry contained a higher level of solids and proved more difficult to pump. The tests were attempted at our standard processing conditions of nominally 350°C and 3000 psig. The Ru/C gasification catalyst was used with a pelletized Raney nickel sulfur scrubbing bed. The solids separation step was in line but no test ever stayed on line long enough to require a separation. The ash content of the feedstock was low (1%) in any case. Inconsistent operation was witnessed throughout because of problems with pumping. The identified problems related to line plugging with viscous tar material. This material was apparently something between melted lignin and hydrothermal liquefaction product bio-oil from lignin.

In the initial test with high concentration feedstock the blockage occurred in the feed line due to fiber bridging at a line restriction. In the next tests a more dilute feedstock was processed, but without any better result. Plugging was found in the transfer line following the preheater and again in the feed line just before reaching the preheater and likely resulted from the lignin melting and sticking to the tube walls. Some byproduct water was recovered, which contained almost no organic material, suggesting that the system had not yet attained steady state operation. In the final test a more dilute feedstock was tested. It was on line only slightly longer before plugging again.

In conclusion, a modified processing system (possibly with larger diameter lines and vessel openings) will be needed to perform hydrothermal liquefaction on more highly purified lignin feedstocks. The gas product recovered was typical of catalytic hydrothermal gasification: 59-62% methane, 36-40% carbon dioxide and 1% hydrogen. Catalyst lifetime could not be judged because of the short length of the tests.

KL Energy Lignin Gasification --
Two tests were performed using lignin residue produced in the lignocellulosic ethanol pilot plant at the KL Energy in South Dakota from pine. Dewatered solids were provided and this material was mixed with additional water to process through our wet mill to make the feed slurry. The test was performed at our standard processing conditions of nominally 350°C and 3000 psig. The Ru/C gasification catalyst was used with a pelletized Raney nickel sulfur scrubbing bed. The solids separation step was required at 5 to 6 hour intervals with this low ash feedstock. Consistent operation was witnessed throughout. The process results in **Table 3** represent two operational setpoints.

Table 3. Process Results with KL Energy Feedstock

Process Parameters	1	2	**Process Results**	1	2
Preheater temp	348	339	gas yield, L/g DS	0.53	0.55
Tubular temp	324-349-349	324-353-350	Gas Composition		
System Pressure	2855	2980	methane	51.5	44
LHSV, L/L cat @ temp/h	1.5	1.9	carbon dioxide	47.3	54
Feed Composition			hydrogen	0.9	2
Carbon		50.2	ethane	0.0	1
Hydrogen		5.5	carbon monoxide	0.00	0.00
Nitrogen		0.3	carbon conversion to gas	58	60
Oxygen		41.5	carbon lost with solids	0	3
Sulfur		0.0	COD reduction	99.7	86
ash	1.9	2.6	mass balance	107	93
Feed dry solids	8.84	6.55	carbon balance	58	77

The first test (columns labeled 1) was short based on the amount of available feedstock and may not be at steady state as suggested by the low carbon balance. Therefore, the high conversion of COD may not be truly representative. As the feedstock dwindled the pump faltered, a plug formed and the test was terminated. In cleaning out the system a plug was found in the transfer line following the preheater. The plug material was solid at room temperature but melted at about 140°C. It is effectively the intermediate liquefied biomass, which is gasified by the catalyst in the tubular reactor.

The second test data in Table 3 (columns labeled 2) represent the later portion of the second test, which should be closer to steady state, but may also represent a situation of partially deactivated catalyst. The more dilute feedstock was processed at a faster rate with the expected result in a lessened COD reduction and carbon conversion to gas becoming evident in the later portion of the test as the system came to steady state. Alternatively, the lower conversion level may be evidence of the catalyst becoming deactivated.

In cleaning out the system following this test, the solids separator vessel was found to have a large portion of solids, which were not swept clean in the separation step nor in the subsequent water flushes used in the shutdown process. The material was not tightly consolidated or coked, but it represents a significant portion of the dry solids fed in this test and probably from previous tests as well, as shown by an over-recovery of dry mass. The three data sets for KL Energy included in Appendix I are for the first test and for the early portion as well as the later portion of the second test.

Genifuel Algae Gasification --
Four tests were performed using different algae feedstocks provided by Genifuel. Dried solids were provided in the first three tests and a dewatered material in the fourth. This material was mixed with additional water to process through our wet mill to make the feed slurry. The test was performed at our standard processing conditions of nominally 350°C and 3000 psig. The Ru/C gasification catalyst was used with a pelletized Raney nickel sulfur scrubbing bed. Consistent operation was witnessed throughout although a valve failure stopped test #2 and a mineral plug in the offgas line was found after test #3.

In test #1 a high-ash mixture of wild algae recovered from the Salt Lake basin with some spirulina commercial product was tested. The feedstock contained 80% of wild cyanobacteria/algae at a 22.2 wt% of dry solids, but contained 60.1% ash on a dry solids basis. The solids separation step was required every half hour in order to maintain operation. The process parameters are presented in column 1 of **Table 4**, and the process results are given in column 1 of **Table 5**. The test was terminated voluntarily but the gas yield was low because of the low concentration of carbon in the feedstock and the large loss of carbon with the mineral separation. The byproduct water was effectively cleaned.

Table 4. Process Parameters with Genifuel Algae Feedstocks

Process Parameters	**1**	**2**	**3a**	**3b**	**4**
Preheater temp	339	334	335	340	345
Tubular temp	333-349-351	334-354-351	324-351-348	315-350-350	327-348-351
System Pressure	3018+/-118	2970+/-42	2934+/-30	2984+/-50	2917+/-62
LHSV, L/L cat @ temp/h	1.9	1.8	1.6	1.4	1.9
Feed Composition					
Carbon	27.1	45.7	47.2	47.2	38.3
Hydrogen	3.7	6.3	6.6	6.6	5.3
Nitrogen	6.0	10.2	10.5	10.5	5.8
Oxygen	15.2	26.7	27.4	27.4	32.3
Sulfur	0.9	0.8	0.9	0.9	1.0
ash	60.1	10.3	8.3	8.3	22.0
Feed dry solids	22.2	21.6	22.4	22.4	8.0

In test #2 spirulina product was used as the algae feedstock. This material had a much lower ash content but a higher nitrogen content. Analysis from the manufacturer suggested that it contained 23.34% protein on a dry basis (N X 6.25) and 12.26% ash. It also had 0.4% fat and 64% carbohydrate. The high loading of organic material in the feed resulted in a lower COD reduction. A greatly reduced loss of carbon with the mineral separation was noted. The test was terminated early when a valve failed. The product water had a high pH of 8.2-8.5 reflecting the high level of ammonia produced from the nitrogen in the

Table 5. Process Results with Genifuel Algae Feedstocks

Process Results	**1**	**2**	**3a**	**3b**	**4**
gas yield	0.10	0.61	0.69	0.55	0.57
Gas Composition					
methane	62.5	52.1	53.0	52.1	59.3
carbon dioxide	36.5	42.0	43.5	43.0	38.8
hydrogen	0.9	3.3	2.0	2.6	1.7
ethane	0.0	2.5	1.4	2.3	0.2*
carbon monoxide	0.00	0.00	0.00	0.00	0.00
carbon conversion to gas	40	90	87	71	106
carbon lost with solids	32	6.1	0.7	4.3	2.7
COD conversion	99.3	96.6	99.7	96.6	99.5
mass balance	101	100	101	95	103
carbon balance	74	99	98	87	111

* trend of increasing ethane noted in final hours of test

feedstock. The somewhat lower methane to carbon dioxide ratio along with higher hydrogen and ethane concentrations in the product gas suggest incomplete conversion or loss of catalyst activity. A sulfate breakthrough was also noted as the sulfate level increased form 34 ppm initially to 95 ppm near the midpoint and 3900 at the end of the test.

The separated mineral byproducts contained 34.6% carbon, 3.5% nitrogen and 41.2% ash. The other elements can be compared to the significant elements in the feedstock composition in **Table 6**. The elements in the feedstock are clearly the source of the mineral precipitates. The alkali metals (probably as carbonates) and alkaline earths (likely as phosphates) are evident. Sulfur (likely as sulfate) may well be combined with the iron.

Test #3 was a repeat test with the spirulina feedstock at lower flow rate. The test was on line for a longer period, but toward the end of the test the catalyst activity appeared to degrade as seen by increasing ethane and hydrogen. Inconsistent pumping in the early stage of the test (suspected to result from plugging) was addressed by reducing the flow rate further in the later stage. The gasification was lower at the lower feed rate (rather than expected higher gasification) but the gas yield correlates with the lower carbon balance. The product water had a high pH of 8.0-8.6 reflecting the high level of ammonia produced from the nitrogen in the feedstock.

Following shutdown, a plug was found in the outlet from the reactor portion of the system. It was a white mineral deposit which was found to contain a significant level of ammonium, suggesting ammonium bicarbonate; however, based on the limited amount of analysis done, the amount of ammonium (as bicarbonate) would account for only about 20% of solid. [ammonium bicarbonate is known to form by bubbling ammonia through concentrated ammonia water -- it decomposes at 60°C] Alkali was present in the solid only at <5ppm for Na, K, or Ca, suggesting that alkali carbonates were not a major component. Similarly, P (1.5 ppm) was not a large component, suggesting that phosphates were not the major component. Fe and Ni were present at 25 and 15 ppm (equivalent to about 2% of the solid as iron carbonate) and Al and Cu were present at 10-15 ppm.

Table 6. Trace Elements of Algae Feedstock and Separated Mineral Byproducts from Test 2

Element	feedstock	mineral 1	mineral 2
Na 589.592	22940	23730	NA
K 766.490	22070	22710	54140
P 213.617	10260	18480	31400
S 180.669	10150	7926	10420
Mg 285.213	3092	11820	12300
Ca 317.933	1081	115400	61030
Fe 238.204	639	22950	11770
Si 251.611	331	2896	2335
Al 396.153	87	5882	2406
Zn 206.200	20	814	440
Mn 257.610	37	497	340
Ni 231.604	26	319	349
Cu 327.393	20	116	55
Ti 334.940	7	201	116
Ba 233.527	2	171	101
Pb 220.353	15	166	92
Hg 253.652	15	115	66
Cr 267.716	8	114	71
Ru 240.272	12	49	31
W 207.912	3	15	9
Mo 202.031	5	11	10
Zr 343.823	2	10	8
B 249.772	-22	28	6
Ag 328.068	-25	587	-83

The separated mineral byproducts contained 34-36% carbon, 3.5-3.7% nitrogen and 44-47% ash. The other elements can be compared to the significant elements in the feedstock composition in **Table 7**. The elements in the feedstock are clearly the source of the mineral precipitates. The alkali metals (probably as carbonates) and alkaline earths (likely as phosphates) are evident. Sulfur (likely as sulfate) may well be combined with the iron and nickel. The reason for the difference in composition between the two byproducts is not known.

Sulfate in the water product effluent was nearly constant throughout the test at 80 to 90 ppm. Chloride was also found at 80 to 100 ppm. These components may prove to be catalyst poisons in long term operation.

In test #4 a purpose-grown algae feedstock provided by Genifuel was processed. The slurry feedstock generated with this material was much more dilute than was found with the spirulina (8% vs. 22%). Operations went much more smoothly and an extended run was accomplished without incident. A higher flow rate was used with the more dilute feedstock and high gas yield and COD reduction was maintained throughout the test. The only contrary evidence was a slight trend of increasing ethane noted in final hours of test. The loss of carbon in the mineral stream was low. The separated mineral byproducts contained only 9.2% carbon, 0.8% nitrogen and 84% ash. There was no evidence of process line deposits. The recovered aqueous byproduct had a COD ranging from 234 to 686 with an average of 457 ppm over the 8.5 hours of steady state operation. The ammonia analysis showed a range from 7,750 to 19,367 mg/liter with an average of 12,197. Recovery and reuse of this dissolved ammonia from the algae protein structures has an obvious positive impact in the sustainability of the technology.

Table 7. Trace Elements of Algae Feedstock and Separated Mineral Byproducts from Test 3

Element	feedstock	mineral 1	mineral 2
K 766.490	18110	65350	7226
Na 589.592	18090	63330	82760
P 213.617	8628	66540	9733
S 180.669	8385	9088	818
Mg 285.213	2627	35750	4827
Ca 317.933	1117	31410	3294
Fe 238.204	533	8072	889
Si 251.611	281	2330	218
Al 396.153	31	2954	274
Ni 231.604	16	1041	47
Zn 206.200	17	227	22
Mn 257.610	30	538	74
Cu 327.393	26	66	14
Cr 267.716	4	206	14
Ba 233.527	2	85	9
Ti 334.940	2	123	15
Pb 220.353	2	35	4
Hg 253.652	7	49	6
Zr 343.823	1	17	2
Ag 328.068	19	-29	9
W 207.912	8	12	1
Mo 202.031	8	7	1
Ru 240.272	4	15	2

Similarly, recycle of the dissolved potassium (shown in **Table 8**) and carbon dioxide should have positive affects if the COD has been reduced to sufficient level to not impact the algae growth. Separation and reuse of the carbon dioxide in the product gas is another opportunity for minimizing the technology carbon footprint.

In cleaning out the system following this test, the solids separator vessel was found to have a large portion of solids, which were not swept clean in the separation step nor in the subsequent water flushes used in the shutdown process. The material was not tightly consolidated or coked, but it represents a significant portion of the dry solids fed in this test. This solid material is described in the data sheet for this test and is reflected in the carbon distribution and mass balance data.

Table 8. Trace Elements of Aqueous Byproduct from Algae Test 4

Element	Algae 4 composite water sample
K 766.490	718.6
Na 589.592	364.2
B 249.772	13.75
Si 251.611	11.03
Al 396.153	5.561
S 180.669	1.534
Ca 317.933	0.505
Ba 233.527	0.087
Cu 327.393	0.066
Sn 189.927	0.052
P 213.617	0.041
Mg 285.213	0.041
Fe 238.204	0.018
Mo 202.031	0.014
Zn 206.200	0.014
Ni 231.604	0.018
V 310.230	0.01
Mn 257.610	0.005
Ti 334.940	0.002
Cr 267.716	0.002
Pb 220.353	0.002
	green is below quantifiable level of 1

Techno-Economic Assessment

Introduction

A technoeconomic assessment of catalytic hydrothermal gasification was undertaken in support of the technology development project. In the analysis the use of the technology was limited to lignocellulosic ethanol residues. No assessment has been completed on the application of the technology to algae feedstocks.

Background

The United States transportation sector, alone, consumed 6.7 billion gallons of ethanol in 2007[2]. This is nearly 4.5 times the volume consumed in 1999[3]. According to the Energy Information Administration (EIA), this number is expected to grow to more than 20 billion gallons by 2020. This projection for rapid growth is a reflection of the expected impacts of the renewable fuel standard set by the Energy Independence and Security Act of 2007 (EISA, 2007). In an effort to meet targets, set forth by EISA, the United States Department of Energy is evaluating means for efficient ethanol production including lignocellulosic ethanol and energy (electrical) recovery from "waste" streams.

Recent efforts toward efficient ethanol production have been focused on lignocellulosic biomass conversion. Conversion of lignocellulosic biomass into useable sugars by enzymatic and acid hydrolysis is advancing, but is still not cost competitive. One means for improving the economics is to recover energy from byproduct streams comprising primarily lignin, water, and some unconverted hemicellulose and cellulose. The National Renewable Energy Laboratory (NREL) has evaluated and compared lignocellulosic ethanol including energy recovery from potential "waste streams" via anaerobic digestion, combustion, and gasification[4]. But high moisture content biomass streams such as these are difficult to convert, efficiently, in conventional combustion or gasification systems. These lignocellulosic ethanol byproduct streams have been identified as potential candidates for catalytic wet gasification (Brown & Elliott, 2008). The following study is a preliminary technoeconomic assessment of wet catalytic gasification of lignocellulosic ethanol residue. The performance and economics of power generation from the wet gasification gases via steam turbine and a combined cycle gas turbine will be compared.

Evaluation Basis

A process model based on the NREL analysis of enzymatic and acid hydrolysis of corn stover, to produce ethanol[4], was developed in CHEMCAD. The model was then modified to incorporate a wet gasification facility in place of lignin dewatering, anaerobic/aerobic waste water treatment facilities, and power

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[2] Conti, J. J., & al., e. (2009). *Annual Energy Outlook 2009 DOE/EIA-0383(2009).* Washington, D.C.: Energy Information Administration.
[3] Brown, M. D., & Elliott, D. C. (2008). *Wet Gasification of Ethanol Residue: A Preliminary Assessment PNNL-17846.* Richland, W.A.: Pacific Northwest National Laboratory.
[4] Aden, A., Ruth, M., Ibsen, K., Jechura, J., Neeves, K., Sheehan, J. (2002). *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover NREL/TP-510-32438.* Golden, CO: National Renewable Energy Laboratory.

generation under two scenarios: a conventional burner/steam boiler and a combined cycle gas turbine (CCGT). A simplified block diagram is shown in **Figure 2.**

Aspen model stream data and cost sheets, developed by NREL, were used to achieve a direct comparison between the NREL case and the modified, wet gasification case. The CHEMCAD process flow models were used to obtain equipment sizes via heat and material balances. Capital costs were obtained from literature, by inputting equipment sizes into Aspen Icarus, or by consultation with an appropriate vendor. Costs are given in 2000 dollars to maintain consistency with the NREL case used for comparison.

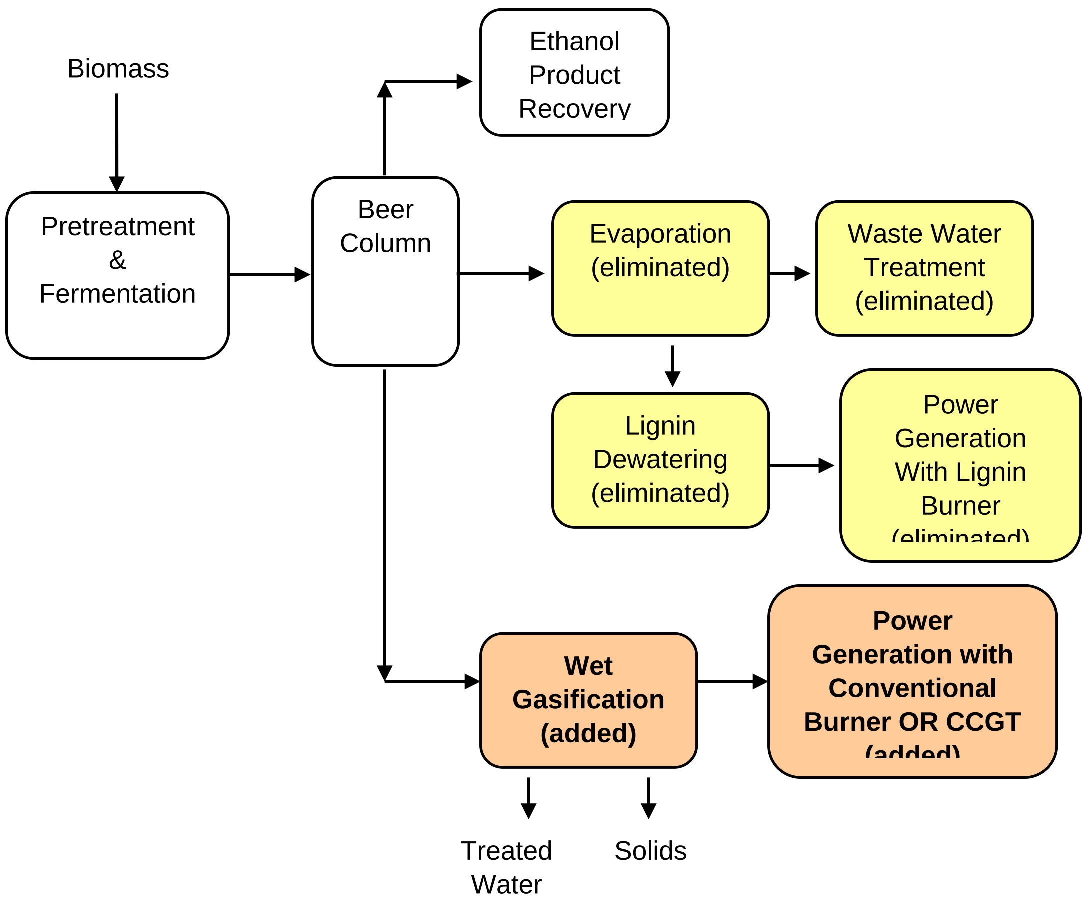

Figure 2. Block Diagram of Wet Gasification of Lignocellulosic Ethanol Residue

Process Design Basis

The NREL model is a co-current dilute acid prehydrolysis of lignocellulosic biomass with enzymatic saccharification of the remaining cellulose and co-fermentation of the glucose and xylose to yield ethanol. Feedstock handling, feedstock storage, product purification, wastewater treatment, lignin combustion, product storage, and utilities are all included in the NREL analysis. The lignocellulosic biomass feedstock is corn stover. It is input at 2,352 tonnes per day, as received, and has a moisture content of 15%.

The stover is washed, treated to remove tramp metal, and shredded. It then undergoes pretreatment and hydrolyzate conditioning. Most of the hemicellulose is converted into soluble sugars using dilute sulfuric acid and high temperature in the prehydrolysis reactor. Liquid and solid fractions of the pretreated slurry are subsequently separated using a pneumapress. This enables treatment of the liquid fraction (hydrolyzate conditioning) to adjust to a pH that is appropriate for fermentation. Once conditioned, the hydrolyzate liquid is recombined with the solids, and the slurry is saccharified and fermented. The resulting ethanol broth is distilled and dried to recover the ethanol product.

The first product separation operation is the beer column, which separates CO_2 and water from the ethanol product. CO_2 distillate is scrubbed to minimize ethanol loss and vented. Water, including dissolved organic components, inorganic solids, and lignin, makes up the beer column bottoms. Ethanol is removed, as a side stream, for further purification, dried in a molecular sieve, and denatured. In the NREL analysis beer column bottoms are dewatered to recover lignin. Some of the water is recycled back to the pretreatment area and the rest is treated by anaerobic digestion. The rest is evaporated to yield a syrup that is combined with the lignin stream and combusted to generate steam. A detailed description of the process is given in Aden et al., 2002[4].

For the wet gasification scenarios, in this analysis, the beer column bottoms are pressurized and heated to liquefy lignin as well as any other organic components that would otherwise be solid at ambient temperatures and pressures. Inorganic solids are separated out using a hydrocyclone. The liquid stream is then run through a nickel guard bed to remove sulfur species and any solids still entrained in the process stream. The process stream is then treated over a ruthenium catalyst at 350°C and 3000 psig where it is converted to mainly methane and carbon dioxide. Heat from the process stream is used to generate low pressure steam for plant use. The wet gasification product pressure is reduced to condense treated water. Product gas is recovered as fuel gas for the boiler system. A simplified box diagram of the wet gasification area is shown in **Figure 3.** More detailed process flow diagrams are given in Appendix II.

