



Gasification of *Leucaena leucocephala* Stemwood

REPORT

Prepared for

Hawaii Natural Energy Institute
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SUMMARY

Hawaii Natural Energy Institute (HNEI) issued a request for bench-scale, fluidized bed, biomass gasification test services. ThermoChem Recovery International, Inc. (TRI) which owns and operates a Feedstock Test Reformer (FTR) was awarded a contract to perform gasification trials of HNEI feedstocks. Two trials were performed, one with clean wood and another with construction and demolition (C&D) waste. The objective of these tests was to evaluate the preliminary performance and operability of the steam reforming system for processing these feedstocks. Specific targets of investigation included operational characteristics such as agglomeration-free operation, product gas composition and yield, tars yield, fate of contaminants, preliminary estimate of carbon conversion, analysis of bed solids and filter catch solids, and stability, reliability, and safety of operation. This report provides details of the test and the results for clean wood, *Leucaena leucocephala* Stemwood supplied by HNEI.

This work comprised tasks pertaining to feeder calibration with feedstock, test facility modification, test plan development, test system preparation, test unit commissioning, testing, data and sample acquisition and analysis, data reduction and reporting.

The test was carried out successfully in the TRI Feedstock Test Reformer located at the TRI Advanced Development Center in Durham, North Carolina. Highlights:

- ➔ The feedstock gasified well with no agglomeration and no operability issues,
- ➔ The feedstock yielded a medium calorific value syngas, and
- ➔ The feedstock is an excellent candidate for conversion into biofuel/power/biochemical using the TRI steam reforming technology.

OBJECTIVES

The primary objectives and evaluation criteria for a successful TRI FTR test are as follows:

1. Determine if the HNEI feedstock can be fed at a steady rate by the feeder
2. Determine the properties of the HNEI feedstock
3. Evaluate the preliminary performance and operability of the steam reforming system for processing the HNEI feedstock
4. Check for the formation of agglomerates or degradation of the bed media
5. Determine the product gas composition, yield, and H₂ to CO molar ratio
6. Confirm that the steam reforming process, using the FTR, can produce a syngas from the HNEI feedstock with a stable gas composition
7. Quantify and speciate the volatile organic compounds (VOC) and semi-volatile organic compounds (SVOC) in the gas stream
8. Quantify the contaminants (S, Cl, and N compounds) and metals in the syngas stream
9. Determine the carbon content of the bed solids and filter catch solids
10. Perform an elemental mass balance and determine the carbon conversion
11. Evaluate the stability, reliability, operability, and safety of the process

TEST FACILITY DESCRIPTION

TRI has constructed and commissioned a nominal 2.25 kg/h (~5 lb/h) feedstock to syngas steam reformer, which is ideally suited to execute project pre-feasibility steam reforming tests on a variety of feedstocks. The FTR is located at TRI's Advanced Development Center (ADC) in Durham, North Carolina and comprises the following components and subsystems:

- Solid feedstock metering and feed subsystem;
- Indirectly heated steam reformer vessel;
- Steam generation and metering subsystem;
- Fluidization gas (other than steam such as CO₂ and O₂) metering and preheating subsystem;
- Hot gas filter;
- Product gas sampling trains for gas composition, particulates, tars, and contaminants;
- Gas chromatograph (GC) for monitoring product gas composition;
- Oxidizer; and,
- Instrumentation and controls.

Figure 1 shows the feeder system, which injects feedstock into the gasifier at a specified rate.

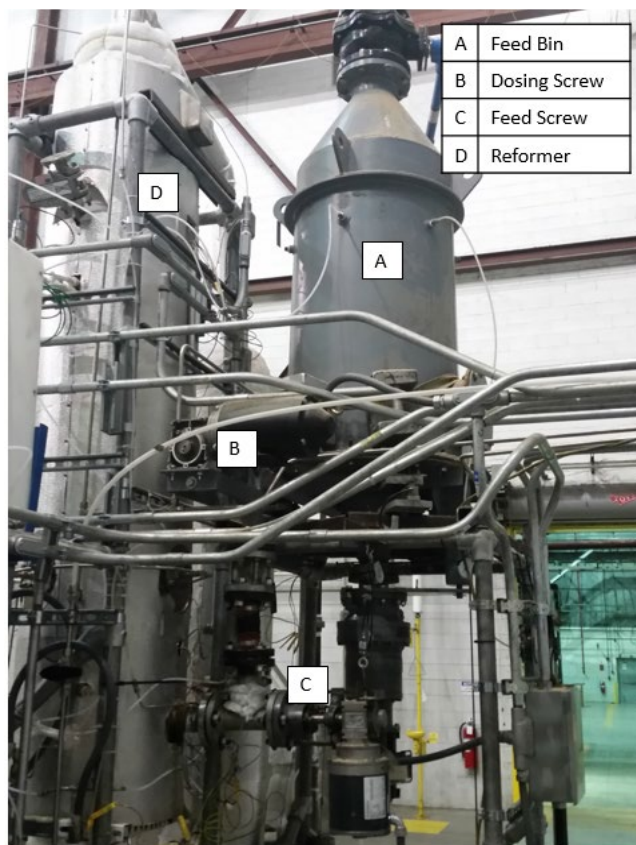


Figure 1. TRI FTR Feeder System

The reformer fluidized bed can operate at a wide range of temperatures, typically ranging from 600°C (~1100°F) to 785°C (~1450°F). The bed is fluidized with steam during normal operation and uses nitrogen or carbon dioxide for fluidization startup and instrumentation purges. Oxygen is added as necessary to simulate commercial scale operation. All fluidization and purge gases are carefully metered. While in the reformer, the feedstock is directly contacted by the fluidized bed particles and rapidly heated close to the bed temperature. It undergoes the following steps:

- Drying and devolatilization, where water and volatiles are released in the form of steam, H₂, CO, CO₂, CH₄, and some hydrocarbons;
- Steam reforming, where organic carbon endothermically reacts with steam to generate H₂ and CO;
- If oxygen is injected, partial oxidation where organic carbon exothermically reacts with oxygen to form mainly CO;
- Water-gas and hydrogenation reactions where pyrolysis products react with steam and hydrogen to reduce contaminants into water-soluble compounds that are readily captured and removed during syngas cleaning steps; and,
- Water-gas shift reaction, a reversible reaction where steam reacts with CO to generate H₂ and CO₂.

Fluidization gas and steam are pre-heated using gas heaters (F) before entering the reformer (D) as shown in Figure 2 below. Clamshell type heaters affixed to the outside of the reformer (D) provide indirect heat to maintain the target bed temperature and supply the endothermic heat of reaction. The temperature of the gas heaters (F), various sensors, and flow rates of all entering and exiting streams are monitored, actuated, and controlled via the control panel (E) and Distributed Control System (DCS) screens (not shown).

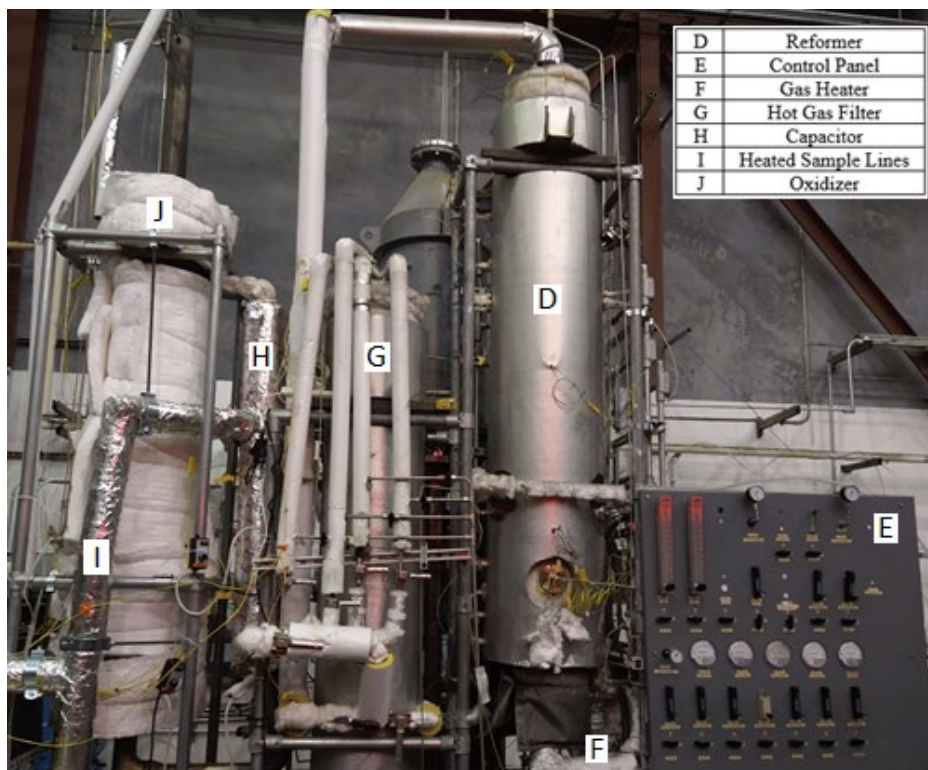


Figure 2. TRI FTR Front Side

Following the reformer (D), the product gas, comprised primarily of H_2 , CO, CO_2 , N_2 (depending on fluidization gas chosen), steam, and hydrocarbons proceeds through a hot gas filter (G) to remove particulates including carbon and ash; the hot gas filter has a pore size of 0.5 microns. From the hot gas filter (G), the product gas goes into a capacitor (H) which has five slipstreams directed from it. Three of these slipstreams are directed through heated sample lines (I) to impinger trains, the other two are directed out the back of the FTR, shown in Figure 3. The remaining product gas that is not pulled through the slipstreams goes from the capacitor to the Oxidizer (J) where it is fully oxidized, and then out through the flue vent (not shown).