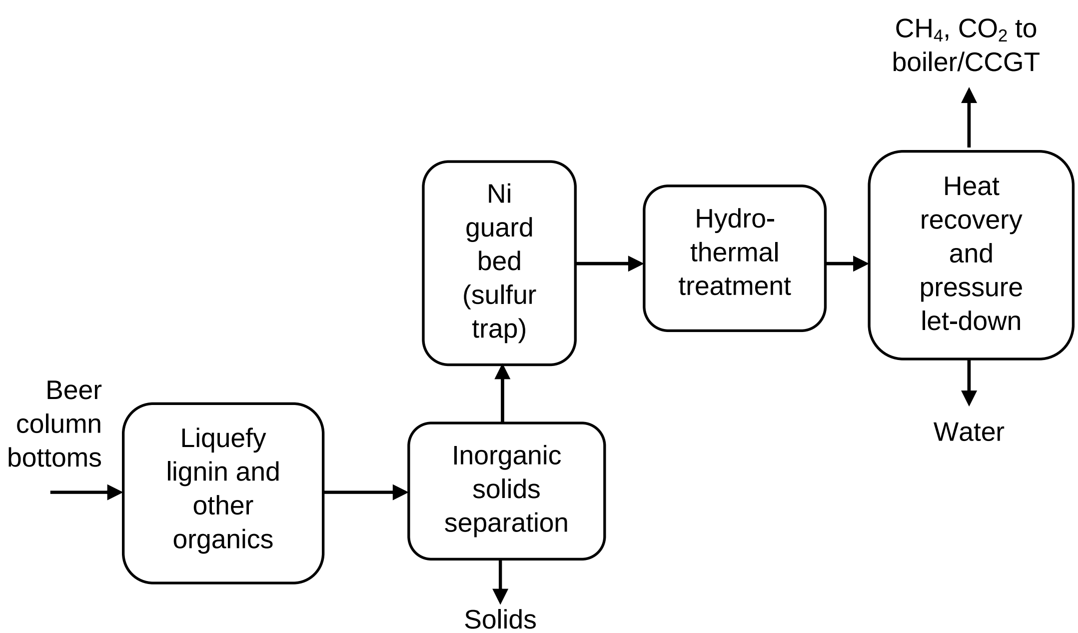

Figure 3. Simplified box diagram of the wet gasification area

Cost Estimation

The process simulations were performed in CHEMCAD 6.1, giving mass and energy balances that could be used to size equipment. Once sized, capital equipment costs were obtained from Aspen Icarus. The capital cost for the hydrocyclone was obtained from a qualified vendor[5]. The capital and operating costs were assembled in an EXCEL spreadsheet using information from the CHEMDAD simulation. A discounted cash flow method was used to estimate the product selling price.

Capital Costs

All capital costs are reported in 2000 dollars. Equipment cost escalation is calculated by using the Chemical Engineering Plant Cost Index (CEPCI). The total capital investment is factored from installed equipment costs as shown in **Table 9**. The performance model provides key operating conditions and

Table 9. Project Investment Factors

	% of TPEC
Total Purchased Equipment Cost (TPEC)	100%
Purchased Equipment Installation	39%
Instrumentation and Controls	26%
Piping	31%
Electrical Systems	10%
Buildings (including services)	29%
Yard Improvements	12%
Total Installed Cost (TIC)	247%
Indirect Costs	
Engineering	32%
Construction	34%
Legal and Contractors Fees	23%
Project Contingency	37%
Total Indirect	126%
Total Project Investment	373%

Source: Peters and Timmerhaus 2003

inlet and outlet streams flow rates for each unit operation, as well as any energy consumed or produced by the process where applicable. This information was used to size standard equipment by using CHEMCAD sizing routines or standard literature sources[6]. ASPEN Icarus was used to obtain bare

[5] Krebs Engineering, vendor contact: Ken Genung

[6] Couper JR, WR Pennery, JR Fair, and SM Walas. 2005. *Chemical Process Equipment Selection and Design.* 2nd ed. Elsevier, Amsterdam;
Perry RH, DW Green, and JO Maloney. 1984. *Perry's Chemical Engineers' Handbook*. Gulf Professional Publishing/Elsevier, Boston/Amsterdam.

equipment costs for sized equipment. The equipment costs assume that this is the "nth" plant. That is, all research and development required to commercialize the process at the given scale is complete, and the manufacturing processes are mature and the equipment readily available. The equipment costs were estimated by scaling the base equipment costs by the appropriate metric (e.g., flow, duty, etc.) and applying an appropriate scaling factor. The equipment costs were estimated by scaling the Base Case equipment costs by the appropriate metric (e.g., flow, duty, etc.) and scaling factor:

$$(\text{Cost } \$) = (\text{Base Cost } \$) * [(\text{Capacity})/(\text{Base Capacity})]^{(\text{scaling factor})} \qquad (2\text{-}1)$$

The Chemical Engineering Index is used to escalate capital costs to the year 2000.

Operating Costs

Table 10 lists the assumptions used to estimate the production costs and their associated references.

Table 10. Operating Cost Assumptions

	Values used in models (2000 basis)
Raw Materials	
Corn Stover, $/dry short ton	30.0 (3)
Clarifier Polymer, $/lb	1.25 (3)
Sulfuric Acid, ¢/lb	1.24 (3)
Hydrated Lime, ¢/lb	3.46 (3)
Corn Steep Liquor, ¢/lb	7.90 (3)
Ammonia, ¢/lb	14.94 (3)
Purchased Cellulase Enzyme, ¢/lb	5.66 (3)
Diammonium Phosphate, ¢/lb	7.02 (3)
Catalyst, $k/yr	872 (4)
Natural Gas, $/1000scf	5.32 (c)
Propane, ¢/lb	0.23 (3)
BFW Chemicals, ¢/lb	174.67 (3)
Cooling Tower Chemicals	104.68 (3)
WWT Chemicals, ¢/lb	16.20 (3)
Waste Water Polymer, ¢/lb	261.69 (3)
Utilities	
Waste water treatment, $/100 ft^3	2.40 (d)
Cooling tower makeup, ¢/1000 gal	245 (d)
Electricity, ¢/kWh	6.68 (d)
Labor	
Operating labor, $/hr burdened & 10% shift overlap	42.5 (e)
Maintenance and overhead	95% of labor & supervision (d)
Materials	
Maintenance	2% of total project investment (c)
Local taxes & insurance	2% of total project investment (c)

Sources: (3) NREL/TP-510-32438; (4) Brown MD & Elliott DC, 2006; (c) Energy Information Administration 2008; (7) Phillips et al. 2007; (e) SRI International 2007

Minimum Fuel Selling Price

The minimum fuel product selling price (MFSP) for the product ethanol was determined using a discounted cash flow rate of return analysis. This methodology is the same as that used in conceptual design cases, such as Aden et al.[4] and Phillips et al[7]. As such, the MFSP is the selling price of the fuel that makes the net present value of the process equal to zero with a 10% discounted cash flow rate of return over a 20 year plant life. **Table 11** gives the economic parameters used to calculate the MFSP.

Table 11. Economic Parameters

	Value
Stream Factor	96%
MACRS Depreciation, yrs	7
Internal Rate of Return, %	10%
Plant life, yrs	20
Construction Period	2.5 years
1st 6 months expenditure	8%
Next 12 months expenditure	60%
Last 12 months expenditure	32%
Start-up time	6 months
Revenues	50%
Variable Costs	75%
Fixed Costs	100%
Working Capital	5% of Total Capital Investment
Land	6% of Total Purchased Equipment Cost (taken as 1st year construction expense)

Source: Phillips *et al.* 2007(7)

Modeling Approach

A comprehensive description of the modeling approach for the NREL goal case is given by Aden et al. [4]. A CHEMCAD version of the NREL goal case was built and used as the Base Case. Wet gasification modifications, one with a steam boiler configuration and one with a CCGT were added to generate the comparisons. The CCGT system parameters were selected to be representative of commercially available equipment, for which reliable cost data could be found.

Key System Assumptions

Major system assumptions for the wet gasification cases are given in **Table 12**.

Table 12. Major System Assumptions for the wet gasification models

[7] Phillips, S., Aden, A., Jechura, J., Dayton, D., & Eggeman, T. (2007). *Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass NREL/TP-510-41168.* Golden, CO: National Renewable Energy Laboratory.

Hydrocyclone –Same for both wet gasification cases		
Operating pressure, psia	3025	
Operating temperature, °C(°F)	371(700)	
Flow rate, gph	952	
Solids density, s.g.	2.5	
Inlet solids content, wt%	1.3	
Wet Gasification Reactor –Same for both wet gasification cases		
Reactor outlet pressure, psia	3015	
Temperature, °C (°F)	350(662)	
Residue feed rate, metric ton/d, wet basis	10,413	
Moisture fraction, wt%	91.6	
Liquid hourly space velocity, hr^{-1}	1.5	
Guard Bed –Same for both wet gasification cases		
Outlet pressure, psia	3035	
Temperature, °C(°F)	372(702)	
Liquid hourly pace velocity, hr^{-1}	150	
Power Cycles		
Configuration	Steam Boiler	CCGT
Boiler feed water condition, °C (^{o}F)/psia	138 (281)/1265	113 (235)/870
Superheated steam condition, °C(°F)/psia	510(950)/1006	482(900)/850
Gas turbine, MWe	-	50.3
Steam cycle, MWe	21.8	8.95

Results and Analysis

Table 13 gives the main performance results for the NREL goal case (hereafter referred to as "Base Case"), taken from Aden *et al.* [4]. It also gives performance results for both of the wet gasification cases. **Table 14** gives the cost results for each of the three cases. Stream data for the wet gasification cases is given in Appendix II.

Installed equipment costs for the avoided equipment and the new equipment, required for the wet gasification cases, are shown above. All three cases assume 2000 dry mtpd corn stover inputs, delivered at $30/dry ston. All three plants produce 69.3 million gallons per year of ethanol plus export power. Therefore, identical costs for feed handling, pretreatment, fermentation, and the ethanol product separation and drying are shared by all three cases. The Base Case then incurs costs associated with recovering and drying the lignin byproduct so that it is suitable for combustion. Water still containing organics is then treated via screening, anaerobic and aerobic digestion using conventional waste water treatment. Steam and power generation costs range from $22MM for the wet gasification plus steam boiler configuration, to $61MM for the Base Case's lignin byproduct boiler configuration. Using the same underlying assumptions, MFSPs based on 10% discounted cash flow and a zero net present process value, over a 20 year plant life, are $1.08, $1.08, and $1.07 for the Base Case, Base Case plus wet gasification with steam boiler, and Base Case plus wet gasification with CCGT, respectively.

Table 13. Performance results

Case	Base Case	Steam Boiler	CCGT
Feed			
Corn stover, metric ton/d, dry basis	2000	2000	2000
Natural gas, scf/hr	-	-	57,331
Propane, kg/hr	20	-	-
Products			
Ethanol, mmgal/y	69.3	69.3	69.3
Power Consumption, MW			
Ethanol production/separation	11.9	14.5	14.5
Air/SNG compression		-	32.5
Air blower		0.45	-
Steam turbine auxiliaries		0.49	2.7
Power Generation, MW			
Gas turbines		-	66.7
Steam turbines	30	22.2	6.9
Net Power, MW	**18.7**	**6.7**	**23.9**
Water Demand, gpm			
Cooling tower makeup		144	144
Total water demand	**822**	**260**	**363**
Wastewater, gpm		423	423

Table 14. Cost results

Total Project Investment (millions USD$ 2000)

	Base Case	Wet Gasification w/steam boiler	Wet Gasification w/CCGT
Feed Handling, Pretreatment & Fermentation	$69	$69	$69
Distillation and Ethanol Drying	$12	$12	$12
Wet Gasification	**$0**	**$52**	**$52**
Evaporation and Lignin Recovery	**$23**	**$0**	**$0**
Wastewater Treatment	**$5**	**$0**	**$0**
Steam Generation & Power	**$61**	**$22**	**$47**
Balance of Plant	$11	$11	$11
Total Capital Investment	$180	$167	$190
startup, permits, etc	$18	$17	$19
Total Project Investment	$198	$184	$210
MFSP, $ (2000)	**$1.08**	**$1.08**	**$1.07**

There is some uncertainty associated with the costs obtained for the wet gasification case due to the large scale (and high pressures) of the theoretical plants. Therefore, preliminary investigation into possible sensitivities, for the wet gasification cases, includes under and over-estimates of total project investments of 10 and 40 percent, respectively. Ruthenium costs are known to vary widely. Sensitivity to metal price fluctuations would appear in the operating costs and was explored by setting the catalyst life to 0.5 and 5 years. Sensitivities to feedstock prices were evaluated for all three cases by setting feedstock costs to $50/dry ton and $80/dry ton. Per gallon cost differences between the Base Case and the wet gasification cases and the wet gasification cases (in general) with some of their potential sensitivities are shown in Figure 3. Future sensitivity studies of the wet gasification configurations should include exploration into possible operating/design pressures, as equipment costs clearly drive much of the economics. Interestingly, the economics show little sensitivity to varying catalyst costs.

Overall, the wet gasification cases appear to be competitive with the Base Case. Interestingly, the more expensive power configurations, such as in the Base Case or the CCGT yield comparable MFSPs. This is due to the greater power export capability of the Base Case and the wet gasification with CCGT case. The main factor driving the reduced power export capability of the wet gasification cases is that only a portion of the offgas from the wet gasification process is sent to power generation. The rest is used as fuel in the wet gasification feed trim pre-heater. This is offset in the wet gasification with CCGT case by importing natural gas. It is recommended that future modeling (and research) efforts focus on optimizing fuel gas requirements and steam/power generation. Experimental data could support further model development, as well, by providing information for stream component definitions and heating/conversion of those components.

Further research on CCGT technology is also recommended. This analysis used data from Craig and Mann[8] study of smaller turbines that would be associated with biomass integrated gasification combined cycle (BIGCC). The cycle used in the wet gasification analysis is at the upper end of the capability of the smallest turbine presented in the Craig and Mann study. Therefore an additional sensitivity is presented in **Figure 4** showing the impact of capital for a gas turbine rated for 122 MW_e.

Figure 4 shows preliminary sensitivities, evaluated as the change in MFSP from the Base Case.

[8] Craig, K. R., & Mann, M. K. (1996). *Cost and Performance Analysis of Biomass-Based Integrated Gasification Combined-Cycle (BIGCC) Power Systems NREL/TP-430-21657* . Golden, CO: National Renewable Energy Laboratory.

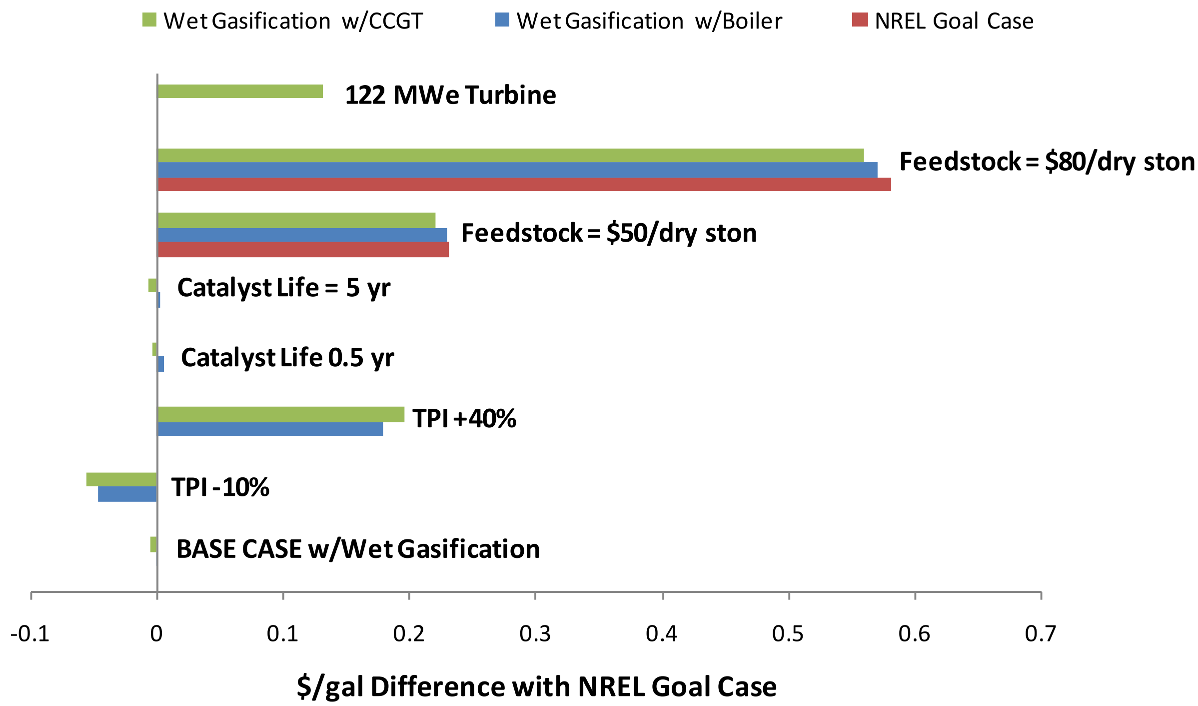

Figure 4. MFSP comparisons for wet gasification cases and potential sensitivities

Conclusions and Recommendations

Conclusions

Initial tests in catalytic hydrothermal gasification have been performed in a continuous-flow reactor at PNNL. The system required feedstock slurry preparation for pumpable materials in high-pressure feeding systems. Representative feedstocks were provided by several commercial interests were processed. The bench-scale tests provided product gas and byproduct materials in sufficient quantity for subsequent analysis and mass and elemental balance. Initial optimization of processing conditions such as temperature, slurry concentration, and residence time was also attempted. A ruthenium on carbon catalyst proved satisfactory for processing all feedstocks.

The lignin-rich feedstocks showed varying levels of processing difficulties related primarily to the physical properties of the lignin (melting and viscosity of liquid intermediates) and also to the apparent slower rate of conversion. Plugging in the feed lines and in the transfer lines was a common problem. The mineral separation step functioned well in most cases with only a small loss of carbon. High conversion of the lignin materials to gas resulted in low contamination levels in the byproduct water. The gas product showed the expected methane and carbon dioxide content (with higher levels of methane) and only low amounts of hydrogen coproducts with minimal amounts of carbon monoxide or hydrocarbon gas products.

The algae feedstocks were much more reliably processed. High conversions were obtained even with high slurry concentrations. Consistent catalyst operation in these short-term tests suggested good stability and minimal poisoning effects. High methane content in the product gas was noted with significant carbon dioxide captured in the aqueous byproduct in combination with alkali constituents and the ammonia byproduct derived from proteins in the algae. High conversion of algae to gas products was found with low levels of byproduct water contamination and minimal loss of carbon in the mineral separation step.

Overall, the wet gasification cases appeared to be competitive with the Base Case. Interestingly, the more expensive power configurations, such as in the Base Case or the Combined Cycle Gas Turbine (CCGT), yielded comparable MFSPs. This was due to the greater power export capability of the Base Case and the wet gasification with CCGT case. The main factor driving the reduced power export capability of the wet gasification cases was that only a portion of the offgas from the wet gasification process was sent to power generation. A certain amount was used as fuel in the wet gasification feed trim pre-heater.

Recommendations

Continued process development will be required with both feedstock types. The process economic advantages have suggested value in processing the lignocellulosic ethanol residues by catalytic hydrothermal gasification. Modification of the PNNL bench-scale reactor system will be required to process residues with high levels of lignin content.

Further development of algae-based technology is also recommended in light of the positive processing results obtained in these limited tests. Longer term operation is needed to demonstrate catalyst lifetime. Larger scale operations are also needed to facilitate design of larger commercial processing units.

A technoeconomic assessment of the application of catalytic hydrothermal gasification to algae feedstocks is needed to determine the value for such an application. Process variations related to integration into the algae growing systems should be modeled. Costs for utilization of the gas product either for direct heat and power production or for introduction into the natural gas pipeline grid following separations and cleanup needs to be modeled and evaluated.

Further developmental studies should be undertaken to provide data for evaluation in the technoeconomic models for the integration of hydrothermal gasification into algae growth systems as well as gas separation and clean up for use as synthetic natural gas.

It is recommended that future modeling (and research) efforts focus on optimizing fuel gas requirements and steam/power generation. Experimental data could support further model development, as well, by providing information for stream component definitions and heating/conversion of those components.

Further research on CCGT technology is also recommended. This analysis used data from a study of smaller turbines that would be associated with biomass integrated gasification combined cycle (BIGCC). The cycle used in the wet gasification analysis was at the upper end of the capability of the smallest turbine presented in the study.

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APPENDIX I

Catalytic Hydrothermal Gasification Experimental Data Sheets

GAS CALCULATIONS			22-Apr-09	Run No.	Lignin 1	Time	12:40-14:40	
		Feed	NREL SSF residue			Pressure	2940	psig
		Pump	ISCO				340	carberry
		Carberry	empty					
		Scrubber	Raney Ni				335	filter
		Catalyst	C3610				331	bottom
							352	middle
							350	top
GAS VOLUME, L/hr			86.00		Temp, C	23		
	, L/hr	at 0 C	79.32		ft3/hr	at 60 F	2.6516	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H2	1.63%	0.0164	1.2929	0.0577		
Carbon Dioxide		CO2	43.90%	0.4425	34.8204	1.5545		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N2+O2	0.80%	0.0000	0.6345	0.0283		
Methane		CH4	53.00%	0.5343	42.0383	1.8767		
Ethylene		C2H4	0.00%	0.0000	0.0000	0.0000		
Ethane		C2H6	0.00%	0.0000	0.0000	0.0000		
Propane	(not from	C3H8	0.00%	0.0000	0.0000	0.0000		
Butane	backflush)	C4H8	0.00%	0.0000	0.0000	0.0000		
Pentane		C5H12	0.00%	0.0000	0.0000	0.0000		
benzene	(backflush)	C6H6	0.00%	0.0000	0.0000	0.0000		
Total			99.33%	0.9932	78.7861	3.5172		
Mole Wt			28.083816	28.084492		Gas Wt,g/hr	98.78	
HHV	Btu/ft3 at 60 F		542	547		Gas Yield		
	KJ/m3 at 0 C		21.36	21.53		9.44	scf/lb solids	
						0.59	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
3.4312	41.21	7.622277	7.70	3.1089654	49.74	0.0567	0.79	
EFFLUENT ANALYSIS			alkali	521	ppm	(17.7 ppm-mole K&Na)		
			NH3,	766	ppm	mole/hr K&Na	0.02	
	Vol, L/hr,	1.212	COD	140		mole/hr NH3	0.05	
			factor	1.15		C in bicarb,g	0.91	
			grams	0.15				
			C, wt%(COD)		43.43	C, wt%(direct)	0	
			C, gr (by COD)		0.06	C, gr (direct)		
			N, gr (by NH3)		0.76			
			ash, g (soluble Na & K)		0.63			

SOLIDS ANALYSIS (from filter blowdown)								
			ash, wt%	65.4	ash, grams	18.57		
	weight, g/hr	28.4	C, wt%	25.71	C, grams	7.30		
FEEDSTOCK ANALYSIS								
	COD	100,933	factor	1.15		feed(by COD)	131.65	g/hr
	wt, g/hr	1500	conc, wt%	8.84		feed(direct)	132.60	g/hr
						water	1367.40	g/hr
	Elemental Analysis		46.57%	C	43.4%			
	(Hazen data)		4.79%	H	5.0%			
			28.79%	O	30.7%			
			1.40%	N	1.4%			
			0.17%	S	0.2%			
			18.28%	ash	18.4%	ash, grams	24.45144	
					99.1%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	57.18		- - -					
direct	57.59		1.83651					
ASH BALANCE				78.54%				
MATERIAL BALANCE				89.28%				
CARBON BALANCE			by COD	86.55%	(incl C in bicarb)			
			by direct	85.82%	(incl C in bicarb)			
NITROGEN BALANCE				84.75%	(nitrogen + ammonia)			
CARBON CONVERSION TO GAS, %				71.56%		gas adj for bicarb	73.14%	
COD CONVERSION, %				99.89%				
CARBON CONVERSION TO SOLIDS, %				12.68%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.88	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.75	g/g/hr			at temperature	400	grams
	Residence	16	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

GAS CALCULATIONS			22-Apr-09	Run No.	Lignin 1	Time	15:10-17:05	
		Feed	NREL SSF residue			Pressure	2940	psig
		Pump	ISCO				340	carberry
		Carberry	empty					
		Scrubber	Raney Ni				335	filter
		Catalyst	C3610				331	bottom
							352	middle
							348	top
GAS VOLUME, L/hr			89.70		Temp, C	24		
	, L/hr	at 0 C	82.45		ft3/hr	at 60 F	2.7564	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H_2	1.85%	0.0210	1.5254	0.0681		
Carbon Dioxide		CO_2	40.50%	0.4602	33.3929	1.4908		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N_2+O_2	12.00%	0.0000	9.8942	0.4417		
Methane		CH_4	44.80%	0.5091	36.9383	1.6490		
Ethylene		C_2H_4	0.00%	0.0000	0.0000	0.0000		
Ethane		C_2H_6	0.80%	0.0091	0.6596	0.0294		
Propane	(not from	C_3H_8	0.00%	0.0000	0.0000	0.0000		
Butane	backflush)	C_4H_8	0.00%	0.0000	0.0000	0.0000		
Pentane		C_5H_{12}	0.00%	0.0000	0.0000	0.0000		
benzene	(backflush)	C_6H_6	0.00%	0.0000	0.0000	0.0000		
Total			99.95%	0.9994	82.4103	3.6790		
Mole Wt			28.65246	28.741432		Gas Wt,g/hr	105.41	
HHV	Btu/ft3 at 60 F		474	539		Gas Yield		
	KJ/m3 at 0 C		18.68	21.23		8.79	scf/lb solids	
						0.55	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
3.1987	38.42	6.908995	6.98	2.9815057	47.70	0.8834	12.37	
EFFLUENT ANALYSIS			alkali	429	ppm	(15.25 ppm-mole K&Na)		
			NH_3,	766	ppm	mole/hr K&Na	0.02	
	Vol, L/hr,	1.424	COD	154		mole/hr NH_3	0.06	
			factor	1.15		C in bicarb,g	1.03	
			grams	0.19				
			C, wt%(COD)		43.43	C, wt%(direct)	0	
			C, gr (by COD)		0.08	C, gr (direct)		
			N, gr (by NH_3)		0.90			
			ash, g (soluble Na & K)		0.61			

SOLIDS ANALYSIS (from filter blowdown)								
			ash, wt%	70.6	ash, grams	18.21		
	weight, g/hr	25.8	C, wt%	25.955	C, grams	6.70		
FEEDSTOCK ANALYSIS								
	COD	100,933	factor	1.15		feed(by COD)	131.21	g/hr
	wt, g/hr	1495	conc, wt%	8.84		feed(direct)	132.16	g/hr
						water	1362.84	g/hr
	Elemental Analysis		46.57%	C	43.4%			
	(Hazen data)		4.79%	H	5.0%			
			28.79%	O	30.7%			
			1.40%	N	1.4%			
			0.17%	S	0.2%			
			18.28%	ash	18.4%	ash, grams	24.3699352	
					99.1%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	56.99		- - -					
direct	57.40		1.8303883					
ASH BALANCE				77.25%				
MATERIAL BALANCE				104.03%				
CARBON BALANCE			by COD	81.12%	(incl C in bicarb)			
			by direct	80.39%	(incl C in bicarb)			
NITROGEN BALANCE				724.69%	(nitrogen + ammonia)			
CARBON CONVERSION TO GAS, %				66.93%		gas adj for bicarb	68.73%	
COD CONVERSION, %				99.85%				
CARBON CONVERSION TO SOLIDS, %				11.67%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.87	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.74	g/g/hr			at temperature	400	grams
	Residence	16	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

GAS CALCULATIONS			17-Jun-09	Run No.	KL Lignin 1	Time	10:45-12:15	
		Feed	KL Energy lignin			Pressure	2855	psig
		Pump	ISCO				348	carberry
		Carberry	empty				332	filter
		Scrubber	Raney Ni				352	S stripper
		Catalyst	C3610				324	bottom
							349	middle
							349	top
GAS VOLUME, L/hr			60.00		Temp, C	21		
	, L/hr	at 0 C	55.71		ft3/hr	at 60 F	1.8625	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H2	0.90%	0.0090	0.5014	0.0224		
Carbon Dioxide		CO2	47.00%	0.4726	26.1857	1.1690		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N2+O2	0.54%	0.0000	0.0000	0.0000	changed to N2-free basis	
Methane		CH4	51.20%	0.5148	28.5257	1.2735		
Ethylene		C2H4	0.00%	0.0000	0.0000	0.0000		
Ethane		C2H6	0.00%	0.0000	0.0000	0.0000		
Propane		C3H8	0.00%	0.0000	0.0000	0.0000		
Butane		C4H8	0.00%	0.0000	0.0000	0.0000		
Pentane		C5H12	0.00%	0.0000	0.0000	0.0000		
benzene		C6H6	0.00%	0.0000	0.0000	0.0000		
Total			99.64%	0.9964	55.2129	2.4649		
Mole Wt			29.07168	29.077498		Gas Wt,g/hr	71.66	
HHV	Btu/ft3 at 60 F		522	524		Gas Yield		
	KJ/m3 at 0 C		20.55	20.66		8.49	scf/lb solids	
						0.53	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
2.4425	29.33	5.138648	5.19	2.3380102	37.41	0.0000	0.00	

Elliott:
heavy tar plug in transfer line upstream from scrubber after overpressure stopped run

Elliott:
gas yield was still climbing when pump shut off. This number is likely low as not yet at steady state.

EFFLUENT ANALYSIS			alkali , est	1500	ppm	(36 ppm-mole K&Na est.)		
			NH3, est	310	ppm	mole/hr K&Na	0.04	
	Vol, L/hr,	1.213	COD	530		mole/hr NH3	0.02	
			factor	1.85		C in bicarb,g	0.79	
			grams	0.35				
			C, wt%(COD)		50.2	C, wt%(direct)	0	
			C, gr (by COD)		0.17	C, gr (direct)		
			N, gr (by NH3)		0.31			
			ash, g (soluble Na & K)		1.82			
SOLIDS ANALYSIS (from filter blowdown)								
			ash, wt%	70.6	ash, grams	0.00		
	weight, g/hr	0	C, wt%	25.955	C, grams	0.00		
FEEDSTOCK ANALYSIS								
	COD	161,333	factor	1.85		feed(by COD)	104.39	g/hr
	wt, g/hr	1197	conc, wt%	8.7		feed(direct)	104.14	g/hr
						water	1092.86	g/hr
	Elemental Analysis			C	50.2%			
	based on second			H	5.5%			
	KL Energy lignin			O	41.5%			
				N	0.3%			
				S	0.0%			
				ash	1.9%	ash, grams	1.978641	
					99.4%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	52.40		- - -					
direct	52.28		0.312417					
ASH BALANCE				91.96%				
MATERIAL BALANCE				107.32%				
CARBON BALANCE			by COD	57.82%	(incl C in bicarb)			
			by direct	57.62%	(incl C in bicarb)			
NITROGEN BALANCE				98.96%	(nitrogen + ammonia)			
CARBON CONVERSION TO GAS, %				56.11%		gas adj for bicarb	57.62%	
COD CONVERSION, %				99.67%				
CARBON CONVERSION TO SOLIDS, %				0.00%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.50	l/l/hr			reactor volume	0.8	liters
	WHSV=	2.99	g/g/hr			at temperature	400	grams
	Residence	20	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

Elliott:
red font indicates estimated data

Elliott:
no blowdown during short run

GAS CALCULATIONS			12-Aug-09	Run No.	KL Lignin 2	Time	08:30-14:30	
		Feed	KL Energy lignin			Pressure	2945	psig
		Pump	ISCO				342	carberry
		Carberry	empty				327	filter
		Scrubber	Raney Ni				348	S stripper
		Catalyst	C3610				327	bottom
							355	middle
							351	top
GAS VOLUME, L/hr			62.25		Temp, C	23		
	, L/hr	at 0 C	57.41		ft3/hr	at 60 F	1.9193	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H2	1.60%	0.0161	0.9186	0.0410		
Carbon Dioxide		CO2	46.50%	0.4669	26.6970	1.1918		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N2+O2	0.40%	0.0000	0.0000	0.0000	changed to N2-free basis	
Methane		CH4	51.50%	0.5171	29.5677	1.3200		
Ethylene		C2H4	0.00%	0.0000	0.0000	0.0000		
Ethane		C2H6	0.00%	0.0000	0.0000	0.0000		
Propane		C3H8	0.00%	0.0000	0.0000	0.0000		
Butane		C4H8	0.00%	0.0000	0.0000	0.0000		
Pentane		C5H12	0.00%	0.0000	0.0000	0.0000		
benzene		C6H6	0.00%	0.0000	0.0000	0.0000		
Total			100.00%	1.0000	57.1834	2.5528		
Mole Wt			28.87472	28.878233		Gas Wt,g/hr	73.71	
HHV	Btu/ft3 at 60 F		527	529		Gas Yield		
	KJ/m3 at 0 C		20.76	20.84		9.32	scf/lb solids	
						0.58	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
2.5118	30.17	5.361965	5.42	2.383665	38.14	0.0000	0.00	

EFFLUENT ANALYSIS			alkali , est	1500	ppm	(36 ppm-mole K&Na est.)		
			NH_3, est	220	ppm	mole/hr K&Na	0.05	
	Vol, L/hr,	1.476	COD	0		mole/hr NH_3	0.02	
			factor	1.85		C in bicarb,g	0.87	
			grams	0.00				
			C, wt%(COD)		50.225	C, wt%(direct)	0	
			C, gr (by COD)		0.00	C, gr (direct)		
			N, gr (by NH_3)		0.27			
			ash, g (soluble Na & K)		2.21		**Elliott:** red font indicates estimated data	
SOLIDS ANALYSIS (from filter blowdown)								
			ash, wt%	81.3625	ash, grams	6.40		
	dry weight, g/hr	7.86	C, wt%	16.755	C, grams	1.32		
FEEDSTOCK ANALYSIS								
	COD, est	121,500	factor	1.85		feed(by COD)	98.51	g/hr
	wt, g/hr	1500	conc, wt%	6.55		feed(direct)	98.25	g/hr
						water	1401.75	g/hr
	Elemental Analysis			C	50.2%			
				H	5.5%			
				O	41.5%			
				N	0.3%			
				S	0.0%			
				ash	2.6%	ash, grams	2.51431575	
					100.1%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	49.48		- - -					
direct	49.35		0.265275					
ASH BALANCE				342.40%				
MATERIAL BALANCE				103.84%				
CARBON BALANCE			by COD	65.38%	(incl C in bicarb)			
			by direct	65.56%	(incl C in bicarb)			
NITROGEN BALANCE				100.64%	(nitrogen + ammonia)			
CARBON CONVERSION TO GAS, %				61.13%		gas adj for bicarb	62.89%	
COD CONVERSION, %				100.00%				
CARBON CONVERSION TO SOLIDS, %				2.67%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.88	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.75	g/g/hr			at temperature	400	grams
	Residence	16	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

GAS CALCULATIONS			12-Aug-09	Run No.	KL Lignin 2	Time	14:30-18:50	
		Feed	KL Energy lignin			Pressure	2980	psig
		Pump	ISCO				339	carberry
		Carberry	empty				327	filter
		Scrubber	Raney Ni				345	S stripper
		Catalyst	C3610				324	bottom
							353	middle
							350	top
GAS VOLUME, L/hr			60.00		Temp, C	24		
	, L/hr	at 0 C	55.15		ft3/hr	at 60 F	1.8437	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H2	1.50%	0.0152	0.8273	0.0369		
Carbon Dioxide		CO2	53.00%	0.5381	29.2303	1.3049		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N2+O2	1.50%	0.0000	0.0000	0.0000	changed to N2-free basis	
Methane		CH4	43.00%	0.4365	23.7152	1.0587		
Ethylene		C2H4	0.00%	0.0000	0.0000	0.0000		
Ethane		C2H6	1.00%	0.0102	0.5515	0.0246		
Propane		C3H8	0.00%	0.0000	0.0000	0.0000		
Butane		C4H8	0.00%	0.0000	0.0000	0.0000		
Pentane		C5H12	0.00%	0.0000	0.0000	0.0000		
benzene		C6H6	0.00%	0.0000	0.0000	0.0000		
Total			100.00%	1.0000	54.3242	2.4252		
Mole Wt			30.9779	31.023249		Gas Wt,g/hr	75.13	
HHV	Btu/ft3 at 60 F		458	465		Gas Yield		
	KJ/m3 at 0 C		18.06	18.34		8.83	scf/lb solids	
						0.55	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
2.4129	28.98	4.456439	4.50	2.6098485	41.76	0.0000	0.00	

EFFLUENT ANALYSIS			alkali , est	1500	ppm	(36 ppm-mole K&Na est.)		
			NH3, est	250	ppm	mole/hr K&Na	0.05	
	Vol, L/hr,	1.3147	COD	19875		mole/hr NH3	0.02	
			factor	1.85		C in bicarb,g	0.80	
			grams	14.12				
			C, wt%(COD)		50.225	C, wt%(direct)	0	
			C, gr (by COD)		7.09	C, gr (direct)		
			N, gr (by NH3)		0.27			
			ash, g (soluble Na & K)		1.97			
SOLIDS ANALYSIS (from filter blowdown)								
			ash, wt%	84.2119	ash, grams	10.53		
	dry weight, g/hr	12.5	C, wt%	12.195	C, grams	1.52		
FEEDSTOCK ANALYSIS								
	COD, est	121,500	factor	1.85		feed(by COD)	98.84	g/hr
	wt, g/hr	1505	conc, wt%	6.55		feed(direct)	98.58	g/hr
						water	1406.42	g/hr
	Elemental Analysis			C	50.2%			
				H	5.5%			
				O	41.5%			
				N	0.3%			
				S	0.0%			
				ash	2.6%	ash, grams	2.5226968	
					100.1%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	49.64		- - -					
direct	49.51		0.26615925					
ASH BALANCE				495.44%				
MATERIAL BALANCE				93.18%				
CARBON BALANCE			by COD	77.35%	(incl C in bicarb)			
			by direct	63.23%	(incl C in bicarb)			
NITROGEN BALANCE				101.53%	(nitrogen + ammonia)			
CARBON CONVERSION TO GAS, %				58.53%		gas adj for bicarb	60.15%	
COD CONVERSION, %				85.71%				
CARBON CONVERSION TO SOLIDS, %				3.08%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.88	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.76	g/g/hr			at temperature	400	grams
	Residence	16	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

Elliott:
red font indicates
estimated data

GAS CALCULATIONS			11-Nov	Run No.	Algae 1	Time	11:00-12:15	
		Feed	Genifuel mixed wild algae			Pressure	3018 +/-118	psig
		Pump	ISCO				339	carberry
		Catalyst	C3610/Raney scrub				338	filter
							352	S scrub
							333	bottom
							349	middle
							351	top
GAS VOLUME, L/hr			36.80		Temp, C	21		
	, L/hr	at 0 C	34.17		ft3/hr	at 60 F	1.1424	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H2	0.92%	0.0092	0.3137	0.0140		
Carbon Dioxide		CO2	36.40%	0.3653	12.4379	0.5553		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N2+O2	0.37%	0.0000	0.1264	0.0056		
Methane		CH4	62.31%	0.6254	21.2917	0.9505		
Ethylene		C2H4	0.00%	0.0000	0.0000	0.0000		
Ethane		C2H6	0.00%	0.0000	0.0000	0.0000		
Propane	(no	C3H8		0.0000	0.0000	0.0000		
Butane	backflush)	C4H8		0.0000	0.0000	0.0000		
Pentane	(no	C5H12		0.0000	0.0000	0.0000		
benzene	backflush)	C6H6		0.0000	0.0000	0.0000		
Total			100.00%	0.9999	34.1697	1.5254		
Mole Wt			26.1416377	26.1347		Gas Wt,g/hr	39.88	
HHV	Btu/ft3 at 60 F		634	637		Gas Yield		
	KJ/m3 at 0 C		24.99	25.08		1.55	scf/lb solids	
						0.10	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
1.5058	18.08	3.8301	3.87	1.11053	17.77	0.0113	0.16	
EFFLUENT ANALYSIS			alkali	1900	ppm	(92.6 ppm-mole K&Na)		
			NH3,	19400	ppm	mole/hr K&Na	0.12	pH
	Vol, L/hr,	1.25	COD	1060		mole/hr NH3	1.42	7.39-7.60
			factor	1		C in bicarb,g	18.48	
			grams	1.33				
			C, wt%(COD)		27.1	C, wt%(direct)	0	
			C, gr (by COD)		0.36	C, gr (direct)		
			N, gr (by NH3)		19.94			
			ash, g (soluble Na & K)		2.38			

SOLIDS ANALYSIS (DS from filter blowdown, not washed)								
			ash, wt%	72.74	ash, g/hr	163.23		
	weight, g/hr	224.4	C, wt%	13.515	C, g/hr	30.33		
			N, wt%	0.475	N, g/hr	1.07		
FEEDSTOCK ANALYSIS								
	COD	120,000	factor	0.51		feed(by COD)	352.94	g/hr
	wt, g/hr	1500	conc, wt%	23.5		feed(direct)	352.50	g/hr
						water	1147.50	g/hr
	Elemental Analysis			C	27.1%			
				H	3.7%			
				O	15.2%			
				N	6.0%	N, g/hr	21.15	
				S	0.9%			
				ash	60.1%	ash, g/hr	211.7115	
					113.0%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	95.65		- - -					
direct	95.53		21.15					
ASH BALANCE				78.22%				
MATERIAL BALANCE				100.95%				
CARBON BALANCE			by COD	70.31%	(incl C in bicarb)			
			by direct	70.03%	(incl C in bicarb)			
NITROGEN BALANCE				100.06%	(nitrogen + ammonia + N in solids)			
CARBON CONVERSION TO GAS, %				18.93%		gas adj for bicarb	38.28%	
COD CONVERSION, %				99.26%				
CARBON CONVERSION TO SOLIDS, %				31.75%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.88	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.75	g/g/hr			at temperature	400	grams
	Residence	16	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

GAS CALCULATIONS			12-Nov	Run No.	Algae 2	Time	10:14-15:04	
		Feed	India algae from BC			Pressure	2970+/-42	psig
		Pump	ISCO				334	carberry
		Catalyst	C3610/Raney scrub				334	filter
							355	S scrub
							334	bottom
							354	middle
			wt avg gas yield				351	top
GAS VOLUME, L/hr			205.00		Temp, C	21		
	, L/hr	at 0 C	190.36		ft3/hr	at 60 F	6.3637	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H_2	3.32%	0.0334	6.3199	0.2821		
Carbon Dioxide		CO_2	41.72%	0.4203	79.4170	3.5454		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N_2+O_2	0.74%	0.0000	1.3991	0.0625		
Methane		CH_4	51.69%	0.5207	98.3956	4.3927		
Ethylene		C_2H_4	0.00%	0.0000	0.0000	0.0000		
Ethane		C_2H_6	2.53%	0.0255	4.8160	0.2150		
Propane	(no	C_3H_8		0.0000	0.0000	0.0000		
Butane	backflush)	C_4H_8		0.0000	0.0000	0.0000		
Pentane	(no	C_5H_{12}		0.0000	0.0000	0.0000		
benzene	backflush)	C_6H_6		0.0000	0.0000	0.0000		
Total			100.00%	0.9999	190.3476	8.4977		
Mole Wt			27.691105	27.6888		Gas Wt,g/hr	235.31	
HHV	Btu/ft3 at 60 F		580	584		Gas Yield		
	KJ/m3 at 0 C		22.84	23.01		9.81	scf/lb solids	
						0.61	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
8.3681	100.50	19.4249	19.62	7.0908	113.45	0.1249	1.75	
EFFLUENT ANALYSIS			alkali, est.	10000	ppm	(92.6 ppm-mole K&Na, est.)		
			NH_3, est.	30000	ppm	mole/hr K&Na	0.11	pH
	Vol, L/hr, est.	1.17	COD	10830		mole/hr NH_3	2.06	8.15-8.52
			factor	1.2		C in bicarb,g	26.04	
			grams	10.56				
			C, wt%(COD)		45.7	C, wt%(direct)	0	
			C, gr (by COD)		4.83	C, gr (direct)		
			N, gr (by NH_3)		28.86			
			ash, g (soluble Na & K)		11.70			

SOLIDS ANALYSIS (DS from filter blowdown, not washed)								
			ash, wt%	41.25	ash, g/hr	8.75		
	weight, g/hr	21.2	C, wt%	34.56	C, g/hr	7.33		
			N, wt%	3.5	N, g/hr	0.74		
SOLIDS ANALYSIS (DS from CSTR cleanout, not washed)								
			ash, wt%	88.83	ash, g/hr	4.78		
	weight, g/hr	5.38	C, wt%	6.035	C, g/hr	1.28		
			N, wt%	0.495	N, g/hr	0.10		
FEEDSTOCK ANALYSIS								
	COD	260,367	factor	1.2		feed(by COD)	309.84	g/hr
	wt, g/hr	1428	conc, wt%	21.6		feed(direct)	308.45	g/hr
	wt avg feed rate					water	1119.55	g/hr
	Elemental Analysis, normalized			C	45.7%			
				H	6.3%			
				O	26.7%			
				N	10.2%	N, g/hr	31.461696	
				S	0.8%			
				ash	10.3%	ash, g/hr	31.770144	
					100.0%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	141.60		- - -					
direct	140.96		31.461696					
ASH BALANCE				64.35%				
MATERIAL BALANCE				100.27%				
CARBON BALANCE			by COD	98.85%	(incl C in bicarb)			
			by direct	95.88%	(incl C in bicarb)			
NITROGEN BALANCE				99.98%	(nitrogen + ammonia + N in solids)			
CARBON CONVERSION TO GAS, %				71.30%		gas adj for bicarb	89.77%	
COD CONVERSION, %				96.59%				
CARBON CONVERSION TO SOLIDS, %				6.11%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.79	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.57	g/g/hr			at temperature	400	grams
	Residence	17	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