As shown in Figure 3, two slipstreams are taken from the rear side of the capacitor (H). The one on the right is a cooled slipstream (L) that allows for metals sampling of the product gas. The left slipstream goes to the GC Water Impinger (M), which is part of the GC sample conditioning system (partially shown here). The GC Water Impinger (M) removes any solid particulate and some of the water that may be entrained in the product gas. After the GC Water Impinger, the product gas enters a chilled, vertical free water knockout vessel (not shown) which removes any remaining water in the product gas which might otherwise form hydrates, tight emulsions, or cause corrosion. The condensate collected in the water knockout (not shown) is stored in a set of two impingers (not shown) which sit in an ice water bath (not shown). From there, the slipstream goes to the GC (not shown). The cooling water to the Cooled Slipstream (L), the GC Water Knockout (M), and the vertical free water knockout vessel (not shown) are provided by the Recirculating Chiller (N).

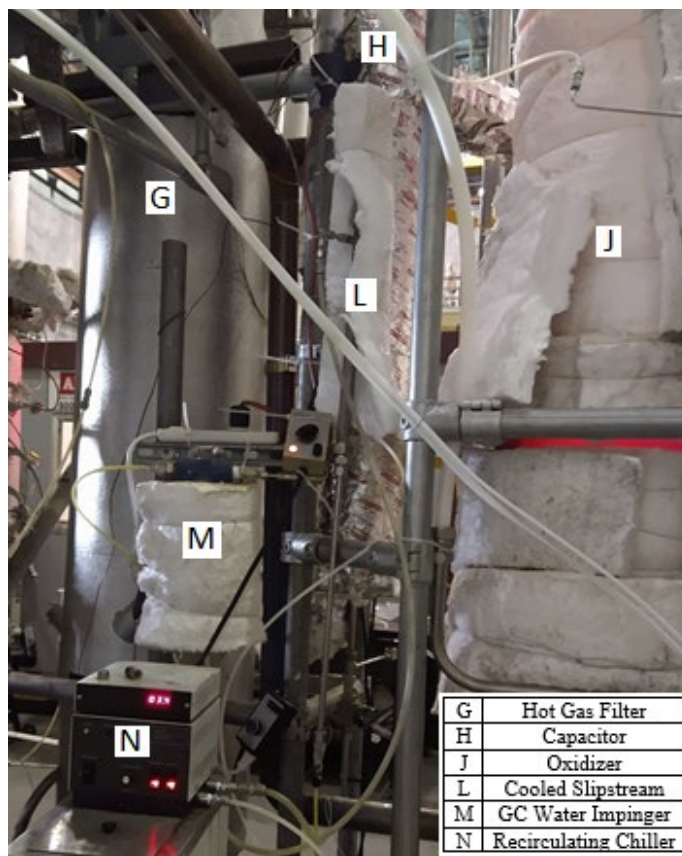


Figure 3. TRI FTR Back Side

System control is achieved through a commercial quality DCS which includes a historian data acquisition system. Temperature and feed rate sensor data are stored in the historian for recording and analysis, including the online GC data, which is collected every 6 minutes, and results are written to the historian. Thermal Desorption Tubes (TDT) and Tedlar Bag samples are taken during periods of steady state operation to measure the concentration of volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and other species in the syngas stream that cannot be quantified by the online GC.

The three slipstreams flow through Heated Sample Lines (I). Line 1 goes to a set of impingers which are used to sample condensate liquids which are condensed from the product gas. Line 2 goes to a sample point that is used for sampling TDT and Tedlar bags. Line 3 goes to a Heated Filter Box which allows for the filtration of particulate materials without cooling the gas stream, after which it goes to a set of impingers that are used to sample HCl, NH₃, and HCN gases. The metals sampling slipstream is directed through a glass tubed heat exchanger (L), then through plastic tubing, and finally through a set of glass impingers. This allows us to sample any condensate in the slipstream that forms on the tube wall without risking metal contamination from tubing material.

Each of the three impinger trains have the same arrangement for the instrument clusters and sample pumps which are used to monitor, calculate, and draw a known volume of sample gas. After the train, there is a coalescing filter, then an instrument cluster consisting of a rotameter, a thermocouple, a manometer, and a dry gas meter. After the instrument cluster, there is a “T”, with one line going to the sample pump and the other going to a needle valve and atmospheric air intake. The needle valve is used to control the suction on the impinger trains by drawing air into the sample pump. After the sample pump, the line goes to the Oxidizer.

FEEDSTOCK

The feedstock used in the FTR trial was 100% *Leucaena leucocephala* Stemwood, ground to a particle size that is less than 6 mm (0.25 inch) in diameter. The feedstock size requirement for the reformer system is based on the projected residence time in the fluid bed and the material handling capabilities of the feeder system. For the FTR, the feedstock particle specification is 6 mm minus (¼") i.e., the top size is nominally 6 mm (¼") or 216 cubic mm equivalent (1/64 cubic inch), suggesting that a small proportion (<5% by weight) of particles up to 18 mm (¾") in length can be accommodated. The feedstock was processed and supplied by HNEI personnel; it was double bagged, shipped, and stored in four separate containers. Shipping and storage conditions were mild, with no temperatures being hot or cold enough to affect the feedstock samples and so it seemed reasonable to assume that no changes to the material occurred between its creation and the testing. There was no visible contamination and the entire sample smelled like tropical wood. Overall, the sampled feedstock was consistent, as can be seen in Figures 4 and 5.

Samples were tested in triplicate at the ADC using TRI's standard methods to measure average Particle Size Diameters, Moisture Content, and Bulk Density; the Sauter Mean Size and Fines Content were also calculated using these measurements. These data are provided in Table 1. The average Sauter Mean Size was 1,158 microns, with a standard deviation of 126 microns. The Fines Content of the material, which is defined as the percentage of mass that falls through #20 Sieve (Mesh Size 841 microns), was 14.3%, with a standard deviation of 2.4%. This follows the TRI feedstock guidelines of fines content below 15% by weight. The average moisture was 9.7% with a standard deviation of 0.1%. The Bulk Density was 266 kg/m³ (16.6 lb/ft³), with a standard deviation of 17.1 kg/m³ (1.07 lb/ft³). Samples of the feedstock were also sent to external labs for ultimate, proximate, and ash elemental analyses and ash fusion temperature. These are provided in Tables 7, 8, and 9 and Appendix A.