GAS CALCULATIONS			19-Nov	Run No.	Algae 3	Time	10:00-15:00	
		Feed	India algae from BC			Pressure	2934+/-30	psig
		Pump	ISCO				335	carberry
		Catalyst	C3610/Raney scrub				330	filter
							347	S scrub
							324	bottom
							351	middle
							348	top
GAS VOLUME, L/hr			218.00		Temp, C	21		
	, L/hr	at 0 C	202.43		ft3/hr	at 60 F	6.7672	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H_2	1.98%	0.0200	4.0081	0.1789		
Carbon Dioxide		CO_2	43.20%	0.4354	87.4491	3.9040		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N_2+O_2	0.77%	0.0000	1.5587	0.0696		
Methane		CH_4	52.60%	0.5301	106.4774	4.7535		
Ethylene		C_2H_4	0.00%	0.0000	0.0000	0.0000		
Ethane		C_2H_6	1.44%	0.0145	2.9150	0.1301		
Propane	(no	C_3H_8		0.0000	0.0000	0.0000		
Butane	backflush)	C_4H_8		0.0000	0.0000	0.0000		
Pentane	(no	C_5H_{12}		0.0000	0.0000	0.0000		
benzene	backflush)	C_6H_6		0.0000	0.0000	0.0000		
Total			99.99%	0.9999	202.4083	9.0361		
Mole Wt			28.143368	28.1445		Gas Wt,g/hr	254.31	
HHV	Btu/ft3 at 60 F		565	569		Gas Yield		
	KJ/m3 at 0 C		22.26	22.44		11.05	scf/lb solids	
						0.69	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
8.9177	107.10	20.1525	20.35	7.80796	124.93	0.1392	1.95	
EFFLUENT ANALYSIS			alkali, est.	10000	ppm	(92.6 ppm-mole K&Na, est.)		
			NH_3	15143	ppm	mole/hr K&Na	0.10	pH
Vol, L/hr, est.		1.062	COD	870		mole/hr NH_3	0.94	8.15-8.52
			factor	1.2		C in bicarb,g	12.52	
			grams	0.77				
			C, wt%(COD)		47.165	C, wt%(direct)	0	
			C, gr (by COD)		0.36	C, gr (direct)		
			N, gr (by NH_3)		13.22			
			ash, g (soluble Na & K)		10.62			

SOLIDS ANALYSIS (DS from filter blowdown, not washed)								
			ash, wt%	44.48	ash, g/hr	1.20		
	weight, g/hr	2.7	C, wt%	36.105	C, g/hr	0.97		
			N, wt%	3.73	N, g/hr	0.10		
SOLIDS ANALYSIS (DS from CSTR cleanout, not washed)								
			ash, wt%	88.83	ash, g/hr	0.00		
	weight, g/hr	0	C, wt%	6.035	C, g/hr	0.00		
			N, wt%	0.495	N, g/hr	0.00		
FEEDSTOCK ANALYSIS								
	COD	241,267	factor	1.2		feed(by COD)	261.37	g/hr
	wt, g/hr	1300	conc, wt%	22.4		feed(direct)	291.20	g/hr
						water	1008.80	g/hr
	Elemental Analysis, normalized			C	47.2%			
				H	6.6%			
				O	27.4%			
				N	10.5%	N, g/hr	30.576	
				S	0.9%			
				ash	8.3%	ash, g/hr	24.25696	
					100.9%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	123.28		- - -					
direct	137.34		30.576					
ASH BALANCE				48.73%				
MATERIAL BALANCE				101.46%				
CARBON BALANCE			by COD	98.12%	(incl C in bicarb)			
			by direct	87.80%	(incl C in bicarb)			
NITROGEN BALANCE				49.95%	(nitrogen + ammonia + N in BD solids)			
CARBON CONVERSION TO GAS, %				77.98%		gas adj for bicarb	87.09%	
COD CONVERSION, %				99.71%				
CARBON CONVERSION TO SOLIDS, %				0.71%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.63	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.25	g/g/hr			at temperature	400	grams
	Residence	18	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

GAS CALCULATIONS			19-Nov	Run No.	Algae 3	Time	15:50-17:50	
		Feed	India algae from BC			Pressure	2984+/-50	psig
		Pump	ISCO				340	carberry
		Catalyst	C3610/Raney scrub				336	filter
							350	S scrub
							315	bottom
							350	middle
							350	top
GAS VOLUME, L/hr			133.00		Temp, C	21		
	, L/hr	at 0 C	123.50		ft3/hr	at 60 F	4.1286	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H2	2.59%	0.0261	3.1987	0.1428		
Carbon Dioxide		CO2	42.70%	0.4299	52.7345	2.3542		
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000		
				0.0000	0.0000	0.0000		
Air		N2+O2	0.68%	0.0000	0.8398	0.0375		
Methane		CH4	51.75%	0.5210	63.9113	2.8532		
Ethylene		C2H4	0.00%	0.0000	0.0000	0.0000		
Ethane		C2H6	2.30%	0.0232	2.8405	0.1268		
Propane	(no	C3H8		0.0000	0.0000	0.0000		
Butane	backflush)	C4H8		0.0000	0.0000	0.0000		
Pentane	(no	C5H12		0.0000	0.0000	0.0000		
benzene	backflush)	C6H6		0.0000	0.0000	0.0000		
Total			100.02%	1.0002	123.5247	5.5145		
Mole Wt			28.032703	28.0329		Gas Wt,g/hr	154.59	
HHV	Btu/ft3 at 60 F		574	578		Gas Yield		
	KJ/m3 at 0 C		22.61	22.76		8.77	scf/lb solids	
						0.55	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
5.4610	65.59	12.4592	12.58	4.70844	75.34	0.0750	1.05	
EFFLUENT ANALYSIS			alkali, est.	10000	ppm	(92.6 ppm-mole K&Na, est.)		
			NH3, est.	15143	ppm	mole/hr K&Na	0.07	pH
Vol, L/hr, est.		0.78	COD	10410		mole/hr NH3	0.69	8.15-8.52
			factor	1.2		C in bicarb,g	9.19	
			grams	6.77				
			C, wt%(COD)		47.165	C, wt%(direct)	0	
			C, gr (by COD)		3.19	C, gr (direct)		
			N, gr (by NH3)		9.71			
			ash, g (soluble Na & K)		7.80			

SOLIDS ANALYSIS (DS from filter blowdown, not washed)								
			ash, wt%	47.06	ash, g/hr	6.21		
	weight, g/hr	13.2	C, wt%	34.31	C, g/hr	4.53		
			N, wt%	3.555	N, g/hr	0.47		
SOLIDS ANALYSIS (DS from CSTR cleanout, not washed)								
			ash, wt%	88.83	ash, g/hr	0.00		
	weight, g/hr	0	C, wt%	6.035	C, g/hr	0.00		
			N, wt%	0.495	N, g/hr	0.00		
FEEDSTOCK ANALYSIS								
	COD	241,267	factor	1.2		feed(by COD)	201.06	g/hr
	wt, g/hr	1000	conc, wt%	22.4		feed(direct)	224.00	g/hr
						water	776.00	g/hr
	Elemental Analysis, normalized			C	47.2%			
				H	6.6%			
				O	27.4%			
				N	10.5%	N, g/hr	23.52	
				S	0.9%			
				ash	8.3%	ash, g/hr	18.6592	
					100.9%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	94.83		- - -					
direct	105.65		23.52					
ASH BALANCE				75.09%				
MATERIAL BALANCE				94.78%				
CARBON BALANCE			by COD	87.00%	(incl C in bicarb)			
			by direct	75.07%	(incl C in bicarb)			
NITROGEN BALANCE				47.75%	(nitrogen + ammonia + N in BD solids)			
CARBON CONVERSION TO GAS, %				62.08%		gas adj for bicarb	70.78%	
COD CONVERSION, %				96.63%				
CARBON CONVERSION TO SOLIDS, %				4.29%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.43	l/l/hr			reactor volume	0.7	liters
	WHSV=	2.86	g/g/hr			at temperature	350	grams
	Residence	21	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

GAS CALCULATIONS			18-Aug	Run No.	Algae 4	Time	11:00-19:30	
		Feed	SLC algae from tanks			Pressure	2917+/-62	psig
		Pump	ISCO				345	carberry
		Catalyst	C3610/Raney scrub				326	filter
							352	S scrub
							327	bottom
							348	middle
							351	top
GAS VOLUME, L/hr			75.20		Temp, C	24		
	, L/hr	at 0 C	69.12		ft3/hr	at 60 F	2.3108	
				Volume				
			Volume	Fraction				
GAS COMPOSITION			Fraction	air free	L/hr	G-Moles/hr		
Hydrogen		H2	1.70%	0.0171	1.1751	0.0525		
Carbon Dioxide		CO2	38.50%	0.3881	26.6124	1.1881	**slow trend**	
Carbon Monoxide		CO	0.00%	0.0000	0.0000	0.0000	**in increasing**	
				0.0000	0.0000	0.0000	**ethane**	
Air		N2+O2	0.80%	0.0000	0.5530	0.0247	**noted in**	
Methane		CH4	58.85%	0.5932	40.6790	1.8160	**final hours**	
Ethylene		C2H4	0.00%	0.0000	0.0000	0.0000	**of the test**	
Ethane		C2H6	0.15%	0.0015	0.1037	0.0046		
Propane	(no	C3H8		0.0000	0.0000	0.0000		
Butane	backflush)	C4H8		0.0000	0.0000	0.0000		
Pentane	(no	C5H12		0.0000	0.0000	0.0000		
benzene	backflush)	C6H6		0.0000	0.0000	0.0000		
Total			100.00%	1.0000	69.1232	3.0859		
Mole Wt			26.692735	26.682193		Gas Wt,g/hr	82.37	
HHV	Btu/ft3 at 60 F		604	609		Gas Yield		
	KJ/m3 at 0 C		23.81	24.00		9.06	scf/lb solids	
						0.57	liter/g solids	
GAS PRODUCT, HOURLY YIELD								
Carbon		Hydrogen		Oxygen		Nitrogen		
moles	grams	moles	grams	moles	grams	moles	grams	
3.0133	36.19	7.396803	7.47	2.3761111	38.02	0.0494	0.69	
EFFLUENT ANALYSIS			alkali	1083	ppm	(34.3 ppm-mole K&Na, est.)		
			NH3	12197	ppm	mole/hr K&Na	0.05	pH
	Vol, L/hr, est.	1.448	COD	457		mole/hr NH3	1.04	7.94-8.16
			factor	1.1		C in bicarb,g	13.04	
			grams	0.60				
			C, wt%(COD)		38.2925	C, wt%(direct)	0	
			C, gr (by COD)		0.23	C, gr (direct)		
			N, gr (by NH3)		14.52			
			ash, g (soluble Na & K)		1.57			

SOLIDS ANALYSIS (DS from filter blowdown after water flush)								
est using filter cleanout DS			ash, wt%	84.03	ash, g/hr	4.03		
	weight, g/hr	4.8	C, wt%	9.195	C, g/hr	0.44		
			N, wt%	0.76	N, g/hr	0.04		
SOLIDS ANALYSIS (DS from filter cleanout, after water flush)								
			ash, wt%	87.7	ash, g/hr	12.19		
	weight, g/hr	13.9	C, wt%	5.755	C, g/hr	0.80		
			N, wt%	0.38	N, g/hr	0.05		
FEEDSTOCK ANALYSIS								
	COD	87,000	factor	1.1		feed(by COD)	119.11	g/hr
	wt, g/hr	1506	conc, wt%	8.05		feed(direct)	121.23	g/hr
						water	1384.77	g/hr
	Elemental Analysis			C	38.3%			
				H	5.3%			
				O	32.3%			
				N	5.8%	N, g/hr	7.0800072	
				S	1.0%			
				ash	22.0%	ash, g/hr	26.6955066	
					104.8%			
	Carbon, g		Nitrogen, g		Oxygen, g			
COD	45.61		- - -					
direct	46.42		7.0800072					
ASH BALANCE				66.65%				
MATERIAL BALANCE				102.86%				
CARBON BALANCE			by COD	111.17%	(incl C in bicarb)			
			by direct	108.73%	(incl C in bicarb)			
NITROGEN BALANCE				216.12%	(nitrogen + ammonia + N in BD solids)			
CARBON CONVERSION TO GAS, %				77.96%		gas adj for bicarb	106.06%	
COD CONVERSION, %				99.49%				
CARBON CONVERSION TO SOLIDS, %				2.67%				
SPACE VELOCITY/RESIDENCE TIME								
	LHSV =	1.88	l/l/hr			reactor volume	0.8	liters
	WHSV=	3.77	g/g/hr			at temperature	400	grams
	Residence	16	minutes			with catalyst		
	Time (O*O)							
	[1/(LHSV/30)]							
	assumes 50% voids in bed							

Elliott:
seems high based on >100% total

low ash recovery suggests that feed analysis is incorrect; normalizing ash content in feed improves balance to 86%

APPENDIX II

Process Flow Diagrams used in Technoeconomic Assessment

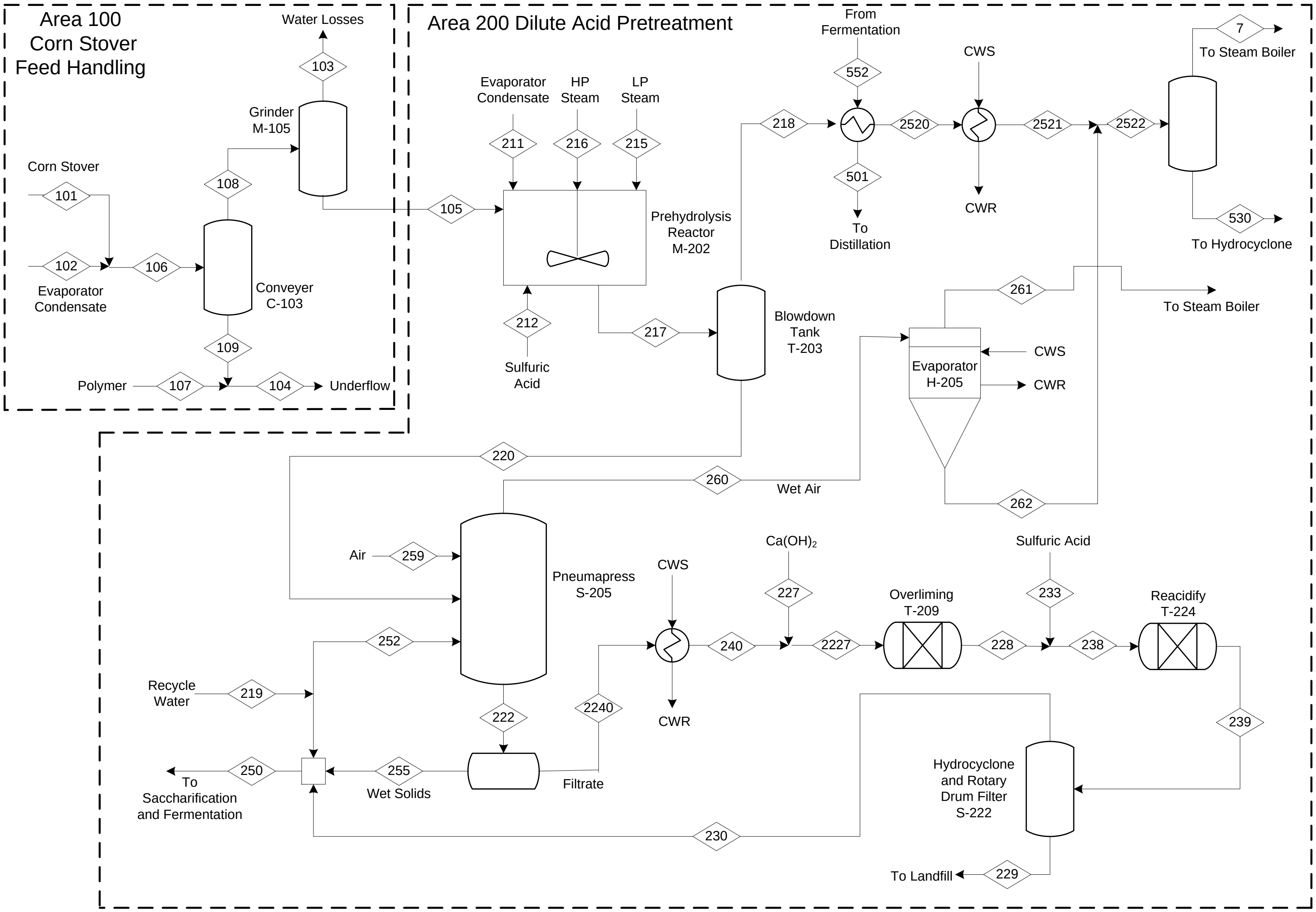

Figure II.1. Area 100, 200 for Wet Gasification with Steam Boiler Case

Stream No.	7	101	102	103	104	105	211	212	215	216	217	218
Stream Name									LP STM	HP STM		
Temp F	98.6233	68	97.4373	113	83.5376	113	97.4373	68	325.8773	512.6	374	213.98
Pres psia	15.6959	14.6959	64.6959	14.6959	14.6959	14.6959	64.6959	50	64.9561	191.0472	562.2667	14.6959
Enth MMBtu/h	-2.1154	-692.84	-643.26	-169.47	-15.034	-1147	-1485.5	-15.98	-143.78	-459.78	-3245.5	-856.73
Vapor mass fraction	1	0	0	0	0	0.001232	0	0	1	1	0.001041	1
Total lb/h	546.204	216139.7	94832.43	24987.72	2207.126	283840	219004.8	4638.526	25368.59	82087	614939	152184.2
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	0	5348.162	0
Cellulose	0	68762.38	0	0	0	68762.38	0	0	0	0	62986.34	0
Xylose	0	0	0	0	0	0	0	0	0	0	39613.35	0
Xylan	0	38733.23	0	0	0	38733.23	0	0	0	0	968.3278	0
Lignin	0	33075.58	0	0	0	33075.58	0	0	0	0	31421.8	0
Acetate	0	5389.846	0	0	0	5389.846	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	0	16349.48	0	0	0	16349.48	0	0	0	0	16349.48	0
Gypsum	0	0	0	0	0	0	0	0	0	0	0	0
Lgnsol	0	0	0	0	0	0	0	0	0	0	1653.779	0
HMF	0	0	0	0	0	0	0	0	0	0	249.9656	0.089
C5Sugar	0	0	0	0	0	0	0	0	0	0	6748.214	0
C6Sugar	0	0	0	0	0	0	0	0	0	0	7675.797	0
C5Solid	0	5373.108	0	0	0	5373.108	0	0	0	0	134.3275	0
C6Solid	0	6427.643	0	0	0	6427.643	0	0	0	0	160.6906	0
CaH2O2	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	9607.981	0	0	0	9607.981	0	0	0	0	9607.981	0
Ethanol	0.0001	0	0	0	0	0	0	0	0	0	0	0
Water	13.5251	32420.45	94475.55	24987.72	2207.126	99763.75	218180.6	0	25368.59	82087	419207.2	148835
Furfural	1.0285	0	0	0	0	0	0	0	0	0	1603.888	1125.513
Sulfuric Acid	0	0	0	0	0	0	0	4638.526	0	0	4638.526	0
Nitrogen	0.0043	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	530.9044	0	205.8701	0	0	205.8701	475.4335	0	0	0	681.3035	681.2469
Oxygen	0.0026	0	0	0	0	0	0	0	0	0	0	0
Ammonia	0.7031	0	151.0095	0	0	151.0095	348.7391	0	0	0	499.7486	424.917
Lactic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0.036	0	0	0	0	0	0	0	0	0	5389.873	1117.39
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	219	220	222	227	228	229	230	233	238	239	240	250
Stream Name	Recycle Watr			Ca(OH)2		To Landfill		SulfuricAcid				
Temp F	124.932	213.98	122	68	122.0591	127.8489	127.9074	68	121.9628	127.7889	122	126.412
Pres psia	63.0456	14.6959	14.5038	14.6959	29.3919	14.6959	29.3919	50	29.3919	14.6959	14.5038	14.5038
Enth MMBtu/h	-3079.5	-2323	-4292.2	-40.875	-3421.7	-91.516	-3339.1	-8.9826	-3430.7	-3430.7	-3376.2	-5388
Vapor mass fraction	0	0	0	0	0	1.99E-06	0	0	0	1.98E-06	1.82E-06	4.15E-05
Total lb/h	456566.3	462755	749920	7139.886	569194.3	17472	554330	2607.346	571802	571802	562054.3	910148
Flowrates in lb/h												
Glucose	0	5348.162	5348.162	0	4990.37	26.3354	4964.035	0	4990.37	4990.37	4990.37	5321.827
Cellulose	0	62986.34	62986.34	0	314.9337	313.359	1.5747	0	314.9337	314.9337	314.9337	62673
Xylose	0	39613.35	39613.35	0	36975.1	195.1269	36780	0	36975.1	36975.1	36975.1	39418.23
Xylan	0	968.3278	968.3278	0	4.8417	4.8174	0.0242	0	4.8417	4.8417	4.8417	963.5104
Lignin	0	31421.8	31421.8	0	157.1095	156.3239	0.7856	0	157.1095	157.1095	157.1095	31265.47
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	0	16349.48	16349.48	0	15427.37	81.4141	15345.96	0	15427.37	15427.37	15427.37	16268.06
Gypsum	0	0	0	0	7605.247	12121.38	60.9115	0	7605.247	12182.29	0	60.9115
Lgnsol	0	1653.779	1653.779	0	1561.002	8.2378	1552.764	0	1561.002	1561.002	1561.002	1645.541
HMF	0.2474	249.8766	250.0329	0	239.7566	1.2653	238.4913	0	239.7566	239.7566	239.7566	248.8587
C5Sugar	0	6748.214	6748.214	0	6302.832	33.2616	6269.57	0	6302.832	6302.832	6302.832	6714.953
C6Sugar	0	7675.796	7675.796	0	7169.194	37.8336	7131.36	0	7169.194	7169.194	7169.194	7637.963
C5Solid	0	134.3275	134.3275	0	0	0	0	0	0	0	0	134.3275
C6Solid	0	160.6906	160.6906	0	0	0	0	0	0	0	0	160.6906
CaH2O2	0	0	0	7139.886	3867.022	1887.837	9.4866	0	3867.022	1897.324	0	9.4866
Ash	0	9607.981	9607.981	0	48.0397	47.7995	0.2402	0	48.0397	48.0397	48.0397	9560.182
Ethanol	41.5393	0	25.6134	0	24.9398	0.1316	24.8082	0	24.9398	24.9398	24.9398	40.7625
Water	453899.5	270372.2	556377.4	0	478818.4	2526.845	476292	0	478818.4	478818.4	478818.4	720822.2
Furfural	714.4283	478.3749	919.2458	0	886.1529	4.6765	881.4764	0	886.1529	886.1529	886.1529	1177.379
Sulfuric Acid	0	4638.526	4638.525	0	0	0	0	2607.346	2607.346	0	4332.383	306.1427
Nitrogen	0	0	4.2355	0	4.2355	0.0224	4.2132	0	4.2355	4.2355	4.2355	4.2132
Carbon Dioxide	810.798	0.0567	9.1462	0	9.1462	0.0483	9.0979	0	9.1462	9.1462	9.1462	307.3583
Oxygen	0	0	2.4953	0	2.4953	0.0132	2.4821	0	2.4953	2.4953	2.4953	2.4821
Ammonia	594.7353	74.8316	435.8528	0	435.8528	2.3001	433.5527	0	435.8528	435.8528	435.8528	652.3321
Lactic Acid	3.8321	0	2.4224	0	2.2964	0.0121	2.2843	0	2.2964	2.2964	2.2964	3.82
Acetic Acid	501.2021	4272.483	4586.359	0	4347.868	22.9448	4324.924	0	4347.868	4347.869	4347.868	4747.787
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	252	255	259	260	261	262	501	530	552	2521	2522
Stream Name		WET SOLI	AIR	WET AIR	To combus	TO 600					
Temp F	124.932	122	104	122	100.4	100.4	203	98.6233	105.4457	98.6	98.6233
Pres psia	63.0456	14.5038	139.6114	14.5038	14.5038	14.5038	58.7838	15.6959	58.7838	14.6959	15.6959
Enth MMBtu/h	-1946.6	-916.05	-0.00697	-7.1545	-4.6412	-3.0421	-5795.4	-1020.4	-5880.8	-1019.5	-1022.5
Vapor mass fraction	0	0	1	1	1	0	0.000434	0	0	0.003667	0.003579
Total lb/h	288614	187865.3	10363.63	11812.35	11362.2	450.1462	955916	152088.1	955916	152184.2	152634.3
Flowrates in lb/h											
Glucose	0	357.7921	0	0	0	0	182.6596	0	182.6596	0	0
Cellulose	0	62671.41	0	0	0	0	2381.573	0	2381.573	0	0
Xylose	0	2638.249	0	0	0	0	2112.233	0	2112.233	0	0
Xylan	0	963.4862	0	0	0	0	963.5104	0	963.5104	0	0
Lignin	0	31264.69	0	0	0	0	31265.48	0	31265.48	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	2947.921	0	2947.921	0	0
Solslds	0	922.1107	0	0	0	0	16268.06	0	16268.06	0	0
Gypsum	0	0	0	0	0	0	60.9115	0	60.9115	0	0
Lgnsol	0	92.777	0	0	0	0	1645.541	0	1645.541	0	0
HMF	0.1564	10.2764	0	0	0	0	248.8586	0.0891	248.8586	0.089	0.0891
C5Sugar	0	445.3821	0	0	0	0	3070.577	0	3070.577	0	0
C6Sugar	0	506.6026	0	0	0	0	7564.396	0	7564.396	0	0
C5Solid	0	134.3275	0	0	0	0	134.3275	0	134.3275	0	0
C6Solid	0	160.6906	0	0	0	0	160.6906	0	160.6906	0	0
CaH2O2	0	0	0	0	0	0	9.4866	0	9.4866	0	0
Ash	0	9559.941	0	0	0	0	9560.183	0	9560.183	0	0
Ethanol	26.2586	0.6736	0	0.6452	0.6119	0.0333	53783.73	0.0333	53783.73	0	0.0333
Water	286928	77559.02	0	922.7144	476.3223	446.392	809422.1	149268	809422.1	148835	149281.4
Furfural	451.6185	33.0928	0	10.7476	9.8961	0.8515	1177.672	1125.335	1177.672	1125.513	1126.364
Sulfuric Acid	0	306.1427	0	0	0	0	306.1426	0	306.1426	0	0
Nitrogen	0	0	7949.79	7945.555	7945.55	0.0043	0.0014	0	0.0014	0	0.0043
Carbon Dioxide	512.5377	0	0	503.4482	503.4362	0.012	693.9644	150.3546	693.9644	681.2469	681.2589
Oxygen	0	0	2413.844	2411.349	2411.346	0.0026	0.066	0	0.066	0	0.0026
Ammonia	375.9559	0	0	14.9347	14.2225	0.7122	655.5604	424.9261	655.5604	424.917	425.6292
Lactic Acid	2.4224	0.126	0	0	0	0	4319.519	0	4319.519	0	0
Acetic Acid	316.8298	238.4906	0	2.9549	0.8167	2.1382	6646.476	1119.492	6646.476	1117.39	1119.528
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	0	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	334.0683	0	334.0683	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0