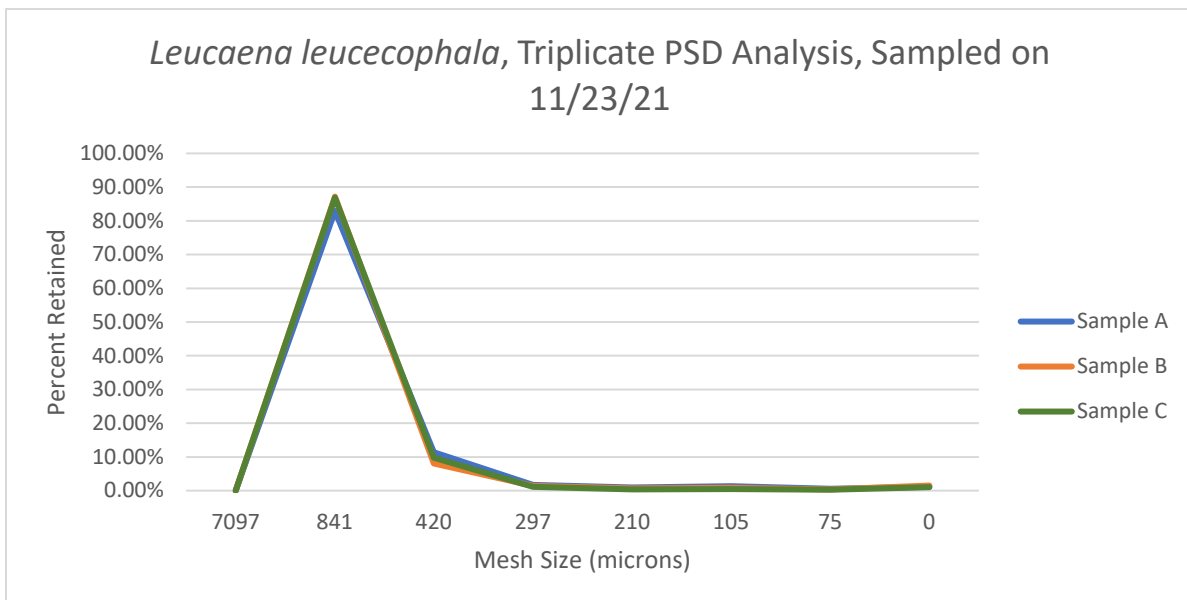


Figure 4. *Leucaena leucocephala* Stemwood, Weight Percent Retained by Sieve Mesh Size

Triplicate Sample Averages for <i>Leucaena leucocephala</i>			
Screen #	Mesh Size (microns)	Mass Fraction, xi	SD
1/4"	7097	0.0%	0.0%
20	841	85.7%	2.4%
40	420	9.7%	1.7%
50	297	1.4%	0.3%
70	210	0.6%	0.3%
140	105	0.9%	0.4%
200	75	0.4%	0.2%
pan	0	1.2%	0.2%

Parameter	Value	SD
Sauter Mean Size (microns)	1158	126
Percent Fines (%)	14.3%	2.4%
Moisture (%)	9.7%	0.1%
Standing Bulk Density (kg/M ³)	266.4	17.1

Table 1. *Leucaena leucocephala* Sample Averages

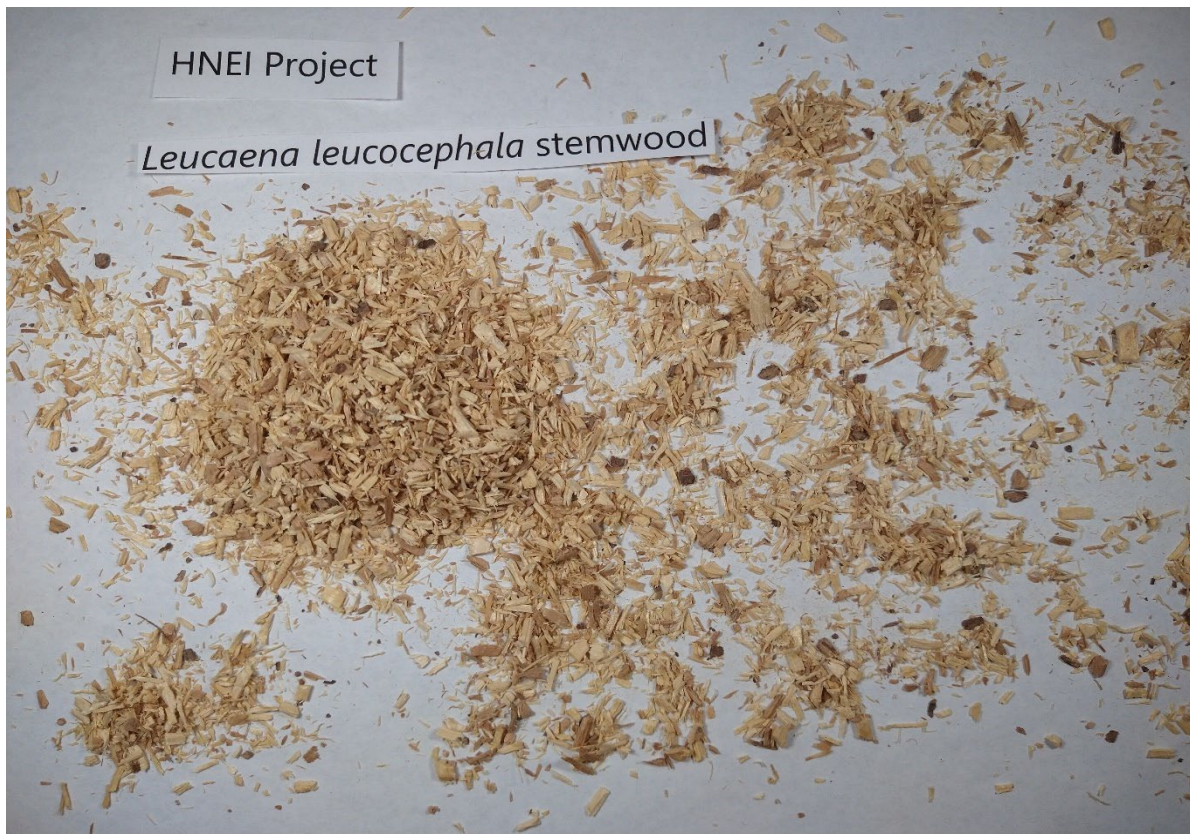


Figure 5. *Leucaena leucocephala* Stemwood Feedstock

TEST AND RESULTS

A detailed test plan was prepared. The test system was prepared and checked out. Feeder calibration tests with the *Leucaena leucocephala* Stemwood feedstock were performed prior to testing. The test was then performed in accordance with the test plan and all process parameters (temperatures, static and differential pressures, flow rates, etc.) were monitored and recorded. During this test, there was an issue with auxiliary equipment (oxidizer connection) which required the feed screw to be stopped and the bed to be slumped for approximately 100 minutes while it was repaired. After the repairs to the auxiliary equipment were completed, the bed was fluidized, and the feeder was restarted. The impinger, TDT and Tedlar bag sampling began after steady state was reached. This sampling period lasted for approximately 2 hours and 40 minutes, during which time temperatures and feed rates were very stable.

The fluidized bed material consisted of 14.5 kg (32.0 lb) of engineered alumina which was weighed and loaded into the FTR before the test.

The fluidization medium was a blend of steam, at a set rate of ~2.25 kg/h (5 lb/h) and 99.9% purity Carbon Dioxide; Carbon Dioxide was used as a cofeed to ensure satisfactory fluidization quality while matching commercial system steam-to-carbon ratio (the driving force for the reactions). Carbon Dioxide was employed as purge gas in the feed hopper and in all the instrumentation ports. Due to the very small size of this unit, the carbon dioxide content of the syngas was disproportionately high (60 to 70% by volume on a dry basis). But for the CO₂ dilution, the syngas composition is representative of the gasification process and therefore provides high-quality, scalable data. In full-scale commercial system, carbon dioxide concentration in the syngas is estimated to be 15-20% by volume.

The weigh bin was loaded with 35.8 kg *Leucaena leucocephala* Stemwood feedstock prior to the test. After the test a total of 20.1 kg of feedstock was retrieved from the weigh bin. A total of 15.7 kg of feedstock was fed into the system over a total time of 6 hours and 24 minutes; this calculates to an overall average feedstock feed rate 2.3 kg/h. The average feedstock feed rate during the sampling window, as measured by the change in the weights in the weigh bin, was ~1.7 kg/h. The nominal average bed temperatures were 729°C with an SD of 5.2°C during the feeding period and 732°C with an SD of 4.1°C during the sampling window. The measured temperature profile is shown in Figure 6. Figures 7 and 8 and Table 2 provide the feedstock's syngas composition during the sampling window. Helium was injected and used as a tie-in element for mass balance.

Syngas Composition												
	Helium	Hydrogen	Nitrogen	Methane	Carbon Monoxide	Carbon Dioxide	Ethylene	Ethane	Hydrogen Sulfide	Propane	Isobutylene	Butane
Average	0.34%	10.75%	0.59%	4.39%	14.87%	66.89%	1.52%	0.39%	0.00%	0.14%	0.12%	0.00%
SD	0.01%	1.12%	0.03%	0.13%	0.76%	1.96%	0.03%	0.01%	0.00%	0.02%	0.02%	0.00%

Table 2. Steady State Syngas Composition of *Leucaena leucocephala* Stemwood Feedstock

Another major component of this successful gasification trial was confirmation of agglomeration-free operation. This was monitored via the steam reformer temperature data and physically verified after the test. Throughout the trial, temperature data were recorded every second via 5 thermocouples at 5 locations within the bed. The temperatures, especially those at locations 1 through 5 did not exhibit any significant divergence i.e., excursions remained below 14°C (25°F) after steady state was achieved thereby confirming absence of hot spots and in turn lack of bed agglomeration. An

examination of the final bed at the conclusion of the trial corroborated this finding as well.

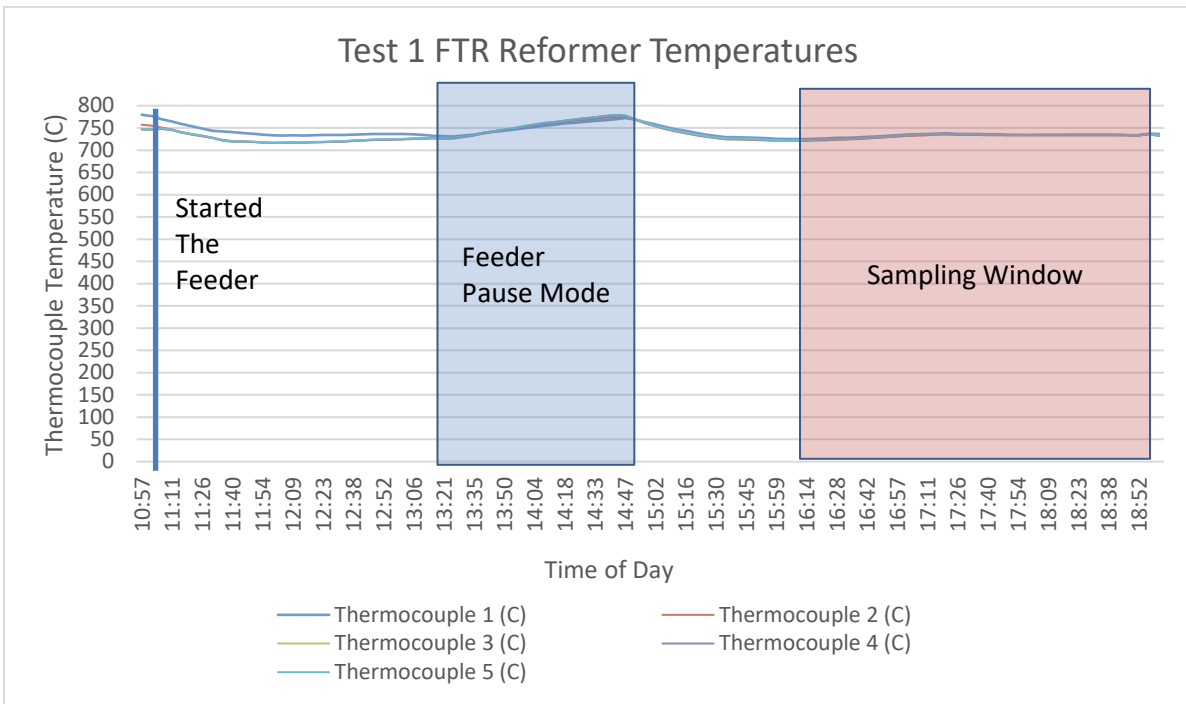


Figure 6. FTR Temperature Profile

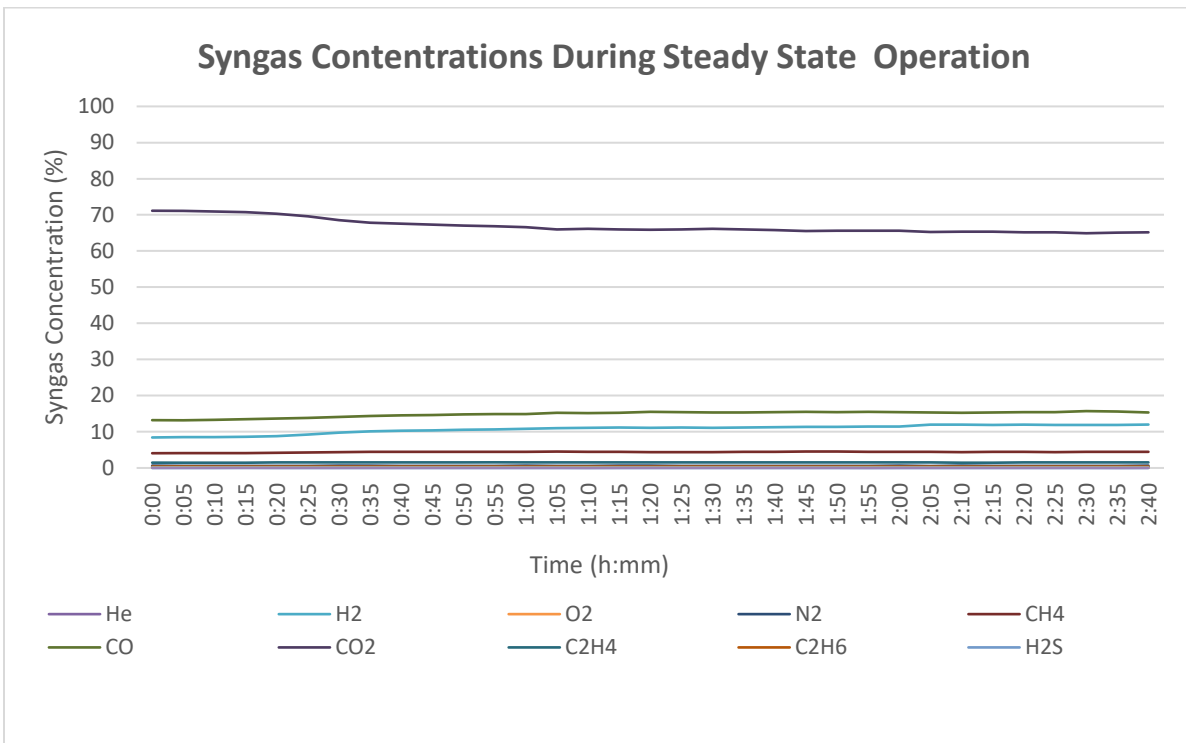


Figure 7. Syngas Concentrations During the Sampling Window

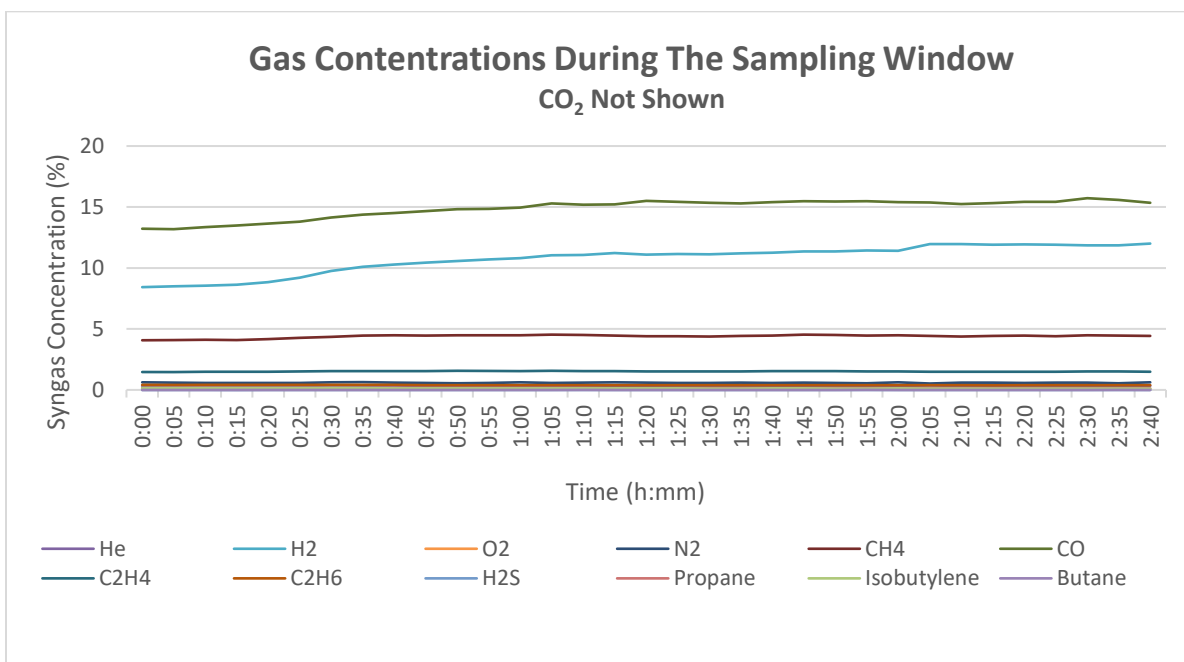


Figure 8. Syngas Concentrations (CO₂ not shown) during the Sampling Window

When the operation was quite steady, three sets of impinger trains were used to sample for Metals, Condensate, HCl, HCN, and NH₃. The table 3 below shows the sampling durations and sampled volumes of process gas, corrected to NPT, as calculated by both the Rotameters and Dry Gas Meters. While the Rotameter provides an instantaneous flow rate measurement, the Dry Gas Meter provides the total volumetric flow for the test duration. During the test sampling period, the rotameter readings seemed very steady. Small leaks were found in front of the Dry Gas Meter in Train C and this is likely what caused Train C to report a high result when compared to the Rotameter. These leaks are not believed to have affected any other sections of the instrument cluster. Both the dry gas meter and rotameter values are presented in the table below.