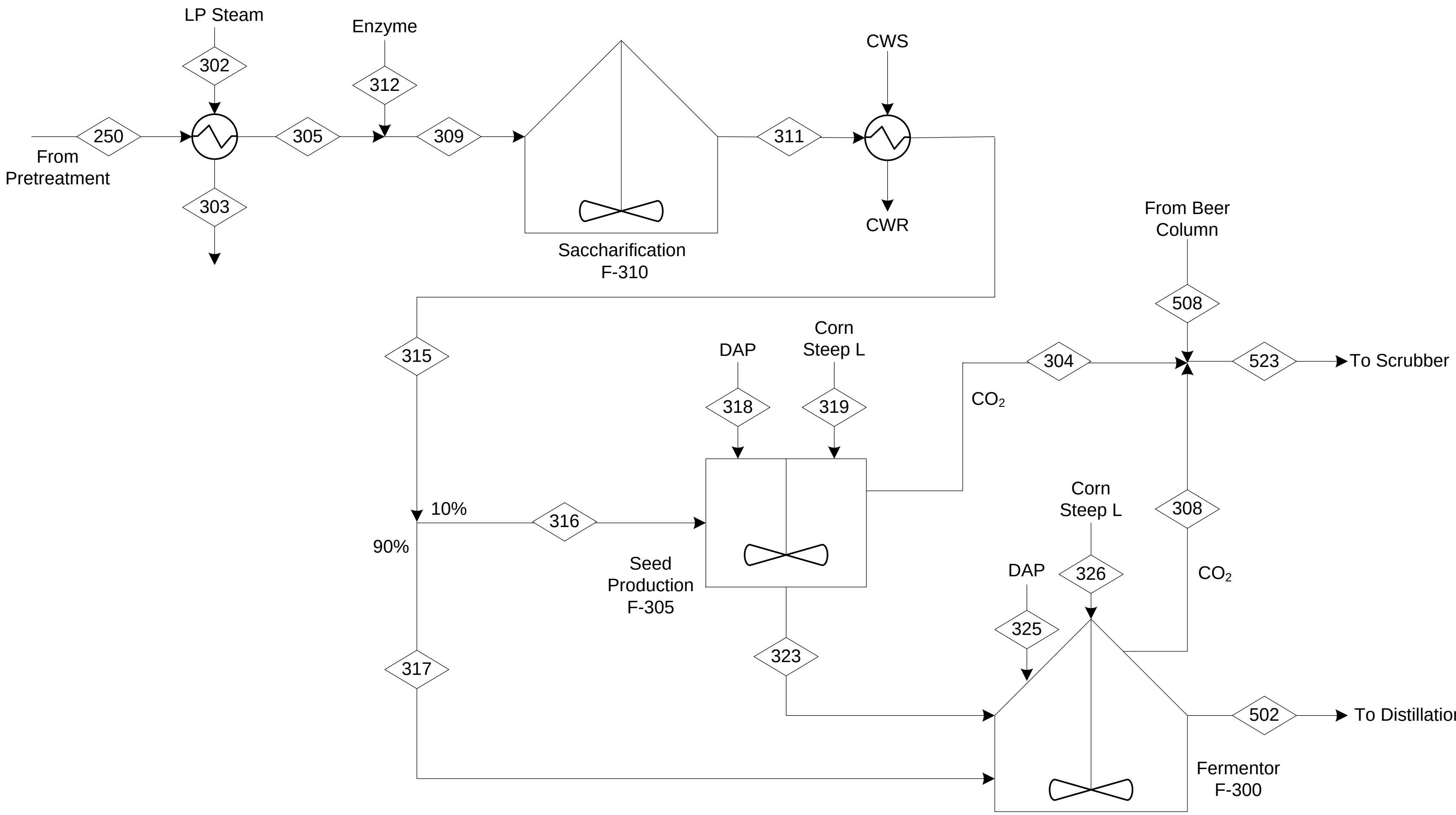

Figure II.2. Area 300 for Wet Gasification with Steam Boiler Case

Stream No.	250	302	303	304	305	308	309	311	312	315	316	317
Stream Name		LP STM							Enzyme			
Temp F	126.412	365	297.9745	105.8	149	105.8	147.5168	149	68	105.8	105.8	105.8
Pres psia	14.5038	64.9959	64.9959	14.6959	29.3919	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959
Enth MMBtu/h	-5388	-104.1	-121.52	-16.469	-5370.5	-192.44	-5467.5	-5466	-97.013	-5499.8	-507.08	-4992.7
Vapor mass fraction	4.15E-05	1	0.000313	1	3.68E-06	1	0.000156	0.000154	0	3.71E-06	3.71E-06	3.71E-06
Total lb/h	910148	18425	18425	4300.198	910148	50194	925193	925193	15044.68	925193	85302.72	839890
Flowrates in lb/h												
Glucose	5321.827	0	0	0	5321.827	0	5321.827	68690.9	0	68690.9	6333.301	62357.6
Cellulose	62673	0	0	0	62673	0	62673	2381.573	0	2381.573	219.581	2161.992
Xylose	39418.23	0	0	0	39418.23	0	39418.23	39418.23	0	39418.23	3634.361	35783.87
Xylan	963.5104	0	0	0	963.5104	0	963.5104	963.5104	0	963.5104	88.8357	874.6747
Lignin	31265.47	0	0	0	31265.47	0	31265.47	31265.47	0	31265.47	2882.677	28382.8
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	1253.222	1253.222	1253.222	1253.222	115.547	1137.675
Solslds	16268.06	0	0	0	16268.06	0	16268.06	16268.06	0	16268.06	1499.915	14768.15
Gypsum	60.9115	0	0	0	60.9115	0	60.9115	60.9115	0	60.9115	5.616	55.2954
Lgnsol	1645.541	0	0	0	1645.541	0	1645.541	1645.541	0	1645.541	151.7189	1493.822
HMF	248.8587	0	0	0	248.8587	0	248.8586	248.8586	0	248.8586	22.9448	225.9139
C5Sugar	6714.953	0	0	0	6714.953	0	6714.953	6714.953	0	6714.953	619.1187	6095.834
C6Sugar	7637.963	0	0	0	7637.963	0	7637.963	11259.05	0	11259.05	1038.085	10220.97
C5Solid	134.3275	0	0	0	134.3275	0	134.3275	134.3275	0	134.3275	12.385	121.9425
C6Solid	160.6906	0	0	0	160.6906	0	160.6906	160.6906	0	160.6906	14.8157	145.8749
CaH2O2	9.4866	0	0	0	9.4866	0	9.4866	9.4866	0	9.4866	0.8747	8.6119
Ash	9560.182	0	0	0	9560.182	0	9560.182	9560.182	0	9560.182	881.4489	8678.733
Ethanol	40.7625	0	0	116.4773	40.7625	1548.187	40.7625	40.7625	0	40.7625	3.7583	37.0042
Water	720822.2	18425	18425	138.4489	720822.2	1611.475	734614	727915	13791.45	727915	67113.77	660801.3
Furfural	1177.379	0	0	1.3607	1177.379	15.452	1177.379	1177.379	0	1177.379	108.5544	1068.825
Sulfuric Acid	306.1427	0	0	0	306.1427	0	306.1426	306.1426	0	306.1426	28.2264	277.9163
Nitrogen	4.2132	0	0	0.3883	4.2132	3.8236	4.2132	4.2132	0	4.2132	0.3885	3.8247
Carbon Dioxide	307.3583	0	0	4021.382	307.3583	46891.95	307.3583	307.3583	0	307.3583	28.3384	279.0198
Oxygen	2.4821	0	0	19.524	2.4821	93.001	2.4821	2.4821	0	2.4821	0.2289	2.2533
Ammonia	652.3321	0	0	2.2093	652.3321	25.4347	652.3321	652.3321	0	652.3321	60.145	592.1871
Lactic Acid	3.82	0	0	0.0001	3.82	0.0033	3.82	3.82	0	3.82	0.3522	3.4678
Acetic Acid	4747.787	0	0	0.4074	4747.787	4.672	4747.787	4747.787	0	4747.787	437.7459	4310.041
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	318	319	323	325	326	502	508	523
Stream Name	DAP			DAP				
Temp F	68	68	105.8	68	68	105.8	140	105.9759
Pres psia	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959	27.4	14.6959
Enth MMBtu/h	-0.31318	-3.3123	-495.68	-1.5391	-16.445	-5332	-3.0867	-211.99
Vapor mass fraction	0	0	0	0	0	0	1	1
Total lb/h	61.0923	485.1779	81548.87	300.2388	2408.773	873954	838.6652	55332.86
Flowrates in lb/h								
Glucose	0	0	411.6645	0	0	182.6596	0	0
Cellulose	0	0	219.581	0	0	2381.573	0	0
Xylose	0	0	508.8105	0	0	2112.233	0	0
Xylan	0	0	88.8357	0	0	963.5104	0	0
Lignin	0	0	2882.677	0	0	31265.48	0	0
Acetate	0	0	0	0	0	0	0	0
Organism	0	0	412.7426	0	0	2947.921	0	0
Solslds	0	0	1499.915	0	0	16268.06	0	0
Gypsum	0	0	5.616	0	0	60.9115	0	0
Lgnsol	0	0	151.7189	0	0	1645.541	0	0
HMF	0	0	22.9448	0	0	248.8586	0	0
C5Sugar	0	0	691.8058	0	0	3070.577	0	0
C6Sugar	0	0	1038.085	0	0	7564.396	0	0
C5Solid	0	0	12.385	0	0	134.3275	0	0
C6Solid	0	0	14.8157	0	0	160.6906	0	0
CaH2O2	0	0	0.8747	0	0	9.4866	0	0
Ash	0	0	881.4489	0	0	9560.183	0	0
Ethanol	0	0	4127.432	0	0	52011	110.3603	1775.024
Water	0	485.1779	67511.2	0	2408.773	729349	34.169	1784.093
Furfural	0	0	107.1936	0	0	1160.566	0.2962	17.109
Sulfuric Acid	0	0	28.2263	0	0	306.1426	0	0
Nitrogen	0	0	0.0001	0	0	0.0012	0.0014	4.2133
Carbon Dioxide	0	0	57.5981	0	0	631.7418	690.4894	51603.82
Oxygen	0	0	0.0134	0	0	0.0598	0.066	112.5909
Ammonia	0	0	57.9357	0	0	624.6881	3.2628	30.9069
Lactic Acid	0	0	146.018	0	0	4319.515	0	0.0035
Acetic Acid	0	0	613.0157	0	0	6641.376	0.0201	5.0996
Ammonium Sulfate	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0
DAP	61.0923	0	56.3113	300.2388	0	334.0683	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0