Impinger Train Sample Durations and Sample Volumes (NPT)			
Impinger Train	A	B	C
Analysis	HCl, HCN, NH₃	Condensate	Metals
Sample Time (HH:MM)	0:55	1:30	1:16
Rotameter Volume (L)	57 +/-16%	167 +/-8%	546 +/-13%
Dry Gas Meter Volume (L)	61 +/-3%	179 +/-3%	869 **
grams of sampled syngas	64 +/- 3%	189 +/- 3%	578 +/- 13%
Rotameter Accuracy: +/- 5% Full Scale			
Dry Gas Meter Accuracy: +/- 3.0% Permissible Error or measurement			
* Rotameters report larger error than Full-Scale error because the measured range was less than the Full-Scale flow rate.			
** Impinger Train C Dry Gas Meter Volume is reading high due to an air leak in front of the Dry Gas Meter. Rotameter values used in calculations.			

Table 3. Sample Durations and Calculated (NPT) Sample Volumes of the Impinger Trains

The Metals sampling was performed via an impinger train set up according to the guidelines of EPA Method 29. In lieu of the sampling probe that the method calls for, a slipstream of process gas is taken at the capacitor and passed through a water-cooled glass heat exchanger, then a

polyline tube, and finally into the impinger train. The particulate filter was not used because the sample point is past the main particulate filter and its catch is already analyzed for metals. The first impinger was a 1 liter, straight stemmed, glass impinger which was left empty. The second impinger was a 0.5 liter, straight stemmed, glass impinger which had 100 ml of a trapping solution consisting of 5% HNO₃ and 10% H₂O₂ in aqueous. The third impinger was a 0.5 liter, Greenburg-Smith stemmed, glass impinger which had 100 ml of a trapping solution consisting of 5% HNO₃ and 10% H₂O₂ in aqueous. The fourth impinger was a 0.5 liter, straight stemmed, glass impinger which was left empty. The fifth impinger was a 0.5 liter, straight stemmed, glass impinger which had 100 ml of a trapping solution consisting of 4% KMnO₄ (W/V) and 10% H₂SO₄ (V/V) in aqueous. The sixth impinger was a 0.5 liter, straight stemmed, glass impinger which had 100 ml of a trapping solution consisting of 4% KMnO₄ (W/V) and 10% H₂SO₄ (V/V) in aqueous. The seventh impinger was a 0.5 liter, straight stemmed, glass impinger with 250 g of Drierite. Each impinger was set into an ice bath for the duration of the test. The target sample volume and flow rate were 1 cubic meter of gas NTP over 1 hour, the actual sample volume and flow rate was calculated to be 0.55 +/- 13% cubic meters of gas NPT over 1 hour and 16 minutes. The glass tube, polyline tubing, impinger glassware, and impinger solutions were collected and rinsed according to EPA Method 29 guidelines. The samples were sent to Element One Inc. for analysis according to EPA Method 29 guidelines. Samples were analyzed for Mercury on a PerkinElmer FIMS-100 CVAA mercury analyzer and for metals on a PerkinElmer Nexlon 350X ICP-MS.

The HCl, HCN, and Ammonia sampling was performed via an impinger train set up as per the guidelines in EPA 26a and CARBM 426 methods. There were a few notable differences. First, the NaOH in the CARBM 426 Method was replaced with KOH due to supply chain issues, this was approved by the customer and the analytical lab and is not anticipated to have changed the underlying chemistry of the analytical procedure. Second, due to the possible presence of oxidative materials precipitating onto the filter or tubing, any rinse used on surfaces after the heated filter is included with the HCL analysis; this may bias the HCN analysis low as any HCN which would have been collected in the rinse is not being analyzed. Third, the H₂SO₄ and KOH (EPA26a) and KOH (CARBM) solution concentrations and volumes were adjusted from those stated in the methods in order to ensure that the concentrations of the measured species (HCl, HCN, and NH₃) are within the instrument measurement limits. Fourth, the decision to include ammonia analysis was made after the test and sampling were performed; therefore, the analysis may have a low bias due to method CTM-027 guidelines not being precisely followed. Fifth, in lieu of the sampling probe which the methods call for, a slipstream of process gas is taken at the capacitor and passes through a heated section of stainless-steel tubing which is kept above 260°C (500°F). Then the slipstream passes through a heated quartz fiber filter with a micron rating of 2.1 to 2.2 microns which is kept above 120°C (250°F), a short polyline tube and finally into the impinger train. The impinger train was set up as follows. The first impinger was a 0.5-liter, shortened straight stemmed, glass impinger which had 50 ml of a trapping solution consisting of 0.1 N H₂SO₄ in aqueous. The second impinger was a 0.5-liter, Greenburg-Smith stem, glass impinger which had 150 ml of a trapping solution consisting of 0.1 N H₂SO₄ in aqueous. The third impinger was a 0.5-liter, Greenburg-Smith stem, glass impinger which had 100 ml of a trapping solution consisting of 0.1 N KOH in aqueous. The fourth impinger was a 0.5-liter, straight stemmed, glass impinger which had 100 ml of a trapping solution consisting of 0.1 N KOH in aqueous. The fifth impinger was a 0.5-liter, straight stemmed, glass impinger with 250 g of Drierite. Each impinger was set into an ice bath for the duration of the test. The target sample volume and flow rate were 60 cubic liters of gas, NTP, over one hour, the actual sample volume and flow rate were calculated to be 61 +/- 3% cubic liters of gas, NPT, over 55 minutes. Sampling was consistent with EPA 26a and CARBM 426 guidelines, and the lines were rinsed with 111.4 g of 0.1 N H₂SO₄ solution and included in the HCL impinger bottle (Bottle 3 in the method) for analysis. Sample preservation was consistent with method guidelines; approximately 1 g of KOH chips was added to the HCN/NH₃ sample to bring the pH back up above 12. No oxidative materials were found in the filter, sample, or rinse via Starch Iodide test strips as per CARBM 426. Samples were sent to Element One for analysis according to EPA 26a and CARBM 426 guidelines. HCl and NH₃

analysis were performed on a Metrohm 861/788 ion chromatograph system, HCN analysis was performed on Genesis 10S UV-VIS Spectrophotometer. The results are presented in Table 4.

The HCl, HCN and NH₃ concentrations in syngas all seem low with NH₃/HCN ratio remarkably high compared to past measurements. There is error either in sampling or analysis or both. Several metals were detected including arsenic but no mercury. It is possible that part of the arsenic vaporized and was present as a compound in the syngas. It is also possible that the rest of the metals were in the very fine solids which slipped through the hot gas filter and carried over in the syngas stream. Some of the elements (Ca, Mg, P, K, and Na) were present in the fuel in a relatively higher concentration, and their measured elemental mass in the fuel input was greater than the elemental mass recovered in the measured outputs (HGF solids, final bed, and syngas). For elements (Fe, Ni, Ti, and Zn) with higher mass recoveries in the output streams than were delivered to the reactor in the fuel, this might indicate that the reactor working surfaces may have been a source. The discrepancies may also be due to sampling and analysis errors; in reality, multiple samples have to be analyzed to provide reasonable closure. The latter will however increase the test cost. It may also be worth considering the addition of a trace inorganic element to the feedstock and track its closure to assess the quality of the test results.

HCL, HCN, NH3, and Metals Impinger Lab Results				
Analytes	Detected Mass		Concentration (per g Syngas)	
HCL	< 0.68	mg	< 1.2E-02	mg/g
HCN	921	ug	1.43E+01	ug/g
NH3	54.9	mg	8.54E-01	mg/g
Arsenic	0.7	ug	1.19E-03	ug/g
Cadmium	< 0.1	ug	< 0.1	ug/g
Chromium	7.8	ug	1.35E-02	ug/g
Lead	0.5	ug	8.83E-04	ug/g
Magnesium	10.7	ug	1.85E-02	ug/g
Phosphorus	5.5	ug	9.44E-03	ug/g
Potassium	50.1	ug	8.68E-02	ug/g
Selenium	< 0.1	ug	< 0.1	ug/g
Sodium	261.5	ug	4.53E-01	ug/g
Zinc	18.1	ug	3.13E-02	ug/g
Mercury	None Detected	ug	None Detected	ug/g

Table 4. HCL, HCN, NH₃, and Metals Impinger Lab Results

The condensate sampling was performed via an impinger train which was set up to condense and collect any water or other condensable in the product gas stream. A slipstream of process gas was taken at the capacitor and passed through a heated section of stainless-steel tubing which was kept above 260°C (500°F), then through a short, uninsulated section of stainless-steel tubing, and then into the impinger train. The first impinger was a 1 liter, straight stemmed, glass impinger which was left empty. The second impinger was a 0.5 liter, straight stemmed, glass impinger which was left empty. The third impinger was a 0.5 liter, straight stemmed, glass impinger with 250 g of Drierite. Each impinger was set into an ice bath for the duration of the test.