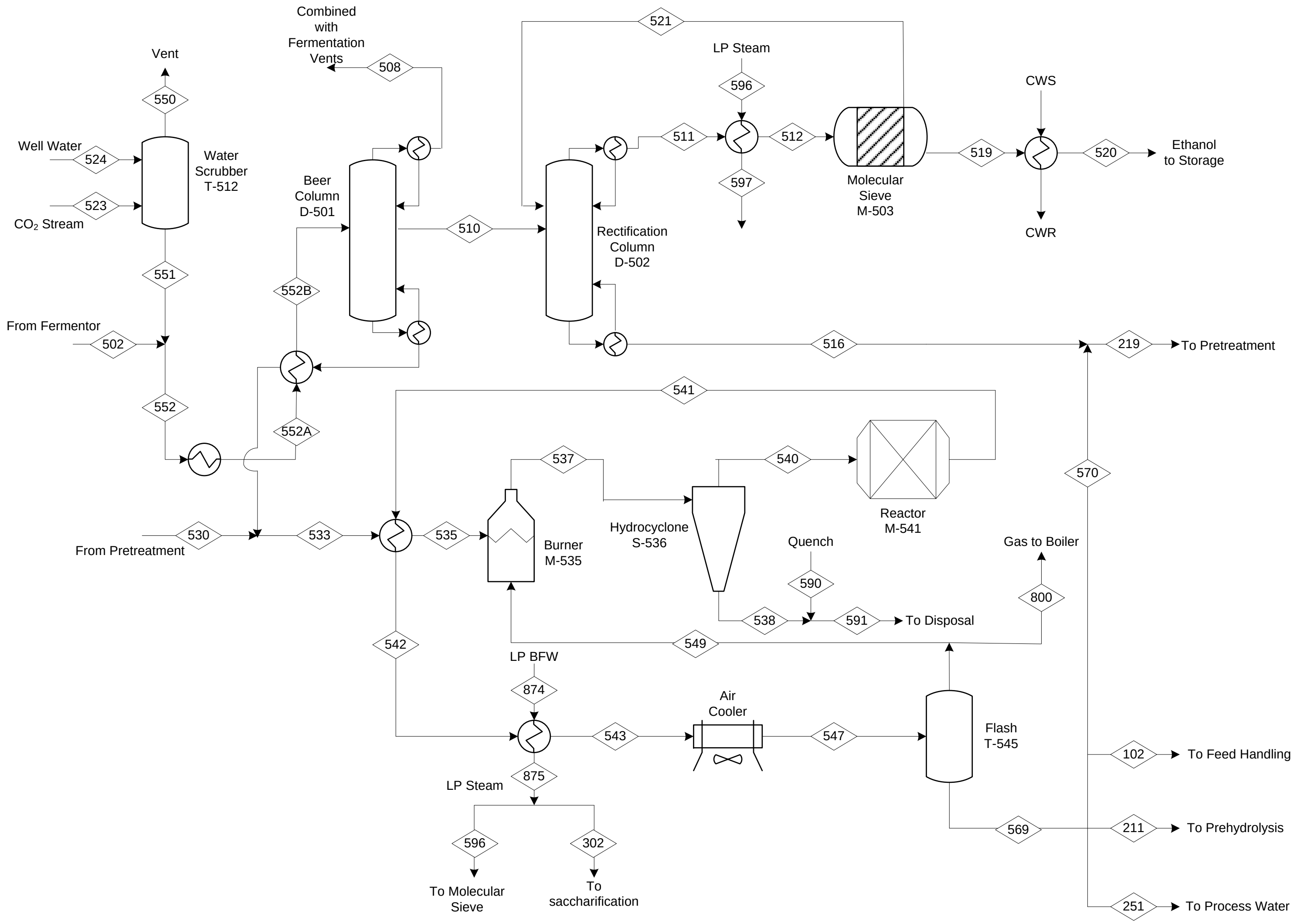

Figure II.3. Area 500 for Wet Gasification with Steam Boiler Case

Stream No.	102	211	219	302	502	508	510	511	512	516	519	520
Stream Name				LP STM								
Temp F	97.4373	97.4373	124.932	365	105.8	140	235.4991	196.1321	240.8	248.7467	197.06	98.6
Pres psia	64.6959	64.6959	63.0456	64.9959	14.6959	27.4	28.1143	24.3365	24.3365	63.0456	21.1622	14.6959
Enth MMBtu/h	-643.26	-1485.5	-3079.5	-104.1	-5332	-3.0867	-586.34	-177.02	-175.68	-547.36	-117.54	-140.48
Vapor mass fraction	0	0	0	1	0	1	1	1	1	0	1	0
Total lb/h	94832.43	219004.8	456566.3	18425	873954	838.6652	137412	72904.73	72904.73	83159.14	54258.05	54258.05
Flowrates in lb/h												
Glucose	0	0	0	0	182.6596	0	0	0	0	0	0	0
Cellulose	0	0	0	0	2381.573	0	0	0	0	0	0	0
Xylose	0	0	0	0	2112.233	0	0	0	0	0	0	0
Xylan	0	0	0	0	963.5104	0	0	0	0	0	0	0
Lignin	0	0	0	0	31265.48	0	0	0	0	0	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	2947.921	0	0	0	0	0	0	0
Solslds	0	0	0	0	16268.06	0	0	0	0	0	0	0
Gypsum	0	0	0	0	60.9115	0	0	0	0	0	0	0
Lgnsol	0	0	0	0	1645.541	0	0	0	0	0	0	0
HMF	0	0	0.2474	0	248.8586	0	0.0222	0	0	0.0222	0	0
C5Sugar	0	0	0	0	3070.577	0	0	0	0	0	0	0
C6Sugar	0	0	0	0	7564.396	0	0	0	0	0	0	0
C5Solid	0	0	0	0	134.3275	0	0	0	0	0	0	0
C6Solid	0	0	0	0	160.6906	0	0	0	0	0	0	0
CaH2O2	0	0	0	0	9.4866	0	0	0	0	0	0	0
Ash	0	0	0	0	9560.183	0	0	0	0	0	0	0
Ethanol	0	0	41.5393	0	52011	110.3603	53428.09	66649.81	66649.81	41.5796	53386.5	53386.5
Water	94475.55	218180.6	453899.5	18425	729349	34.169	82403.66	5670.527	5670.527	82121.79	287.1624	287.1624
Furfural	0	0	714.4283	0	1160.566	0.2962	700.3403	0.0443	0.0443	700.2903	0.0443	0.0443
Sulfuric Acid	0	0	0	0	306.1426	0	0	0	0	0	0	0
Nitrogen	0	0	0	0	0.0012	0.0014	0	0	0	0	0	0
Carbon Dioxide	205.8701	475.4335	810.798	0	631.7418	690.4894	3.475	3.475	3.475	0	3.475	3.475
Oxygen	0	0	0	0	0.0598	0.066	0.0001	0.0001	0.0001	0	0.0001	0.0001
Ammonia	151.0095	348.7391	594.7353	0	624.6881	3.2628	588.2902	580.875	580.875	7.4151	580.875	580.875
Lactic Acid	0	0	3.8321	0	4319.515	0	2.6702	0	0	2.6702	0	0
Acetic Acid	0	0	501.2021	0	6641.376	0.0201	285.3784	0	0	285.3784	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	334.0683	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	530	533	535	537	538	540	541	542	543	547	549	550
Stream Name											to E-535	Vent
Temp F	98.6233	218.4942	701.6	701.6	701.6	701.6	666.3584	427.7151	412.7293	150	148.176	81.0005
Pres psia	15.6959	74.6959	3054.696	3054.696	3034.696	3034.696	3014.696	3009.696	3004.696	2994.696	64.6959	13.2263
Enth MMBtu/h	-1020.4	-6095	-5492.2	-5492.2	-53.293	-5402	-5402	-5833.7	-5853.4	-6101.9	-112.34	-202.81
Vapor mass fraction	0	0	0.38745	0.38669	0	0.57825	0.79803	0.09543	0.1143	0.086163	1	1
Total lb/h	152088.1	969730	969730	969730	12912.57	956511	956503	956549	956549	956549	33168	52543.39
Flowrates in lb/h												
Glucose	0	182.6596	182.6596	182.6596	0	182.6596	0	0	0	0	0	0
Cellulose	0	2381.573	2381.573	2381.573	0	2381.573	0	0	0	0	0	0
Xylose	0	2112.233	2112.233	2112.233	0	2112.233	0	0	0	0	0	0
Xylan	0	963.5104	963.5104	963.5104	0	963.5104	0	0	0	0	0	0
Lignin	0	31265.48	31265.48	31265.48	0	31265.48	0	0	0	0	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	2947.921	2947.921	2947.921	2947.921	0	0	0	0	0	0	0
Solslds	0	16268.06	16268.06	16268.06	0	16268.06	0	0	0	0	0	0
Gypsum	0	60.9115	60.9115	60.9115	60.9115	0	0	0	0	0	0	0
Lgnsol	0	1645.541	1645.541	1645.541	0	1645.541	0	0	0	0	0	0
HMF	0.0891	248.9255	248.9254	248.9254	0	248.9254	0	0	0	0	0	0
C5Sugar	0	3070.577	3070.577	3070.577	0	3070.577	0	0	0	0	0	0
C6Sugar	0	7564.396	7564.396	7564.396	0	7564.396	0	0	0	0	0	0
C5Solid	0	134.3275	134.3275	134.3275	0	134.3275	0	0	0	0	0	0
C6Solid	0	160.6906	160.6906	160.6906	0	160.6906	0	0	0	0	0	0
CaH2O2	0	9.4866	9.4866	9.4866	9.4866	0	0	0	0	0	0	0
Ash	0	9560.183	9560.183	9560.183	9560.183	0	0	0	0	0	0	0
Ethanol	0.0333	245.3298	245.3298	245.3298	0	245.3298	0	0	0	0	0	2.2506
Water	149268	876230	876230	876230	0	876230	856104	856138.1	856138.1	856138.1	1197.817	882.701
Furfural	1125.335	1601.532	1601.532	1601.532	0	1601.532	0	0	0	0	0	0.003
Sulfuric Acid	0	306.1426	306.1426	306.1426	0	0	0	0	0	0	0	0
Nitrogen	0	0	0	0	0	0	0	0	0	0	0	4.2132
Carbon Dioxide	150.3546	150.3297	150.3297	150.3297	0	150.3297	70799.44	70807.32	70807.32	70807.32	22781.64	51541.6
Oxygen	0	0	0	0	0	0	0	0	0	0	0	112.5847
Ammonia	424.9261	488.8763	488.8763	488.8763	0	488.8763	1531.865	1532.293	1532.293	1532.293	30.9393	0.0346
Lactic Acid	0	4316.849	4316.849	4316.849	0	4316.849	0	0	0	0	0	0
Acetic Acid	1119.492	7480.36	7480.36	7480.36	0	7480.36	0	0	0	0	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	28068.28	28071.14	28071.14	28071.14	9157.603	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	334.0683	334.0683	334.0683	334.0683	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	551	552	552A	552B	569	570	590	591	596	597	800	874	Stream No.	875
Stream Name							QUENCH		LP STM				Stream Name	
Temp F	102.0065	105.4457	203	212	148.176	148.176	142.2207	270.0169	325.868	297.9338	148.176	271.1281	Temp F	365
Pres psia	13.2263	58.7838	58.7838	69.9527	64.6959	64.6959	64.6959	64.6959	64.9561	64.9561	64.6959	69.9959	Pres psia	64.9959
Enth MMBtu/h	-548.83	-5880.8	-5795.4	-5787.4	-5757.9	-2515.3	-74.438	-127.73	-8.1358	-9.4675	-231.7	-133.88	Enth MMBtu/h	-114.21
Vapor mass fraction	0	0	0.000434	0.000431	0	0	0	0	1	0	1	0	Vapor mass fraction	1
Total lb/h	81961.88	955916	955916	955916	854969	373491	11023.11	23935.68	1435.447	1435.447	68412.11	20214.18	Total lb/h	20214.18
Flowrates in lb/h													Flowrates in lb/h	
Glucose	0	182.6596	182.6596	182.6596	0	0	0	0	0	0	0	0	Glucose	0
Cellulose	0	2381.573	2381.573	2381.573	0	0	0	0	0	0	0	0	Cellulose	0
Xylose	0	2112.233	2112.233	2112.233	0	0	0	0	0	0	0	0	Xylose	0
Xylan	0	963.5104	963.5104	963.5104	0	0	0	0	0	0	0	0	Xylan	0
Lignin	0	31265.48	31265.48	31265.48	0	0	0	0	0	0	0	0	Lignin	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0	Acetate	0
Organism	0	2947.921	2947.921	2947.921	0	0	0	2947.921	0	0	0	0	Organism	0
Solslds	0	16268.06	16268.06	16268.06	0	0	0	0	0	0	0	0	Solslds	0
Gypsum	0	60.9115	60.9115	60.9115	0	0	0	60.9115	0	0	0	0	Gypsum	0
Lgnsol	0	1645.541	1645.541	1645.541	0	0	0	0	0	0	0	0	Lgnsol	0
HMF	0	248.8586	248.8586	248.8586	0	0	0	0	0	0	0	0	HMF	0
C5Sugar	0	3070.577	3070.577	3070.577	0	0	0	0	0	0	0	0	C5Sugar	0
C6Sugar	0	7564.396	7564.396	7564.396	0	0	0	0	0	0	0	0	C6Sugar	0
C5Solid	0	134.3275	134.3275	134.3275	0	0	0	0	0	0	0	0	C5Solid	0
C6Solid	0	160.6906	160.6906	160.6906	0	0	0	0	0	0	0	0	C6Solid	0
CaH2O2	0	9.4866	9.4866	9.4866	0	0	0	9.4866	0	0	0	0	CaH2O2	0
Ash	0	9560.183	9560.183	9560.183	0	0	0	9560.183	0	0	0	0	Ash	0
Ethanol	1772.774	53783.73	53783.73	53783.73	0	0	0	0	0	0	0	0	Ethanol	0
Water	80073.79	809422.1	809422.1	809422.1	852470	372399	11023.11	11023.11	1435.447	1435.447	2470.609	20214.18	Water	20214.18
Furfural	17.106	1177.672	1177.672	1177.672	0	0	0	0	0	0	0	0	Furfural	0
Sulfuric Acid	0	306.1426	306.1426	306.1426	0	0	0	0	0	0	0	0	Sulfuric Acid	0
Nitrogen	0.0001	0.0014	0.0014	0.0014	0	0	0	0	0	0	0	0	Nitrogen	0
Carbon Dioxide	62.2227	693.9644	693.9644	693.9644	1036.414	452.7544	0	0	0	0	46989.27	0	Carbon Dioxide	0
Oxygen	0.0062	0.066	0.066	0.066	0	0	0	0	0	0	0	0	Oxygen	0
Ammonia	30.8723	655.5604	655.5604	655.5604	1437.539	627.9847	0	0	0	0	63.8152	0	Ammonia	0
Lactic Acid	0.0035	4319.519	4319.519	4319.519	0	0	0	0	0	0	0	0	Lactic Acid	0
Acetic Acid	5.0996	6646.476	6646.476	6646.476	0	0	0	0	0	0	0	0	Acetic Acid	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0	Ammonium Sulfate	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0	NH4ACET	0
Methane	0	0	0	0	25.1299	10.9779	0	0	0	0	18888.41	0	Methane	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0	Nitrogen Dioxide	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0	Sulfur Dioxide	0
DAP	0	334.0683	334.0683	334.0683	0	0	0	334.0683	0	0	0	0	DAP	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0	2-2-4-TriMth-C5	0

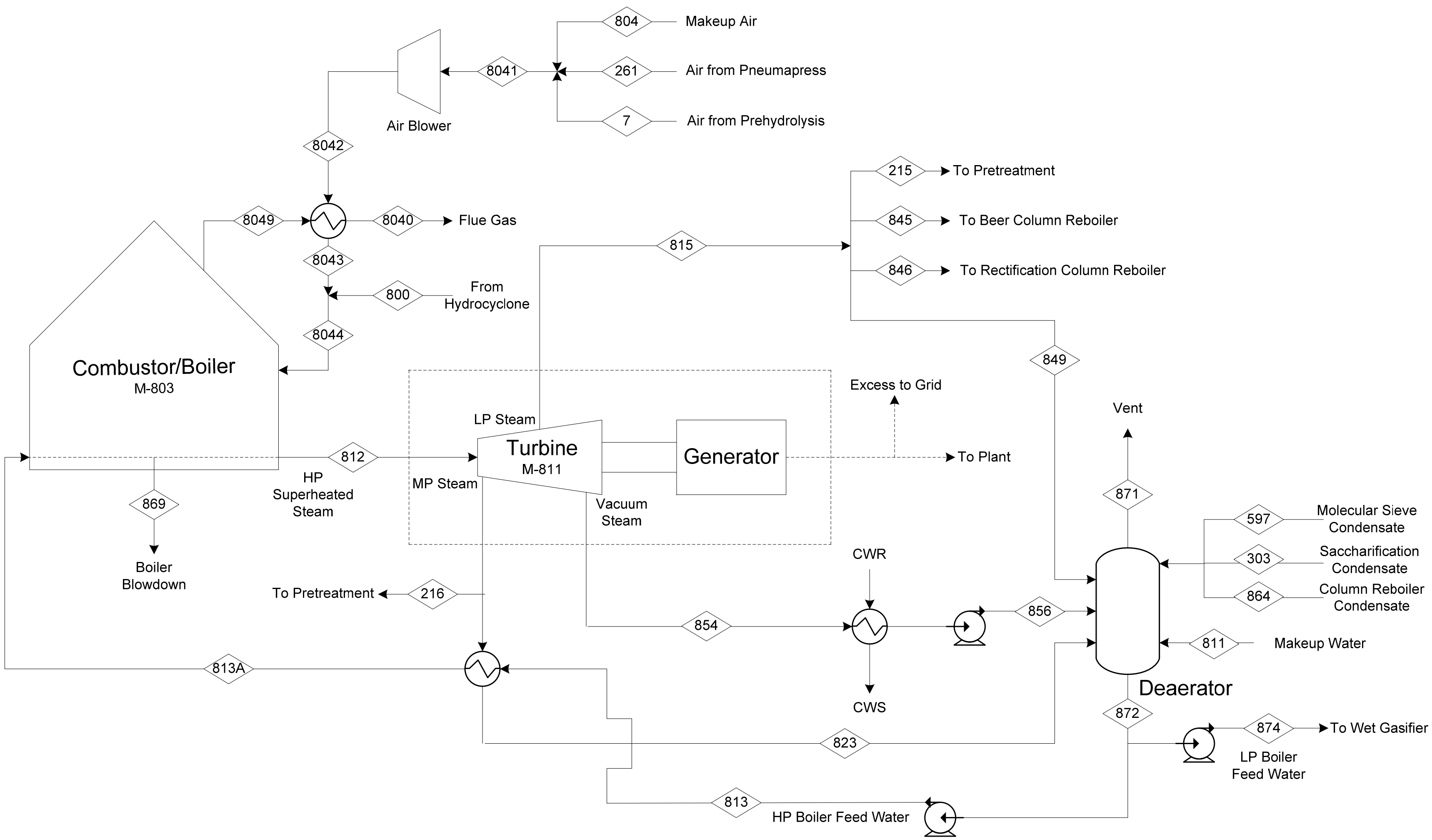

Figure II.4. Area 800 for Wet Gasification with Steam Boiler Case

Stream No.	7	215	216	261	303	597	800	804	811	812	813	813A
Stream Name		LP STM	HP STM					Air			BFW	
Temp F	98.6233	325.8773	512.6	100.4	297.9745	297.9338	148.176	75.2	78.8	950	281.0891	317
Pres psia	15.6959	64.9561	191.0472	14.5038	64.9959	64.9561	64.6959	14.6959	24.9831	1006.76	1292.696	1282.703
Enth MMBtu/h	-2.1154	-143.78	-459.78	-4.6412	-121.52	-9.4675	-231.7	-0.22103	-964.32	-1694.5	-2186.8	-2176.4
Vapor mass fraction	1	1	1	1	0.000313	0	1	1	0	1	0	0
Total lb/h	546.204	25368.59	82087	11362.2	18425	1435.447	68412.11	507063.2	141475	314158	330693.4	330693.4
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	0	0	0
Cellulose	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
Xylan	0	0	0	0	0	0	0	0	0	0	0	0
Lignin	0	0	0	0	0	0	0	0	0	0	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	0	0	0	0	0	0	0	0	0	0	0	0
Gypsum	0	0	0	0	0	0	0	0	0	0	0	0
Lgnsol	0	0	0	0	0	0	0	0	0	0	0	0
HMF	0	0	0	0	0	0	0	0	0	0	0	0
C5Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C6Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C5Solid	0	0	0	0	0	0	0	0	0	0	0	0
C6Solid	0	0	0	0	0	0	0	0	0	0	0	0
CaH2O2	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0
Ethanol	0.0001	0	0	0.6119	0	0	0	0	0	0	0	0
Water	13.5251	25368.59	82087	476.3223	18425	1435.447	2470.609	0	141475	314158	330693.4	330693.4
Furfural	1.0285	0	0	9.8961	0	0	0	0	0	0	0	0
Sulfuric Acid	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	0.0043	0	0	7945.55	0	0	0	400580	0	0	0	0
Carbon Dioxide	530.9044	0	0	503.4362	0	0	46989.27	0	0	0	0	0
Oxygen	0.0026	0	0	2411.346	0	0	0	106483.3	0	0	0	0
Ammonia	0.7031	0	0	14.2225	0	0	63.8152	0	0	0	0	0
Lactic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0.036	0	0	0.8167	0	0	0	0	0	0	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	18888.41	0	0	0	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	815	823	845	846	849	854	856	864	869	871	872	874
Stream Name			To D501	To D502					To WWT	VENT		
Temp F	364.7811	373.2065	364.7811	364.7811	364.7811	122.3431	122.3705	297.932	258.7722	278.6	278.6	271.1281
Pres psia	64.9561	181.054	64.9561	64.9561	64.9561	1.4696	61.7229	64.9561	34.6959	48.4966	48.4966	69.9959
Enth MMBtu/h	-1200.4	-120.86	-896.72	-96.838	-0.62347	-65.134	-75.183	-1080.9	-73.237	0	-2394.7	-133.88
Vapor mass fraction	1	0.50952	1	1	1	0.88472	0	0	0	1	0	0
Total lb/h	212229.4	19841.6	158541	17121.1	110.2311	11088.45	11088.45	163691	11024.18	0	361576.2	20214.18
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	0	0	0
Cellulose	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
Xylan	0	0	0	0	0	0	0	0	0	0	0	0
Lignin	0	0	0	0	0	0	0	0	0	0	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	0	0	0	0	0	0	0	0	0	0	0	0
Gypsum	0	0	0	0	0	0	0	0	0	0	0	0
Lgnsol	0	0	0	0	0	0	0	0	0	0	0	0
HMF	0	0	0	0	0	0	0	0	0	0	0	0
C5Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C6Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C5Solid	0	0	0	0	0	0	0	0	0	0	0	0
C6Solid	0	0	0	0	0	0	0	0	0	0	0	0
CaH2O2	0	0	0	0	0	0	0	0	0	0	0	0
Ash	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
Water	212229.4	19841.6	158541	17121.1	110.2311	11088.45	11088.45	163691	11024.18	0	361576.2	20214.18
Furfural	0	0	0	0	0	0	0	0	0	0	0	0
Sulfuric Acid	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
Carbon Dioxide	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
Ammonia	0	0	0	0	0	0	0	0	0	0	0	0
Lactic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	8040	8041	8042	8043	8044
Stream Name	FLUE GAS				
Temp F	282.5036	76.2667	92.5274	399.2	356.1588
Pres psia	15.6959	14.5038	15.6959	15.6959	15.6959
Enth MMBtu/h	-615.69	-6.9776	-4.9329	33.996	-198.08
Vapor mass fraction	1	1	1	1	1
Total lb/h	587378	518972	518972	518972	587384
Flowrates in lb/h					
Glucose	0	0	0	0	0
Cellulose	0	0	0	0	0
Xylose	0	0	0	0	0
Xylan	0	0	0	0	0
Lignin	0	0	0	0	0
Acetate	0	0	0	0	0
Organism	0	0	0	0	0
Solslds	0	0	0	0	0
Gypsum	0	0	0	0	0
Lgnsol	0	0	0	0	0
HMF	0	0	0	0	0
C5Sugar	0	0	0	0	0
C6Sugar	0	0	0	0	0
C5Solid	0	0	0	0	0
C6Solid	0	0	0	0	0
CaH2O2	0	0	0	0	0
Ash	0	0	0	0	0
Ethanol	0	0.6119	0.6119	0.6119	0.6119
Water	45507.95	489.8474	489.8474	489.8474	2960.457
Furfural	0	10.9246	10.9246	10.9246	10.9246
Sulfuric Acid	0	0	0	0	0
Nitrogen	408590	408525.5	408525.5	408525.5	408525.5
Carbon Dioxide	99860	1034.341	1034.341	1034.341	48023.61
Oxygen	33419.24	108894.6	108894.6	108894.6	108894.6
Ammonia	0	14.9256	14.9256	14.9256	78.7408
Lactic Acid	0	0	0	0	0
Acetic Acid	0	0.8528	0.8528	0.8528	0.8528
Ammonium Sulfate	0	0	0	0	0
NH4ACET	0	0	0	0	0
Methane	0	0	0	0	18888.41
Nitrogen Dioxide	0.6315	0	0	0	0
Sulfur Dioxide	0	0	0	0	0
DAP	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0