The prerogative of the condensate sampling was to collect as much condensate as possible over the duration of the test. A volume of 63.3 g of condensate was collected from a calculated volume of 0.179 +/- 3% cubic meters of gas, NPT, collected over 1 hour and 30 minutes. The condensate was collected in a plastic bottle, along with 139.7 g of DI water used to rinse the impingers and stored

at an ambient temperature until it could be diluted to an adequate volume of 5.5 kg and sent to ENCO Laboratories for analysis. The sample was diluted in a polypropylene vessel which was cleaned to the same standards as the impingers and put into bottles which were provided by the lab. The dilution factor was 89.2, made by initially diluting the collected 63.3 g of condensate with 139.7 grams of DI H₂O rinse and later to a mass of 5,648.1 g. A 5.5 kg sample of the type 2 DI H₂O drum was also placed in the dilution vessel and sent to the lab for analysis as a blank.

A summary table of the analytical lab results is provided in Table 5 after correcting for DI water blank. The full report is included in Appendix B. The condensate indicates the presence of organics (mainly phenol), suspended solids (confirms slippage of exceptionally fine particulates from the hot gas filter), and nitrogen compounds. The ammonia and HCN concentrations seem reasonable and the NH₃/HCN ratio also is in the range of past syngas test measurements. The pH is 7.4 which is very slightly alkaline.

<i>Leucaena leucocephala</i> Stemwood				
Analyte	Results		Concentration in Syngas	
Acrylonitrile	210	ug/L	70	ug/g
Benzene	120	ug/L	40	ug/g
Biochemical Oxygen Demand	>72	mg/L	>24	mg/g
Chemical Oxygen Demand	250	mg/L	84	mg/g
Chloromethane	0.79	ug/L	0	ug/g
Ethylbenzene	1.31	ug/L	0	ug/g
pH	7.4	pH		
Phenol	2900	ug/L	972	ug/g
Sulfide	0.01	mg/L	0	mg/g
Toluene	52.16	ug/L	17	ug/g
Total Organic Carbon	74	mg/L	25	mg/g
Total Suspended Solids	3.2	mg/L	1	mg/g
Ammonia as N	26	mg/L	9	mg/g
Cyanide (total) - Total	1.5	mg/L	1	mg/g
Total Kjeldahl Nitrogen	28	mg/L	9	mg/g

Table 5. Condensate Summary

The initial and final solids inventory is provided in Table 6. A total of 15.7 kg of feedstock was fed into the FTR. There is an increase in bed mass due to partially devolatilized feedstock and char retention. The hot gas filter collection comprised fine char particles carried over in the syngas stream as well as some attrited bed material.

Solids Budget			
	Feedstock	Bed	Hot Gas Filter
Start (kg)	35.8	14.5	0
End (kg)	20.1	15.1	1.0

Table 6. Test 1 Solids Budget

Ultimate, proximate, and ash analyses of feedstock, final bed material and hot gas filter catch are presented in Tables 7, 8, and 9, respectively. The feedstock has a typical wood composition and has low sulfur and some chlorine; there are traces of arsenic and mercury. The computed alkali number is modest (~0.2 kg/GJ) but is below the limit of 0.34 kg/GJ for operation of the reformer in dry ash rejection mode or non-slugging mode.

$$\text{Alkali Number} = \frac{\sum((\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{Li}_2\text{O}) \text{ by weight fraction in bone dry feedstock})}{\text{HHV}}$$

The minerals data suggest that some of the ash is retained within the bed. Under steady state operating conditions, the fluidized bed ash and carbon content will achieve equilibrium and the carryover rates of carbon and ash will closely match those in the feed provided there is no bed agglomeration or clinker formation. The data in this test demonstrates agglomeration-free operation. The presence of volatiles in the hot gas filter catch suggests that some of the elutriated particles did not fully devolatilize in the steam reformer due to the short residence time. There is chlorine and sulfur present in both bed material and hot gas filter catch. Either these were not yet released from the feedstock or present in inorganic form in the ash due to reaction with alkali and calcium. Hot gas filter catch has a relatively high alumina content suggesting bed material attrition and carryover. Arsenic is present in both final bed material and hot gas filter catch. However, the arsenic balance or closure is poor with arsenic outflow in bed and hot gas filter catch far exceeding the arsenic inflow in feedstock suggesting either non-homogeneity of the feedstock in arsenic content or measurement error. Most of the other metals show similar discrepancy.

Ultimate Analysis						
Parameter	Feedstock		Bed		Hot Gas Filter Catch	
	As Received	Dry Basis	As Received	Dry Basis	As Received	Dry Basis
Total Moisture (%)	9.68		0.24		0.29	
Ash (%)	1.15	1.27	94.67	94.90	69.86	70.05
Carbon (%)	44.18	48.91	4.83	4.84	28.99	29.07
Hydrogen (%)	5.35	5.93	0.18	0.18	0.13	0.14
Nitrogen (%)	0.46	0.51	0.04	0.04	0.18	0.18
Oxygen (%)	39.17	43.37	0.00	0.00	0.00	0.00
Sulfur (%)	0.01	0.01	0.02	0.02	0.02	0.02
Chlorine (%)	0.131	0.145	0.019	0.019	0.533	0.535

Table 7. Ultimate Analysis

Proximate Analysis				
Parameter	Feedstock		Hot Gas Filter Catch	
	As Received	Dry Basis	As Received	Dry Basis
Total Moisture (%)	9.68		0.30	
% Ash	1.15	1.27	71.96	72.17
% Volatile Matter	73.51	81.39	2.55	2.55
% Fixed Carbon	15.65	17.33	25.17	25.26

Table 8. Proximate Analysis

Test 1 Ash Elemental Analysis			
Parameter	Feedstock	Bed	Hot Gas Filter Catch
Aluminum (Al) mg/kg	19.6	47710	35730
Antimony (Sb) mg/kg	< 0.22 ^a	< 0.22 ^a	5.13
Arsenic (As) mg/kg	< 0.040 ^a	0.266	1.386
Barium (Ba) mg/kg	15	6.8	53.4
Cadmium (Cd) mg/kg	< 0.010 ^a	0.03	0.323
Calcium (Ca) mg/kg	2354	1124	9363
Chlorine (Cl) %	0.145		
Chromium (Cr) mg/kg	< 5.0 ^a	317.2	1688
Cobalt (Co) mg/kg	0.7	2.98	13.14
Copper (Cu) mg/kg	< 2.3 ^a	8.4	48.4
Fluorine (F) mg/kg	< 5.0 ^a		
Iron (Fe) mg/kg	31	1377	3922
Lead (Pb) mg/kg	0.55	0.36	9.7
Magnesium (Mg) mg/kg	751.3	172.9	2650
Manganese (Mn) mg/kg	38.5	30.7	200.8
Mercury (Hg) mg/kg	< 0.020 ^a	< 0.020 ^a	< 0.020 ^a
Molybdenum (Mo) mg/kg	< 0.6 ^a	20	19
Nickel (Ni) mg/kg	< 0.3 ^a	468.4	6168
Phosphorus (P) mg/kg	424	151	1424
Potassium (K) mg/kg	3008	1567	6814
Selenium (Se) mg/kg	< 0.50 ^a	< 0.50 ^a	0.72
Silicon (Si) mg/kg	< 300.0 ^a	5754	5441
Sodium (Na) mg/kg	219	557.2	1609
Tellurium (Te) mg/kg	< 1.0 ^a	< 1.0 ^a	< 1.0 ^a
Thallium (Tl) mg/kg	< 3.9 ^a	< 3.9 ^a	< 3.9 ^a
Tin (Sn) mg/kg	< 0.3 ^a	0.6	4.1
Titanium (Ti) mg/kg	1.9	43.3	409
Vanadium (V) mg/kg	< 1.0 ^a	1.9	4.9
Zinc (Zn) mg/kg	4.6	105.6	1279
^a detection limit of the method			

Table 9. Ash Elemental Analysis

A Tedlar Bag sample was analyzed by Intertek using GC-FID (per ASTM D7833 method), GC-TCD (per ASTM D7833), GC-SCD (per ASTM D5504), and GC-NCD (per ITM 1535). These analyses are to determine the speciation and quantification of various carbon, nitrogen, and sulfur compounds present in the syngas. Potential issues with these analyses may be the decomposition of certain species due to the relatively long hold time between sampling and analysis, as well as the adhesion to the inside of the bag. The results summary is provided in Table 10. The GC-TCD and GC-FID data of syngas composition are in reasonable agreement with the GC data indicated in Table 2 and Figures 8 and 9. The GC-NCD indicates an ammonia concentration of 4.6 ppmw in syngas which is about half of that estimated from condensate analysis (Table 5). The GC-SCD data

suggests a high concentration of COS relative to H₂S which is opposite of what TRI has measured in past steam reforming tests. It seems that either H₂S condensed out or adsorbed/reacted with the sample transit container to yield a low value. The data indicates the presence of methyl mercaptan and other sulfur species such as dimethyl sulfide.