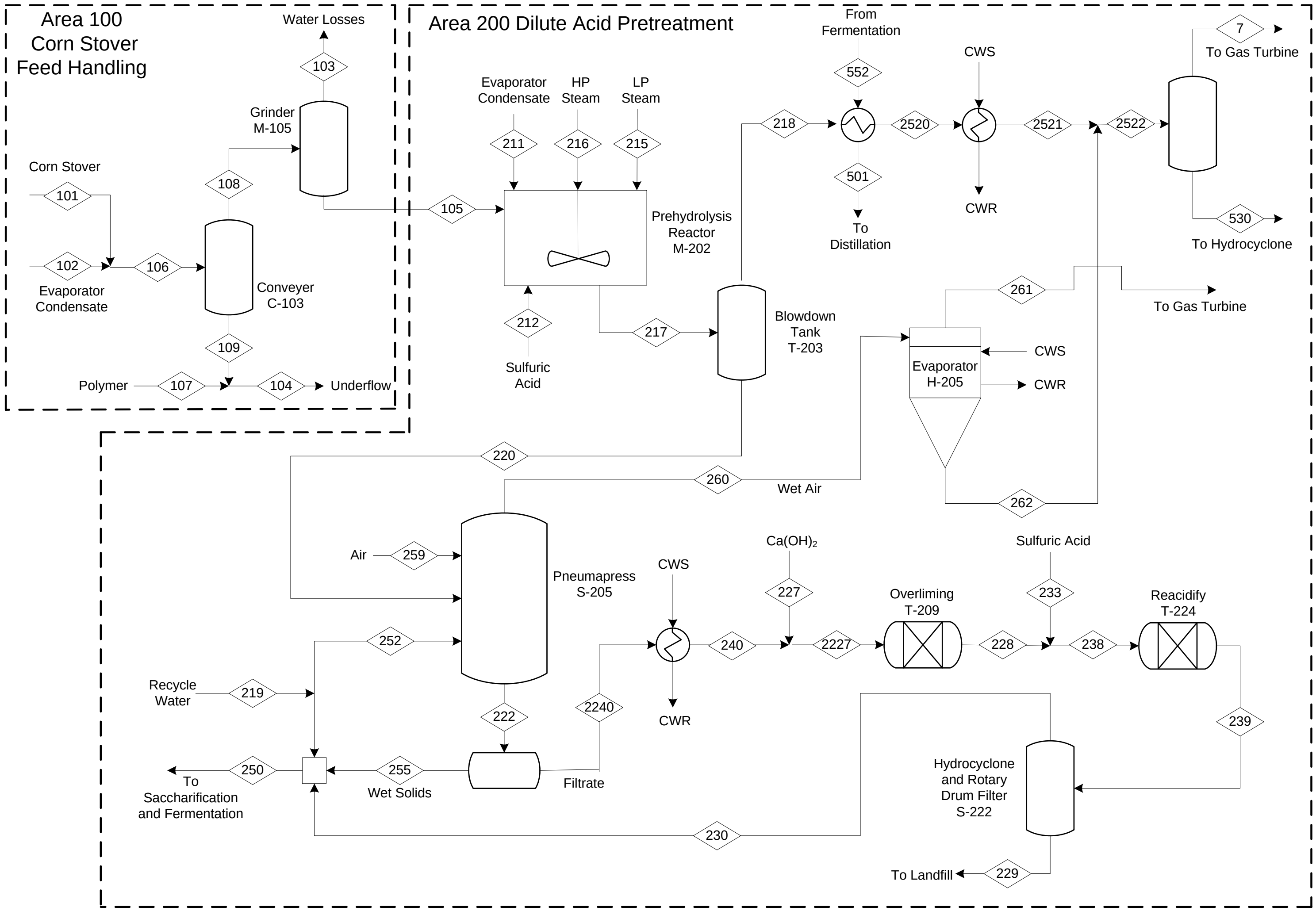

Figure II.5. Area 100,200 for Wet Gasification with CCGT Case

Stream No.	101	102	103	104	105	106	107	108	109	211	212	215
Stream Name	Corn Stove	A500 Water		Underflow	Underflow		Polymer	Water Los	Underflow	From A500	SulfuricAci	LP STM
Temp F	68	97.4373	113	83.5376	113	83.9914	68	83.9914	83.9914	97.4373	68	267.2453
Pres psia	14.6959	64.6959	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959	64.6959	50	39.9959
Enth MMBtu/h	-692.84	-643.26	-169.47	-15.034	-1147	-1336.1	-0.42725	-1321.5	-14.606	-1485.5	-15.98	-3.8509
Vapor mass fraction	0	0	0	0	0.001232	0.000317	0	0.00034	0	0	0	1
Total lb/h	216139.7	94832.43	24987.72	2207.126	283840	310972.2	62.5833	308827.6	2144.543	219004.8	4638.526	676.8192
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	0	0	0
Cellulose	68762.38	0	0	0	68762.38	68762.38	0	68762.38	0	0	0	0
Xylose	0	0	0	0	0	0	0	0	0	0	0	0
Xylan	38733.23	0	0	0	38733.23	38733.23	0	38733.23	0	0	0	0
Lignin	33075.58	0	0	0	33075.58	33075.58	0	33075.58	0	0	0	0
Acetate	5389.846	0	0	0	5389.846	5389.846	0	5389.846	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	16349.48	0	0	0	16349.48	16349.48	0	16349.48	0	0	0	0
Gypsum	0	0	0	0	0	0	0	0	0	0	0	0
Lgnsol	0	0	0	0	0	0	0	0	0	0	0	0
HMF	0	0	0	0	0	0	0	0	0	0	0	0
C5Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C6Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C5Solid	5373.108	0	0	0	5373.108	5373.108	0	5373.108	0	0	0	0
C6Solid	6427.643	0	0	0	6427.643	6427.643	0	6427.643	0	0	0	0
CaH2O2	0	0	0	0	0	0	0	0	0	0	0	0
Ash	9607.981	0	0	0	9607.981	9607.981	0	9607.981	0	0	0	0
Ethanol	0	0	0	0	0	0	0	0	0	0	0	0
Water	32420.45	94475.55	24987.72	2207.126	99763.75	126896	62.5833	124751.5	2144.543	218180.6	0	676.8192
Furfural	0	0	0	0	0	0	0	0	0	0	0	0
Sulfuric Acid	0	0	0	0	0	0	0	0	0	0	4638.526	0
Nitrogen	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	0	205.8701	0	0	205.8701	205.8701	0	205.8701	0	475.4335	0	0
Oxygen	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	0	151.0095	0	0	151.0095	151.0095	0	151.0095	0	348.7391	0	0
Lactic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	217	218	219	220	222	227	228	229	230	233	238	239
Stream Name			Recycle Watr			Ca(OH)2		To Landfill		SulfuricAcid		
Temp F	374	213.98	124.932	213.98	122	68	122.0591	127.8068	127.8652	68	121.9642	127.7477
Pres psia	162	14.6959	63.0456	14.6959	14.5038	14.6959	29.3919	14.6959	29.3919	50	29.3919	14.6959
Enth MMBtu/h	-3157	-1014.7	-3079.5	-2351.7	-4321.3	-40.875	-3446.7	-91.648	-3364	-8.9826	-3455.7	-3455.7
Vapor mass fraction	0.65075	1	0	0	0	0	0	1.99E-06	0	0	0	1.98E-06
Total lb/h	646910	179984.5	456566.3	466925.5	754092	7139.886	572766	17490.83	557882.1	2607.346	575373	575373
Flowrates in lb/h												
Glucose	5348.162	0	0	5348.162	5348.162	0	4990.37	26.3354	4964.034	0	4990.37	4990.37
Cellulose	62986.34	0	0	62986.34	62986.34	0	314.9337	313.359	1.5747	0	314.9337	314.9337
Xylose	39613.35	0	0	39613.35	39613.35	0	36975.1	195.1269	36780	0	36975.1	36975.1
Xylan	968.3278	0	0	968.3278	968.3278	0	4.8417	4.8174	0.0242	0	4.8417	4.8417
Lignin	31421.8	0	0	31421.8	31421.8	0	157.1095	156.3239	0.7856	0	157.1095	157.1095
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	16349.48	0	0	16349.48	16349.48	0	15427.37	81.4141	15345.96	0	15427.37	15427.37
Gypsum	0	0	0	0	0	0	7605.247	12121.38	60.9115	0	7605.247	12182.29
Lgnsol	1653.779	0	0	1653.779	1653.779	0	1561.002	8.2378	1552.764	0	1561.002	1561.002
HMF	249.9656	0.1038	0.2474	249.8618	250.0181	0	239.7424	1.2652	238.4772	0	239.7424	239.7424
C5Sugar	6748.214	0	0	6748.214	6748.214	0	6302.832	33.2616	6269.57	0	6302.832	6302.832
C6Sugar	7675.797	0	0	7675.797	7675.797	0	7169.194	37.8336	7131.361	0	7169.194	7169.194
C5Solid	134.3275	0	0	134.3275	134.3275	0	0	0	0	0	0	0
C6Solid	160.6906	0	0	160.6906	160.6906	0	0	0	0	0	0	0
CaH2O2	0	0	0	0	0	7139.886	3867.022	1887.837	9.4866	0	3867.022	1897.323
Ash	9607.981	0	0	9607.981	9607.981	0	48.0397	47.7995	0.2402	0	48.0397	48.0397
Ethanol	0	0	41.5393	0	25.6176	0	24.9438	0.1316	24.8122	0	24.9438	24.9438
Water	451178.4	176431.1	453899.5	274747.3	560752.3	0	482583.5	2546.714	480037	0	482583.5	482583.5
Furfural	1603.888	1178.707	714.4283	425.181	866.6915	0	835.4907	4.4091	831.0816	0	835.4907	835.4907
Sulfuric Acid	4638.526	0	0	4638.526	4638.526	0	0	0	0	2607.346	2607.346	0
Nitrogen	0	0	0	0	4.2672	0	4.2672	0.0225	4.2447	0	4.2672	4.2672
Carbon Dioxide	681.3036	681.255	810.798	0.0486	9.2132	0	9.2132	0.0486	9.1646	0	9.2132	9.2132
Oxygen	0	0	0	0	2.5139	0	2.5139	0.0133	2.5007	0	2.5139	2.5139
Ammonia	499.7485	434.1805	594.7353	65.5679	427.0073	0	427.0073	2.2534	424.7539	0	427.0073	427.0073
Lactic Acid	0	0	3.8321	0	2.4224	0	2.2964	0.0121	2.2843	0	2.2964	2.2964
Acetic Acid	5389.873	1259.176	501.2021	4130.696	4444.687	0	4213.563	22.236	4191.327	0	4213.563	4213.563
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	240	250	252	255	259	260	261	262	501	522	2227	2240	2520	2521	2522
Stream Name				WET SOL	AIR	WET AIR		TO 600				FILTRATE			
Temp F	122	126.3876	124.932	122	104	122	100.4	100.4	203	240.8	121.7401	122	211.6125	98.6	98.6201
Pres psia	14.5038	14.5038	63.0456	14.5038	139.6114	14.5038	14.5038	14.5038	58.7838	24.3365	14.5038	14.5038	14.6959	14.6959	15.6959
Enth MMBtu/h	-3401.2	-5417	-1946.6	-920.16	-0.00697	-7.1542	-4.64	-3.0431	-5824.1	-116.59	-3442	-3401.2	-1100.5	-1207.6	-1210.6
Vapor mass fraction	1.83E-06	4.07E-05	0	0	1	1	1	0	0.000434	1	1.79E-06	1.83E-06	0.50704	0.002954	0.002871
Total lb/h	565626	914301	288614	188466	10363.63	11811.26	11361.07	450.1874	960074	54248.69	572766	565626	179984.5	179984.5	180434.7
Flowrates in lb/h															
Glucose	4990.37	5321.826	0	357.7921	0	0	0	0	182.6596	0	4990.37	4990.37	0	0	0
Cellulose	314.9337	62673	0	62671.41	0	0	0	0	2381.573	0	314.9337	314.9337	0	0	0
Xylose	36975.1	39418.23	0	2638.249	0	0	0	0	2112.233	0	36975.1	36975.1	0	0	0
Xylan	4.8417	963.5104	0	963.4862	0	0	0	0	963.5104	0	4.8417	4.8417	0	0	0
Lignin	157.1095	31265.47	0	31264.69	0	0	0	0	31265.48	0	157.1095	157.1095	0	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	2947.92	0	0	0	0	0	0
Solslds	15427.37	16268.06	0	922.1107	0	0	0	0	16268.06	0	15427.37	15427.37	0	0	0
Gypsum	0	60.9115	0	0	0	0	0	0	60.9115	0	0	0	0	0	0
Lgnsol	1561.002	1645.541	0	92.777	0	0	0	0	1645.541	0	1561.002	1561.002	0	0	0
HMF	239.7424	248.8439	0.1564	10.2757	0	0	0	0	248.8439	0	239.7424	239.7424	0.1038	0.1038	0.1039
C5Sugar	6302.832	6714.953	0	445.3821	0	0	0	0	3070.577	0	6302.832	6302.832	0	0	0
C6Sugar	7169.194	7637.963	0	506.6026	0	0	0	0	7564.396	0	7169.194	7169.194	0	0	0
C5Solid	0	134.3275	0	134.3275	0	0	0	0	134.3275	0	0	0	0	0	0
C6Solid	0	160.6906	0	160.6906	0	0	0	0	160.6906	0	0	0	0	0	0
CaH2O2	0	9.4866	0	0	0	0	0	0	9.4866	0	7139.886	0	0	0	0
Ash	48.0397	9560.182	0	9559.941	0	0	0	0	9560.183	0	48.0397	48.0397	0	0	0
Ethanol	24.9438	40.7666	26.2586	0.6737	0	0.6411	0.608	0.0331	53784.33	53385.3	24.9438	24.9438	0	0	0.0331
Water	482583.4	725177.2	286928	78168.88	0	922.9312	476.3419	446.5893	813779	287.4269	482583.5	482583.4	176431.1	176431.1	176877.7
Furfural	835.4907	1125.092	451.6185	31.2009	0	10.108	9.3093	0.7987	1125.374	0.0455	835.4907	835.4907	1178.707	1178.707	1179.505
Sulfuric Acid	4332.383	306.1427	0	306.1427	0	0	0	0	306.1427	0	4332.383	4332.383	0	0	0
Nitrogen	4.2672	4.2447	0	0	7949.79	7945.523	7945.519	0.0043	0.0014	0	4.2672	4.2672	0	0	0.0043
Carbon Dioxide	9.2132	307.4249	512.5377	0	0	503.373	503.361	0.012	697.2119	3.3244	9.2132	9.2132	681.255	681.255	681.267
Oxygen	2.5139	2.5007	0	0	2413.844	2411.33	2411.327	0.0026	0.0664	0.0001	2.5139	2.5139	0	0	0.0026
Ammonia	427.0073	643.5334	375.9559	0	0	14.5164	13.824	0.6924	646.7361	572.5936	427.0073	427.0073	434.1805	434.1805	434.873
Lactic Acid	2.2964	3.82	2.4224	0.126	0	0	0	0	4319.519	0	2.2964	2.2964	0	0	0
Acetic Acid	4213.563	4606.823	316.8298	231.1237	0	2.8394	0.7844	2.055	6505.512	0	4213.563	4213.563	1259.176	1259.176	1261.231
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	334.0683	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

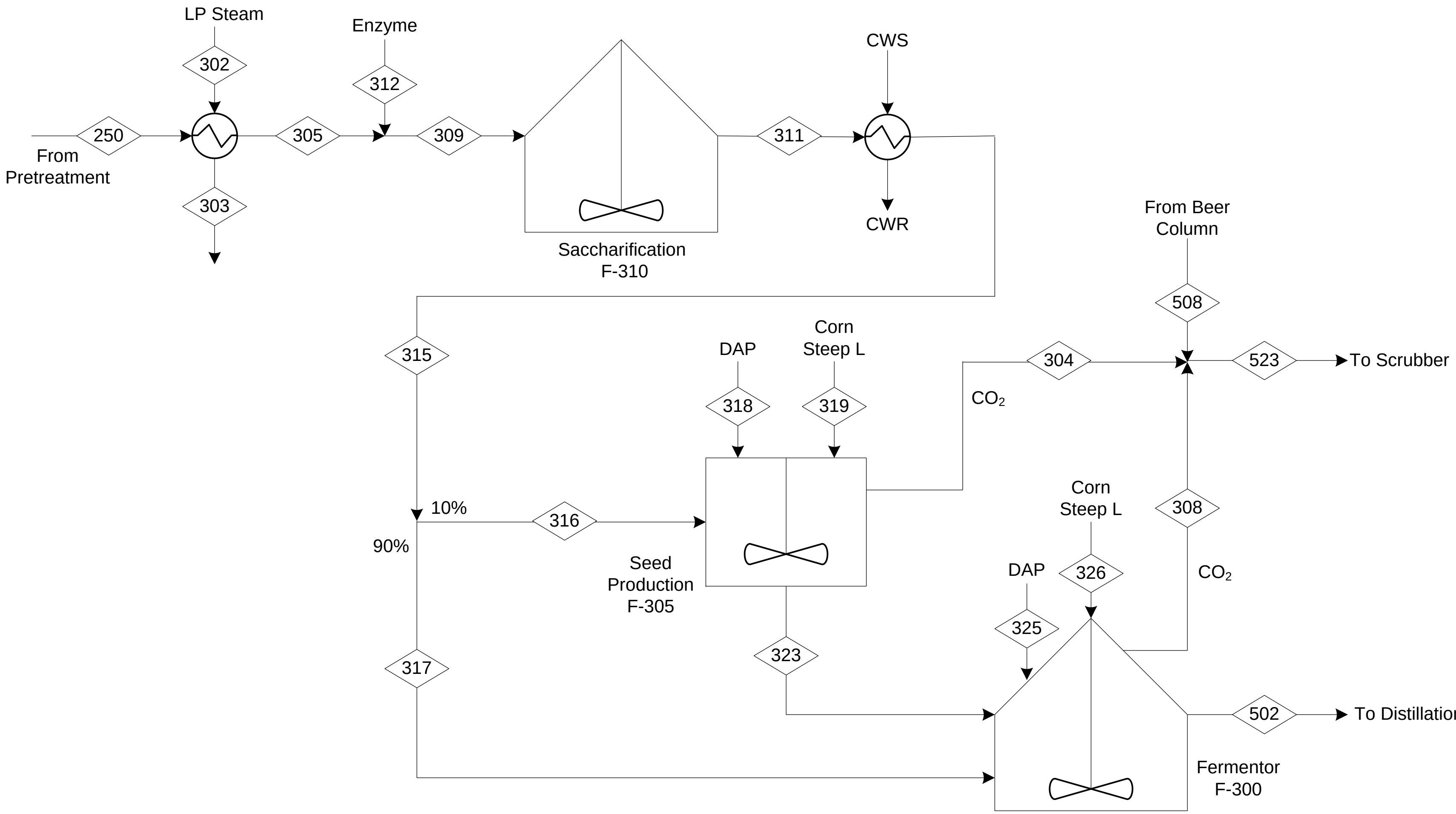

Figure II.6. Area 300 for Wet Gasification with CCGT Case

Stream No.	250	302	303	304	305	308	309	311	312	315	316	317
Stream Name		LP STM							Enzyme			
Temp F	126.3876	267.2453	267.2433	105.8	149	105.8	147.5256	149	68	105.8	105.8	105.8
Pres psia	14.5038	39.9959	39.9959	14.6959	29.3919	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959
Enth MMBtu/h	-5417	-106.47	-124.01	-16.467	-5399.4	-192.41	-5496.4	-5494.9	-97.013	-5528.8	-509.76	-5019.1
Vapor mass fraction	4.07E-05	1	0.000313	1	3.45E-06	1	0.000154	0.000153	0	3.64E-06	3.64E-06	3.64E-06
Total lb/h	914301	18712.77	18712.77	4299.328	914301	50183.76	929346	929346	15044.68	929346	85685.66	843660
Flowrates in lb/h												
Glucose	5321.826	0	0	0	5321.826	0	5321.826	68690.9	0	68690.9	6333.301	62357.6
Cellulose	62673	0	0	0	62673	0	62673	2381.573	0	2381.573	219.581	2161.992
Xylose	39418.23	0	0	0	39418.23	0	39418.23	39418.22	0	39418.22	3634.36	35783.87
Xylan	963.5104	0	0	0	963.5104	0	963.5104	963.5104	0	963.5104	88.8357	874.6747
Lignin	31265.47	0	0	0	31265.47	0	31265.47	31265.47	0	31265.47	2882.677	28382.8
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	1253.222	1253.222	1253.222	1253.222	115.547	1137.675
Solslds	16268.06	0	0	0	16268.06	0	16268.06	16268.06	0	16268.06	1499.916	14768.15
Gypsum	60.9115	0	0	0	60.9115	0	60.9115	60.9115	0	60.9115	5.616	55.2954
Lgnsol	1645.541	0	0	0	1645.541	0	1645.541	1645.541	0	1645.541	151.7189	1493.822
HMF	248.8439	0	0	0	248.8439	0	248.8439	248.8439	0	248.8439	22.9434	225.9005
C5Sugar	6714.953	0	0	0	6714.953	0	6714.953	6714.953	0	6714.953	619.1187	6095.834
C6Sugar	7637.963	0	0	0	7637.963	0	7637.963	11259.05	0	11259.05	1038.085	10220.97
C5Solid	134.3275	0	0	0	134.3275	0	134.3275	134.3275	0	134.3275	12.385	121.9425
C6Solid	160.6906	0	0	0	160.6906	0	160.6906	160.6906	0	160.6906	14.8157	145.8749
CaH2O2	9.4866	0	0	0	9.4866	0	9.4866	9.4866	0	9.4866	0.8747	8.6119
Ash	9560.182	0	0	0	9560.182	0	9560.182	9560.182	0	9560.182	881.4489	8678.733
Ethanol	40.7666	0	0	115.9986	40.7666	1541.969	40.7666	40.7666	0	40.7666	3.7587	37.0079
Water	725177.2	18712.77	18712.77	138.4553	725177.2	1611.556	738969	732270.1	13791.45	732270.1	67515.3	664755
Furfural	1125.092	0	0	1.2989	1125.092	14.7507	1125.092	1125.092	0	1125.092	103.7335	1021.359
Sulfuric Acid	306.1427	0	0	0	306.1427	0	306.1427	306.1427	0	306.1427	28.2264	277.9164
Nitrogen	4.2447	0	0	0.3912	4.2447	3.8522	4.2447	4.2447	0	4.2447	0.3914	3.8533
Carbon Dioxide	307.4249	0	0	4021.094	307.4249	46889.11	307.4249	307.4249	0	307.4249	28.3446	279.0803
Oxygen	2.5007	0	0	19.5256	2.5007	93.0176	2.5007	2.5007	0	2.5007	0.2306	2.2701
Ammonia	643.5334	0	0	2.1677	643.5334	24.9561	643.5334	643.5334	0	643.5334	59.3338	584.1996
Lactic Acid	3.82	0	0	0.0001	3.82	0.0033	3.82	3.82	0	3.82	0.3522	3.4678
Acetic Acid	4606.823	0	0	0.3965	4606.823	4.547	4606.823	4606.823	0	4606.823	424.7491	4182.074
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	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
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	318	319	323	325	326	502	508	523
Stream Name	DAP	Corn Steep L		DAP	Corn Steep L			
Temp F	68	68	105.8	68	68	105.8	140	105.9761
Pres psia	14.6959	14.6959	14.6959	14.6959	14.6959	14.6959	27.4	14.6959
Enth MMBtu/h	-0.31318	-3.3123	-498.36	-1.5391	-16.445	-5361	-3.1019	-211.98
Vapor mass fraction	0	0	0	0	0	0	1	1
Total lb/h	61.0923	485.1779	81932.66	300.2388	2408.773	878118	842.7695	55325.86
Flowrates in lb/h								
Glucose	0	0	411.6645	0	0	182.6596	0	0
Cellulose	0	0	219.581	0	0	2381.573	0	0
Xylose	0	0	508.8102	0	0	2112.233	0	0
Xylan	0	0	88.8357	0	0	963.5104	0	0
Lignin	0	0	2882.677	0	0	31265.48	0	0
Acetate	0	0	0	0	0	0	0	0
Organism	0	0	412.7426	0	0	2947.92	0	0
Solslds	0	0	1499.916	0	0	16268.06	0	0
Gypsum	0	0	5.616	0	0	60.9115	0	0
Lgnsol	0	0	151.7189	0	0	1645.541	0	0
HMF	0	0	22.9434	0	0	248.8439	0	0
C5Sugar	0	0	691.8058	0	0	3070.577	0	0
C6Sugar	0	0	1038.085	0	0	7564.396	0	0
C5Solid	0	0	12.385	0	0	134.3275	0	0
C6Solid	0	0	14.8157	0	0	160.6906	0	0
CaH2O2	0	0	0.8747	0	0	9.4866	0	0
Ash	0	0	881.4489	0	0	9560.183	0	0
Ethanol	0	0	4127.911	0	0	52017.65	110.9376	1768.905
Water	0	485.1779	67912.73	0	2408.773	733703.2	34.3363	1784.347
Furfural	0	0	102.4347	0	0	1109.043	0.2845	16.3341
Sulfuric Acid	0	0	28.2264	0	0	306.1427	0	0
Nitrogen	0	0	0.0001	0	0	0.0013	0.0014	4.2448
Carbon Dioxide	0	0	57.8915	0	0	634.9404	693.8873	51604.09
Oxygen	0	0	0.0134	0	0	0.0601	0.0663	112.6095
Ammonia	0	0	57.1661	0	0	616.4096	3.2363	30.3601
Lactic Acid	0	0	146.0181	0	0	4319.516	0	0.0034
Acetic Acid	0	0	600.0297	0	0	6500.549	0.0197	4.9632
Ammonium Sulfate	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0
DAP	61.0923	0	56.3113	300.2388	0	334.0683	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0

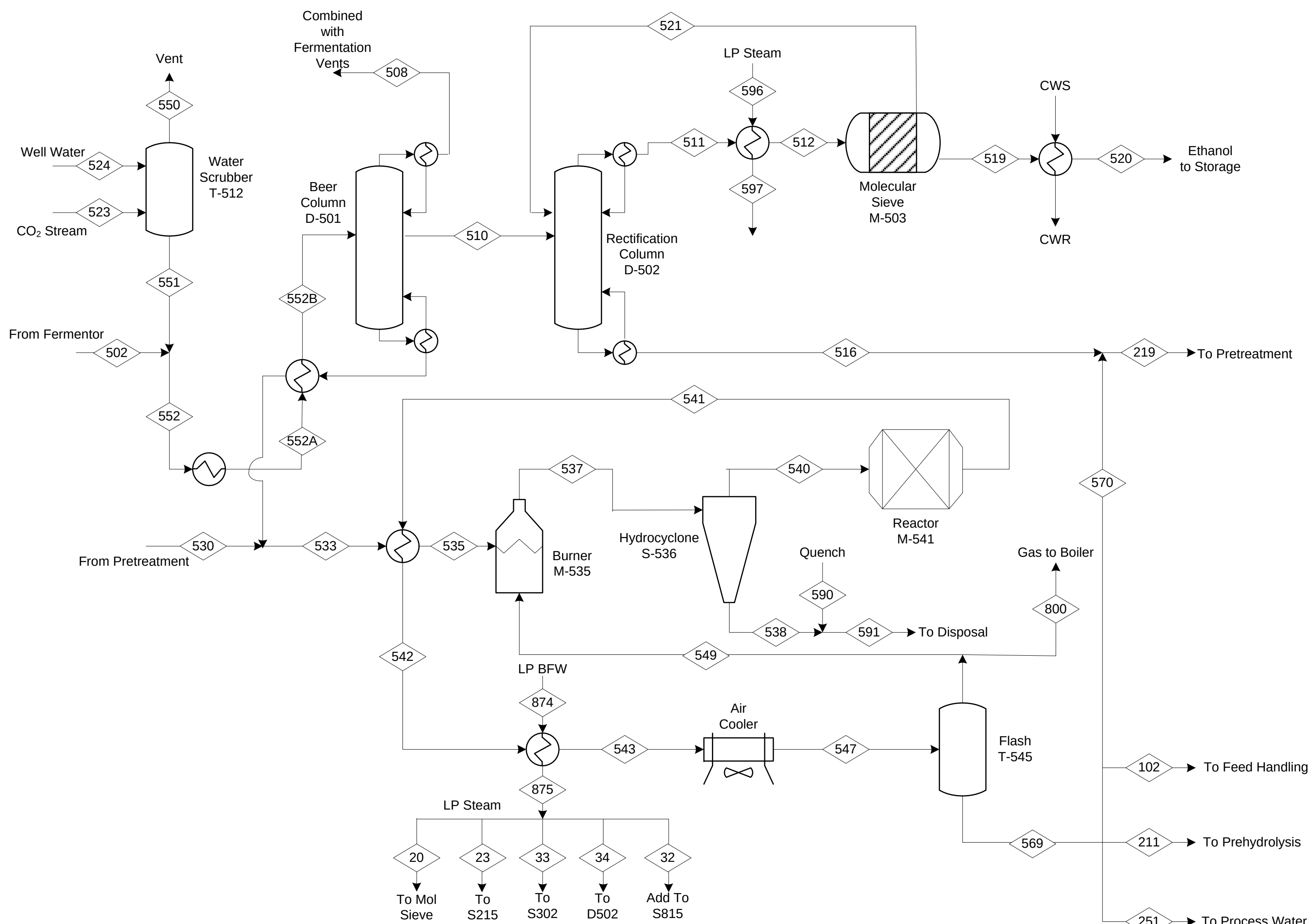

Figure II.7. Area 500 for Wet Gasification with CCGT Case

Stream No.	20	23	32	33	34	102	211	219	5251	502	508	510
Stream Name		To S215		To S302	To D502	A500 Wate	From A500	Recycle W	To T-914			
Temp F	267.2494	267.2494	267.2494	267.2494	267.2494	97.4373	97.4373	124.932	150.7043	105.8	140	235.5072
Pres psia	40	40	40	40	40	64.6959	64.6959	63.0456	139.6959	14.6959	27.4	28.1143
Enth MMBtu/h	-8.0945	-3.8572	-592.05	-106.64	-96.694	-643.26	-1485.5	-3079.5	-1363.7	-5361	-3.1019	-586.56
Vapor mass fraction	0.99	0.99	0.99	0.99	0.99	0	0	0	0	0	1	1
Total lb/h	1420.331	676.8192	103886.3	18712.77	16966.68	94832.43	219004.8	456566.3	202697.2	878118	842.7695	137412
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	182.6596	0	0
Cellulose	0	0	0	0	0	0	0	0	0	2381.573	0	0
Xylose	0	0	0	0	0	0	0	0	0	2112.233	0	0
Xylan	0	0	0	0	0	0	0	0	0	963.5104	0	0
Lignin	0	0	0	0	0	0	0	0	0	31265.48	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	2947.92	0	0
Solslds	0	0	0	0	0	0	0	0	0	16268.06	0	0
Gypsum	0	0	0	0	0	0	0	0	0	60.9115	0	0
Lgnsol	0	0	0	0	0	0	0	0	0	1645.541	0	0
HMF	0	0	0	0	0	0	0	0.2474	0	248.8439	0	0.0221
C5Sugar	0	0	0	0	0	0	0	0	0	3070.577	0	0
C6Sugar	0	0	0	0	0	0	0	0	0	7564.396	0	0
C5Solid	0	0	0	0	0	0	0	0	0	134.3275	0	0
C6Solid	0	0	0	0	0	0	0	0	0	160.6906	0	0
CaH2O2	0	0	0	0	0	0	0	0	0	9.4866	0	0
Ash	0	0	0	0	0	0	0	0	0	9560.183	0	0
Ethanol	0	0	0	0	0	0	0	41.5393	0	52017.65	110.9376	53426.85
Water	1420.331	676.8192	103886.3	18712.77	16966.68	94475.55	218180.6	453899.5	201821.3	733703.2	34.3363	82451.67
Furfural	0	0	0	0	0	0	0	714.4283	0	1109.043	0.2845	669.5151
Sulfuric Acid	0	0	0	0	0	0	0	0	0	306.1427	0	0
Nitrogen	0	0	0	0	0	0	0	0	0	0.0013	0.0014	0
Carbon Dioxide	0	0	0	0	0	205.8701	475.4335	810.798	522.0995	634.9404	693.8873	3.3244
Oxygen	0	0	0	0	0	0	0	0	0	0.0601	0.0663	0.0001
Ammonia	0	0	0	0	0	151.0095	348.7391	594.7353	340.5571	616.4096	3.2363	579.9099
Lactic Acid	0	0	0	0	0	0	0	3.8321	0	4319.516	0	2.6574
Acetic Acid	0	0	0	0	0	0	0	501.2021	0	6500.549	0.0197	277.9614
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	0	0	0	13.2637	0	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	334.0683	0	0
2-2-4-TriMth-C5	0		0	0	0	0		0	0	0	0	0

Stream No.	511	512	516	519	520	521	523	524	530	533	535	537
Stream Name								Well Water				
Temp F	196.1459	240.8	248.7643	197.06	98.6	150.7043	105.9761	78.8	98.6194	215.0917	635	701.6
Pres psia	24.3365	24.3365	63.0456	21.1622	14.6959	139.6959	14.6959	14.6959	15.6959	74.6959	3064.696	3054.696
Enth MMBtu/h	-177.03	-175.7	-547.56	-117.53	-140.46	-1363.7	-211.98	-539.66	-1208.6	-6311.4	-5856.1	-5680.3
Vapor mass fraction	1	1	0	1	0	0	1	0	0	0	0	0.40905
Total lb/h	72900.04	72900.04	83158	54248.69	54248.69	202697.2	55325.86	79172.41	179916.8	1001713	1001713	1001713
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	182.6596	182.6596	182.6596
Cellulose	0	0	0	0	0	0	0	0	0	2381.573	2381.573	2381.573
Xylose	0	0	0	0	0	0	0	0	0	2112.233	2112.233	2112.233
Xylan	0	0	0	0	0	0	0	0	0	963.5104	963.5104	963.5104
Lignin	0	0	0	0	0	0	0	0	0	31265.48	31265.48	31265.48
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	2947.92	2947.92	2947.92
Solslds	0	0	0	0	0	0	0	0	0	16268.06	16268.06	16268.06
Gypsum	0	0	0	0	0	0	0	0	0	60.9115	60.9115	60.9115
Lgnsol	0	0	0	0	0	0	0	0	0	1645.541	1645.541	1645.541
HMF	0	0	0.0221	0	0	0	0	0	0.1039	248.9257	248.9257	248.9257
C5Sugar	0	0	0	0	0	0	0	0	0	3070.577	3070.577	3070.577
C6Sugar	0	0	0	0	0	0	0	0	0	7564.396	7564.396	7564.396
C5Solid	0	0	0	0	0	0	0	0	0	134.3275	134.3275	134.3275
C6Solid	0	0	0	0	0	0	0	0	0	160.6906	160.6906	160.6906
CaH2O2	0	0	0	0	0	0	0	0	0	9.4866	9.4866	9.4866
Ash	0	0	0	0	0	0	0	0	0	9560.183	9560.183	9560.183
Ethanol	66648.31	66648.31	41.579	53385.3	53385.3	0	1768.905	0	0.033	246.5779	246.5779	246.5779
Water	5675.757	5675.757	82159	287.4269	287.4269	201821.3	1784.347	79172.41	176865	908136	908136	908136
Furfural	0.0455	0.0455	669.4694	0.0455	0.0455	0	16.3341	0	1178.627	1633.43	1633.43	1633.43
Sulfuric Acid	0	0	0	0	0	0	0	0	0	306.1427	306.1427	306.1427
Nitrogen	0	0	0	0	0	0	4.2448	0	0	0	0	0
Carbon Dioxide	3.3244	3.3244	0	3.3244	3.3244	522.0995	51604.09	0	177.6546	177.6264	177.6264	177.6264
Oxygen	0.0001	0.0001	0	0.0001	0.0001	0	112.6095	0	0	0	0	0
Ammonia	572.5936	572.5936	7.3159	572.5936	572.5936	340.5571	30.3601	0	434.2969	497.839	497.839	497.8389
Lactic Acid	0	0	2.6574	0	0	0	0.0034	0	0	4316.863	4316.863	4316.863
Acetic Acid	0	0	277.9614	0	0	0	4.9632	0	1261.198	7488.544	7488.544	7488.544
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	13.2637	0	0	0	0	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	334.0683	334.0683	334.0683
2-2-4-TriMth-C5	0	0	0		0	0	0	0	0	0	0	0

Stream No.	538	541	542	543	547	549	550	551	552	552A	552B	569
Stream Name						to E-535	Vent					
Temp F	701.6	667.3715	434.0524	300	150	150.7043	80.964	101.9665	105.443	203	212	150.7043
Pres psia	3034.696	3014.696	3009.696	3004.696	2994.696	139.6959	13.2263	13.2263	58.7838	58.7838	69.9527	139.6959
Enth MMBtu/h	-53.293	-5589.9	-6032.7	-6174.4	-6317.3	-123.42	-202.81	-548.83	-5909.9	-5824.1	-5816	-5988.1
Vapor mass fraction	0	0.80419	0.092306	0.10077	0.082874	1	1	0	0	0.000434	0.000431	0
Total lb/h	12912.57	988487	988530	988530	988530	36926.32	52542.55	81955.71	960074	960074	960074	890038
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	182.6596	182.6596	182.6596	0
Cellulose	0	0	0	0	0	0	0	0	2381.573	2381.573	2381.573	0
Xylose	0	0	0	0	0	0	0	0	2112.233	2112.233	2112.233	0
Xylan	0	0	0	0	0	0	0	0	963.5104	963.5104	963.5104	0
Lignin	0	0	0	0	0	0	0	0	31265.48	31265.48	31265.48	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	2947.92	0	0	0	0	0	0	0	2947.92	2947.92	2947.92	0
Solslds	0	0	0	0	0	0	0	0	16268.06	16268.06	16268.06	0
Gypsum	60.9115	0	0	0	0	0	0	0	60.9115	60.9115	60.9115	0
Lgnsol	0	0	0	0	0	0	0	0	1645.541	1645.541	1645.541	0
HMF	0	0	0	0	0	0	0	0	248.8439	248.8439	248.8439	0
C5Sugar	0	0	0	0	0	0	0	0	3070.577	3070.577	3070.577	0
C6Sugar	0	0	0	0	0	0	0	0	7564.396	7564.396	7564.396	0
C5Solid	0	0	0	0	0	0	0	0	134.3275	134.3275	134.3275	0
C6Solid	0	0	0	0	0	0	0	0	160.6906	160.6906	160.6906	0
CaH2O2	9.4866	0	0	0	0	0	0	0	9.4866	9.4866	9.4866	0
Ash	9560.183	0	0	0	0	0	0	0	9560.183	9560.183	9560.183	0
Ethanol	0	0	0	0	0	0	2.229	1766.677	53784.33	53784.33	53784.33	0
Water	0	887992	888024	888024	888024	687.0106	881.6156	80075.13	813779	813779	813779	886192
Furfural	0	0	0	0	0	0	0.0028	16.3312	1125.374	1125.374	1125.374	0
Sulfuric Acid	0	0	0	0	0	0	0	0	306.1427	306.1427	306.1427	0
Nitrogen	0	0	0	0	0	0	4.2447	0.0001	0.0014	0.0014	0.0014	0
Carbon Dioxide	0	70869.87	70877.34	70877.34	70877.34	25713.6	51541.82	62.2714	697.2119	697.2119	697.2119	2292.524
Oxygen	0	0	0	0	0	0	112.6033	0.0062	0.0664	0.0664	0.0664	0
Ammonia	0	1540.828	1541.242	1541.242	1541.242	17.1958	0.0337	30.3264	646.7361	646.7361	646.7361	1495.377
Lactic Acid	0	0	0	0	0	0	0	0.0034	4319.519	4319.519	4319.519	0
Acetic Acid	0	0	0	0	0	0	0	4.9632	6505.512	6505.512	6505.512	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	28084.44	28087.15	28087.15	28087.15	10508.51	0	0	0	0	0	58.2405
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	334.0683	0	0	0	0	0	0	0	334.0683	334.0683	334.0683	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	570	590	591	596	597	800	874	875
Stream Name		QUENCH		LP STM			BFW	
Temp F	150.7043	142.2207	270.0169	267.2453	267.2433	150.7043	196.1521	267.2494
Pres psia	139.6959	64.6959	64.6959	39.9959	39.9959	139.6959	45	40
Enth MMBtu/h	-2512.8	-74.438	-127.73	-8.0812	-9.4124	-205.77	-948.98	-807.34
Vapor mass fraction	0	0	0	1	0.000313	1	0	0.99
Total lb/h	373490.6	11023.11	23935.68	1420.331	1420.331	61565.71	141663	141663
Flowrates in lb/h								
Glucose	0	0	0	0	0	0	0	0
Cellulose	0	0	0	0	0	0	0	0
Xylose	0	0	0	0	0	0	0	0
Xylan	0	0	0	0	0	0	0	0
Lignin	0	0	0	0	0	0	0	0
Acetate	0	0	0	0	0	0	0	0
Organism	0	0	2947.92	0	0	0	0	0
Solslds	0	0	0	0	0	0	0	0
Gypsum	0	0	60.9115	0	0	0	0	0
Lgnsol	0	0	0	0	0	0	0	0
HMF	0	0	0	0	0	0	0	0
C5Sugar	0	0	0	0	0	0	0	0
C6Sugar	0	0	0	0	0	0	0	0
C5Solid	0	0	0	0	0	0	0	0
C6Solid	0	0	0	0	0	0	0	0
CaH2O2	0	0	9.4866	0	0	0	0	0
Ash	0	0	9560.183	0	0	0	0	0
Ethanol	0	0	0	0	0	0	0	0
Water	371877	11023.11	11023.11	1420.331	1420.331	1145.424	141663	141663
Furfural	0	0	0	0	0	0	0	0
Sulfuric Acid	0	0	0	0	0	0	0	0
Nitrogen	0	0	0	0	0	0	0	0
Carbon Dioxide	962.0226	0	0	0	0	42871.22	0	0
Oxygen	0	0	0	0	0	0	0	0
Ammonia	627.512	0	0	0	0	28.6698	0	0
Lactic Acid	0	0	0	0	0	0	0	0
Acetic Acid	0	0	0	0	0	0	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0
Methane	24.4397	0	0	0	0	17520.4	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0
DAP	0	0	334.0683	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0

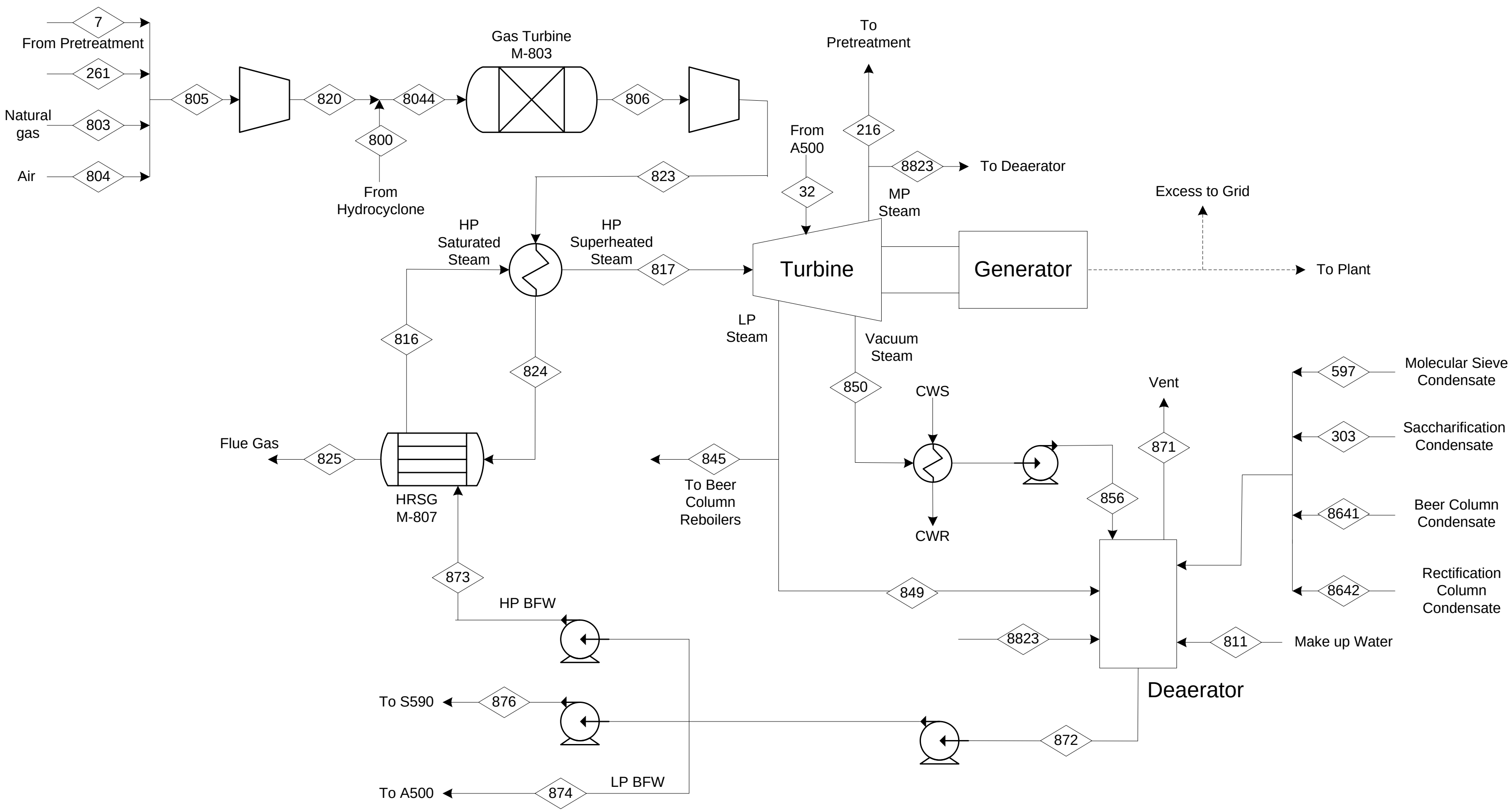

Figure II.8. Area 800 for Wet Gasification with CCGT Case

Stream No.	7	32	216	261	303	800	803	804	805	806	811	816
Stream Name			HP STM			GAS TO B	NG	Air		806	Well MU Wate	
Temp F	98.6194	267.2494	534.4369	100.4	267.2433	150.7043	77	75.2	75.8736	2190.071	78.8	526.6034
Pres psia	15.6959	40	191.0959	14.5038	39.9959	139.6959	139.6959	14.6959	14.5038	139.6959	24.9831	860
Enth MMBtu/h	-2.0065	-592.05	-775.72	-4.64	-124.01	-205.77	-5.2704	-0.33274	-12.25	-142.13	-1239.8	-1112.8
Vapor mass fraction	1	0.99	1	1	0.000313	1	1	1	1	1	0	0.99
Total lb/h	517.9357	103886.3	138749.9	11361.07	18712.77	61565.71	2500.001	763326	777705	839270	181894	196074.6
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	0	0	0
Cellulose	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
Xylan	0	0	0	0	0	0	0	0	0	0	0	0
Lignin	0	0	0	0	0	0	0	0	0	0	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	0	0	0	0	0	0	0	0	0	0	0	0
Gypsum	0	0	0	0	0	0	0	0	0	0	0	0
Lgnsol	0	0	0	0	0	0	0	0	0	0	0	0
HMF	0	0	0	0	0	0	0	0	0	0	0	0
C5Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C6Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C5Solid	0	0	0	0	0	0	0	0	0	0	0	0
C6Solid	0	0	0	0	0	0	0	0	0	0	0	0
CaH2O2	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0
Ethanol	0	0	0	0.608	0	0	0	0	0.608	0	0	0
Water	12.8299	103886.3	138749.9	476.3419	18712.77	1145.424	0	0	489.1718	46401.25	181894	196074.6
Furfural	0.8778	0	0	9.3093	0	0	0	0	10.1871	0	0	0
Sulfuric Acid	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	0.0043	0	0	7945.519	0	0	0	603027	610973	611004.1	0	0
Carbon Dioxide	503.6124	0	0	503.361	0	42871.22	120.0001	0	1126.973	98616.18	0	0
Oxygen	0.0026	0	0	2411.327	0	0	0	160298.5	162710	83235.08	0	0
Ammonia	0.576	0	0	13.824	0	28.6698	0	0	14.4001	0	0	0
Lactic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0.0326	0	0	0.7844	0	0	0	0	0.8169	0	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	0	0	0	0	17520.4	2380.001	0	2380.001	0	0	0
Nitrogen Dioxide	0	0	0	0	0	0	0	0	0	12.6947	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	817	820	823	824	825	845	849	850	856	871	872	873
Stream Name					Flue Gas	To D501	to Dearatr			VENT		HP BFW
Temp F	900	501.4625	1256.878	1102.389	250	267.2494	267.2494	122.3441	122.3716	195.7284	195.7284	197.0124
Pres psia	850	139.6959	14.6959	14.6959	14.6959	40	40	1.4696	61.7229	39.9959	39.9959	870
Enth MMBtu/h	-1075.4	63.735	-379.16	-416.53	-609.51	-894.85	-9.1463	-0.01177	-0.01356	0	-2549.9	-1314.7
Vapor mass fraction	1	1	1	1	1	0.99291	0.99291	0.87327	0	1	0	0
Total lb/h	196064	777705	839270	839270	839270	157092.8	1605.666	2	2	0	380189.2	196107.1
Flowrates in lb/h												
Glucose	0	0	0	0	0	0	0	0	0	0	0	0
Cellulose	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
Xylan	0	0	0	0	0	0	0	0	0	0	0	0
Lignin	0	0	0	0	0	0	0	0	0	0	0	0
Acetate	0	0	0	0	0	0	0	0	0	0	0	0
Organism	0	0	0	0	0	0	0	0	0	0	0	0
Solslds	0	0	0	0	0	0	0	0	0	0	0	0
Gypsum	0	0	0	0	0	0	0	0	0	0	0	0
Lgnsol	0	0	0	0	0	0	0	0	0	0	0	0
HMF	0	0	0	0	0	0	0	0	0	0	0	0
C5Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C6Sugar	0	0	0	0	0	0	0	0	0	0	0	0
C5Solid	0	0	0	0	0	0	0	0	0	0	0	0
C6Solid	0	0	0	0	0	0	0	0	0	0	0	0
CaH2O2	0	0	0	0	0	0	0	0	0	0	0	0
Ash	0	0	0	0	0	0	0	0	0	0	0	0
Ethanol	0	0.608	0	0	0	0	0	0	0	0	0	0
Water	196064	489.1718	46401.25	46401.25	46401.25	157092.8	1605.666	2	2	0	380189.2	196107.1
Furfural	0	10.1871	0	0	0	0	0	0	0	0	0	0
Sulfuric Acid	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	0	610973	611004.1	611004.1	611004.1	0	0	0	0	0	0	0
Carbon Dioxide	0	1126.973	98616.18	98616.18	98616.18	0	0	0	0	0	0	0
Oxygen	0	162710	83235.08	83235.08	83235.08	0	0	0	0	0	0	0
Ammonia	0	14.4001	0	0	0	0	0	0	0	0	0	0
Lactic Acid	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	0	0.8169	0	0	0	0	0	0	0	0	0	0
Ammonium Sulfate	0	0	0	0	0	0	0	0	0	0	0	0
NH4ACET	0	0	0	0	0	0	0	0	0	0	0	0
Methane	0	2380.001	0	0	0	0	0	0	0	0	0	0
Nitrogen Dioxide	0	0	12.6947	12.6947	12.6947	0	0	0	0	0	0	0
Sulfur Dioxide	0	0	0	0	0	0	0	0	0	0	0	0
DAP	0	0	0	0	0	0	0	0	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0	0	0	0	0	0	0	0	0

Stream No.	874	876	8642	8823
Stream Name	BFW	To S590		
Temp F	196.1521	188.2149	267.2494	537.4555
Pres psia	45	65	40	191.0959
Enth MMBtu/h	-948.98	-73.93	-112.57	-13.951
Vapor mass fraction	0	0	0	1
Total lb/h	141663	11023	16966.68	2500
Flowrates in lb/h				
Glucose	0	0	0	0
Cellulose	0	0	0	0
Xylose	0	0	0	0
Xylan	0	0	0	0
Lignin	0	0	0	0
Acetate	0	0	0	0
Organism	0	0	0	0
Solslds	0	0	0	0
Gypsum	0	0	0	0
Lgnsol	0	0	0	0
HMF	0	0	0	0
C5Sugar	0	0	0	0
C6Sugar	0	0	0	0
C5Solid	0	0	0	0
C6Solid	0	0	0	0
CaH2O2	0	0	0	0
Ash	0	0	0	0
Ethanol	0	0	0	0
Water	141663	11023	16966.68	2500
Furfural	0	0	0	0
Sulfuric Acid	0	0	0	0
Nitrogen	0	0	0	0
Carbon Dioxide	0	0	0	0
Oxygen	0	0	0	0
Ammonia	0	0	0	0
Lactic Acid	0	0	0	0
Acetic Acid	0	0	0	0
Ammonium Sulfate	0	0	0	0
NH4ACET	0	0	0	0
Methane	0	0	0	0
Nitrogen Dioxide	0	0	0	0
Sulfur Dioxide	0	0	0	0
DAP	0	0	0	0
2-2-4-TriMth-C5	0	0	0	0