ASTM D7833, GC-TCD	
COMPONENT	MOL %
HELIUM	0.22
HYDROGEN	9.81
CARBON DIOXIDE	61.22
HYDROGEN SULFIDE	<0.03
OXYGEN/ARGON	0.36
NITROGEN	0.93
CARBON MONOXIDE	21.27
Sum of TCD Gases; methane is a fixed gas but is not included	93.82

ASTM D7833, GC-FID	
COMPONENT	MOL %
METHANE	4.237
ETHANE	0.177
ETHYLENE	1.223
PROPANE	0.007

ITM 1535, GC-NCD		
COMPONENT	Compound	Units
Ammonia	4.6	ppm Wt
Acetonitrile	<2.5	ppm Wt
Acrylonitrile	<2.5	ppm Wt
Diethyl hydroxylamine (DEHA)	<2.5	ppm Wt

ASTM D5504, GC-SCD		
COMPONENT	Compound	Units
H ₂ S	1	ppm Wt
Carbonyl Sulfide	22.6	ppm Wt
Methyl Mercaptan	2.5	ppm Wt
Unknown Sulfur as Dimethyl Sulfide	10.3	ppm Wt

Table 10. C, N, S speciation data summary

Tars, otherwise termed VOC and SVOC, present within the syngas were identified with the use of Prism Analytical Technologies, Inc.'s (PATI) wide spectrum, multi-matrix thermal desorption tube. To avoid pulling moisture into the TDT, the syngas was sampled by filling a Tedlar bag and drawing the sample into TDT. After sampling in triplicate, the sorbent tubes were sent to PATI for the quantitative identification of all VOC and SVOC compounds. A summary is provided in Table 11. The complete data are included in Appendix B. The VOC and SVOC values are comparable to those observed with TRI systems that gasify wood and other agri-waste feedstocks. It has been found that the SVOC condensable fraction generated in the TRI steam reforming environment is much lower than those reported in the literature for other gasifiers. The method utilized here is

however different from those used in the literature and this may have contributed to the difference. The average VOC/SVOC generation rate in this test has been estimated to be 0.025 kg/kg dry biomass feed. With woody biomass feed into the PDU (4 tpd dry throughput) at Durham, North Carolina, tars generation rate in steam reforming has been observed to be quite low (<0.004 kg/kg of dry biomass feed); tests in the bench scale unit generally have indicated higher tars content in syngas due to short gas residence time and faster temperature decrease in the freeboard due to relatively high heat loss.

Thermal Desorption Tube Summary Results		
Total VOCs	Sample Concentration ng/L 8.10E+06	
Average Quantitative Results		
Compound	ng/L	PPB
Benzene	1.01E+06	3.10E+05
Toluene	7.00E+05	1.80E+05
Ethylbenzene	3.43E+04	7.83E+03
m,p-Xylene	1.97E+05	4.43E+04
o-Xylene	6.83E+04	1.57E+04
4-Ethyltoluene	2.17E+03	4.30E+02
Isopropyl benzene	1.57E+02	3.10E+01
Styrene	2.93E+05	6.83E+04
Chlorobenzene	7.33E+01	1.60E+01
Naphthalene	1.05E+05	2.00E+04
Tetrahydrofuran	2.40E+02	7.97E+01
Ethanol	6.27E+03	3.27E+03
Acetone	2.57E+05	1.09E+05
Acetonitrile	1.60E+05	9.20E+04
Acrylonitrile	1.11E+05	4.90E+04
Propionitrile	1.87E+04	8.07E+03
Semiquantitative Results		
Compound	CAS	PPB
Phenol	1.40E+05	3.57E+04
Indene	2.60E+05	5.37E+04
Furan	1.83E+04	6.57E+03
Pyridine	4.57E+04	1.40E+04
2,3-Benzofuran	6.23E+04	1.27E+04
Phenyl ethyne	5.57E+04	1.30E+04
Fluorene	2.23E+04	3.23E+03

Table 11. Summary of Thermal Desorption Tube Results

The mass balance for this test is provided in Figure 9. The overall closure is considered satisfactory but not some of the elemental closures. It's possible that water condensate measurement was inaccurate, and this affected both hydrogen and oxygen closure. During the test, there was an oxidizer connection outage, and the feeder was in pause mode for more than an hour. Since the mass balance was performed over the sampling period and the char and ash in the final bed and filter catch corresponded to the overall test duration and were apportioned for the sampling period, this may have overstated carbon and ash content and affected closure. The mass fraction of char elutriated from the

bed and its weight fraction of carbon retained within are shown in Figure 9. It is to be noted that most of the ash was retained within the bed. This is attributed to the lower operating velocity of the bench scale unit. The Process Demonstration Unit (PDU) and commercial scale systems generally operate at much higher fluidization velocities and therefore most of the ash is expected to carryover in the syngas to permit removal through the second stage gasifier external cyclone. The carbon conversion was good (> 85%) considering the operation comprised a single stage gasification step. The TRI PDU and commercial systems do incorporate a 2-stage gasification step to achieve high (~99%) carbon conversion.

Based on an energy balance around the indirectly heater FTR, the endothermic heat of reaction for gasification was estimated to be 1,686 kJ/kg of biomass (725 Btu/lb of biomass).

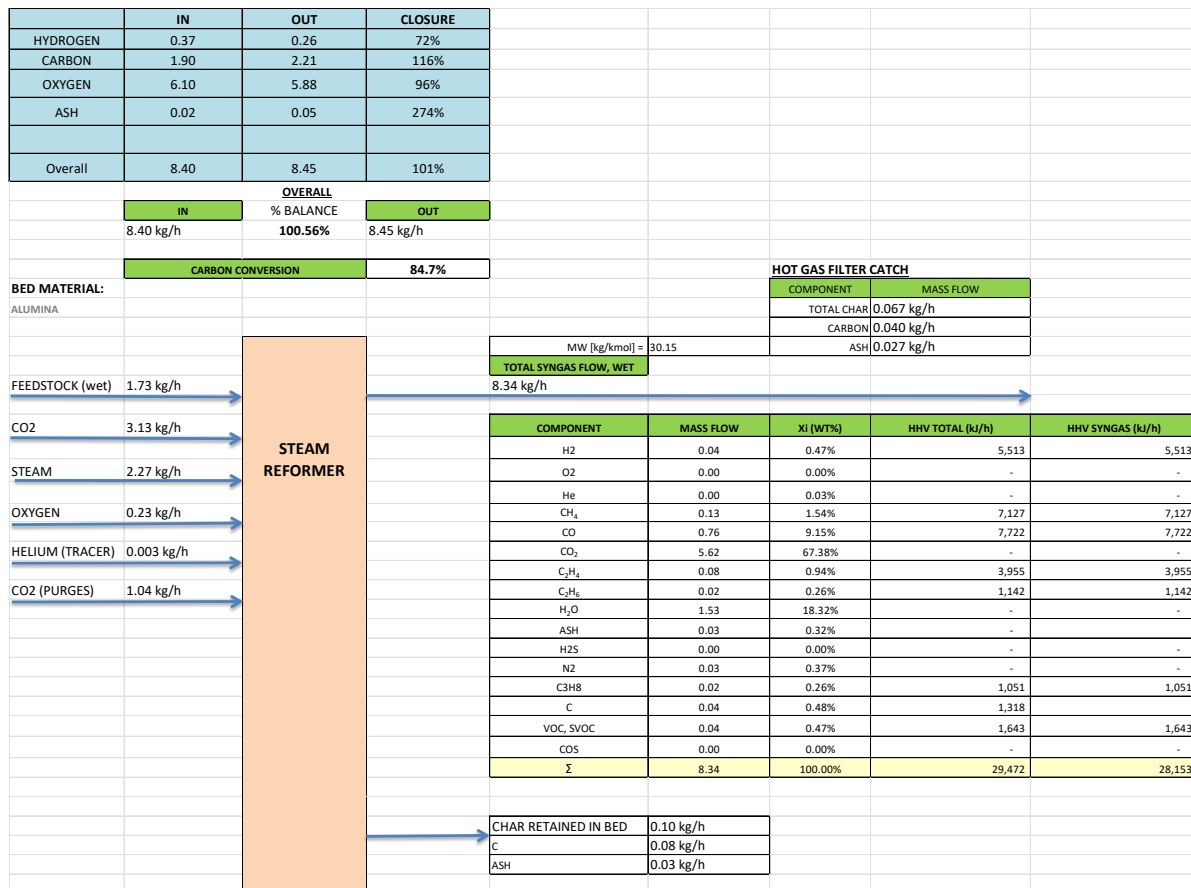


Figure 9. *Leucaena leucocephala* Stemwood Mass Balance

Figure 10 shows the hot gas filter catch which comprises fine char (carbon/ash) and carried over fine bed material. This has a significant carbon content. In the TRI 2-stage gasifier system, this stream will be routed to the 2nd stage gasifier termed Carbon Trim Cell and converted at a higher temperature partial oxidation mode and the remaining ash collected for disposal.



Figure 10. *Leucaena leucocephala* Stemwood Filter Catch Carbon & Ash

Figure 11 shows the initial and final bed material samples. The initial bed is engineered alumina and the final bed has carbon and ash. The final bed appears dark and has biomass particles injected towards the end of the test undergoing drying and devolatilization; the carbon content however is less than 5% by weight.



Figure 11. *Leucaena leucocephala* Stemwood Initial and Final Bed Material Samples

CONCLUSIONS

The screening test with *Leucaena leucocephala* Stemwood was successful and indicated the following:

- The steam reformer demonstrated safe, stable, and reliable operation.
- There were no operational problems such as agglomeration, defluidization, channeling or heater fouling.
- The final bed had little carbon and exhibited a free-flowing characteristic.
- The carbon conversion was good (~85%) considering the operation comprised a single stage gasification step; the PDU and commercial systems incorporate a 2-stage gasification step to achieve high (~99%) carbon conversion.
- The impinger sampling and analysis for acid gases and metals were not satisfactory and will require a root cause analysis.
- Sample integrity during shipping and transportation for external laboratory analysis by GC-TCD, GC-FID, GC-SCD and GC-NCD seems to be an issue and this needs to be addressed for credible results.
- The concentration of metals such as arsenic is so low that the mass balance closure for these elements is poor. This may be due to inhomogeneity of these elements in the feedstock or analytical inaccuracy or sample inhomogeneity or all the above.

There were no surprises, and the test results support the application of the steam reformer system to generate syngas from this feedstock to produce biofuel or renewable power or biochemicals.

RECOMMENDATION

A long duration continuous test (1 to 3 week) with one or more feedstocks in the TRI integrated biorefinery PDU at Durham, North Carolina is recommended to fully characterize steam reformer performance and facilitate reliable and refined design and cost estimate of the commercial plant.

APPENDIX A

<i>Leucaena Leucocephala</i> Individual Sample Data						
Screen #	Sample A		Sample B		Sample C	
	Before Shake	After Shake	Before Shake	After Shake	Before Shake	After Shake
	tare, (g)	gross, (g)	tare, (g)	gross, (g)	tare, (g)	gross, (g)
1/4"	522.5	522.5	522.5	522.5	522.5	522.5
20	401.3	489.3	401.6	494.1	401.6	499.1
40	341.6	353.7	341.6	350.1	341.6	352.6
50	335.7	337.5	335.7	337.2	335.6	336.9
70	331.0	332.0	330.9	331.6	331.0	331.4
140	315.4	316.8	315.4	316.3	315.4	315.9
200	308.6	309.2	308.7	309.1	308.6	308.9
pan	274.6	275.8	274.6	276.2	274.6	275.8
Sum	2830.7	2936.8	2831.0	2937.1	2830.9	2943.1
Moisture	9.8%		9.7%		9.7%	
Bulk Density	283.3 kg/M ³		249.2 kg/M ³		266.7 kg/M ³	
Sauter Mean Size	1084 microns		1099 microns		1309 microns	
% Fines	17.1%		12.8%		13.1%	

Table 12. Individual Feedstock Data, TRI Generated

APPENDIX B - External Lab Summaries

<i>Leucaena leucocephala</i> Stemwood							
Analyte	Results	Flag	MDL	PQL	Units	Method	Notes
Acrylonitrile	210.00		3.5	10.0	ug/L	EPA 624.1	
Benzene	120.00		0.57	1.0	ug/L	EPA 624.1	
Biochemical Oxygen Demand	>72		2.0	2.0	mg/L	SM 5210 B-2011	B-02
Chemical Oxygen Demand	250.00		10	10.0	mg/L	SM 5220D-2011	
Chloroform	5.60		0.46	1.0	ug/L	EPA 624.1	
Chloromethane	0.79	J	0.46	1.0	ug/L	EPA 624.1	
Ethylbenzene	1.80		0.46	1.0	ug/L	EPA 624.1	
pH	7.40		1.0	1.0	pH	SM 4S00H+B-2011	Q-01
Phenol	2900.00	D	280	500.0	ug/L	EPA 625.1	R-05
Sulfide	0.01	J	0.010	0.1	mg/L	SM 450052 D-2011	
Temperature for pH (deg. C)	20.00				pH	SM 4S00H+B-2011	Q-01
Toluene	53.00		0.57	1.0	ug/L	EPA 624.1	
Total Organic Carbon	74.00		0.90	1.0	mg/L	SM 5310B-2011	
Total Suspended Solids	3.20		2.5	2.5	mg/L	SM 2540D-2011	
Zinc - Total	5.86	J	4.40	10.0	ug/L	EPA 200.7	
Ammonia as N	26	D	0.90	2.0	mg/L	EPA 350.1	
Cyanide (total) - Total	1.5	D	0.049	0.050	mg/L	EPA 335.4	
Total Kjeldahl Nitrogen	28	D	1.3	2.4	mg/L	EPA 351.2	

J	Reported value is between the Laboratory Method Detection Limit (MDL) and the Laboratory Method Reporting Limit (MRL), adjusted for actual sample preparation data and moisture content where applicable.
D	The sample was analyzed at dilution.
Q-01	Analysis performed outside of sample hold time
B-02	The sample dilutions set up for the analysis failed to meet the criteria of a residual dissolved Oxygen of at least 1 mg/l. Therefore, the reported result is an estimated value only.
R-05	The sample was diluted due to the presence of high levels of non-target analytes resulting in elevated reporting limits.
* These <i>Leucaena leucocephala</i> results are from the lab report and have not been corrected for the 1:89.2 (Sample: Dilute) dilution factor when sampling.	

Table 13. *Leucaena leucocephala* Condensation Lab Summary

Thermal Desorption Tube 1					
Compound	Sample Concentration		Reporting Limit		
Total VOCs	ng/L 8.00E+06		ng/L 200		
Quantitative Results					
		Sample Concentration		Reporting limit	
Compound	CAS	ng/L	ppb	ng/L	Additional Information
1,3-Butadiene	106-99-0	2.20E+06	970000	50	J*
Ethanol	64-17-5	6000	3100	500	
Acetone	67-64-1	260000	110000	250	J*
Isopropanol	67-63-0	270	110	250	
Carbon Disulfide	75-15-0	92	29	50	
Acetonitrile	75-05-8	150000	88000	100	J*
Acrylonitrile	107-13-1	110000	48000	50	J*
Propionitrile	107-12-0	18000	7600	50	
Methacrylonitrile	126-98-7	7500	2700	50	
Tetrahydrofuran	109-99-9	250	84	50	
Benzene	71-43-2	920000	280000	50	J*K*
Toluene	108-88-3	630000	160000	50	J*K*
Ethylmethacrylate	97-63-2	180	39	50	
Chlorobenzene	108-90-7	77	17	50	
Ethylbenzene	100-41-4	33000	7600	50	J*
m,p-Xylene	108-38-3; 106-42-3	190000	43000	100	J*
o-Xylene	95-47-6	65000	15000	50	J*
Styrene	100-42-5	270000	63000	50	J*
Isopropylbenzene	98-82-8	150	29	50	
trans 1,4-Dichloro-2-butene	110-57-6	870	170	50	
n-Propylbenzene	103-65-1	520	100	50	
4-Ethyltoluene	622-96-8	2100	420	50	
1,3,5-Trimethylbenzene	108-67-8	3800	750	50	
1,2,4-Trimethylbenzene	95-63-6	12000	2400	50	
Naphthalene	91-20-3	89000	17000	100	J*
2-Methylnaphthalene	91-57-6	20000	3400	100	

Semiquantitative Results					
Compound	CAS	ng/L	ppb	ng/L	RI
Propylene	115-07-1	1.20E+06	710000	10000	329
C2-C4 Hydrocarbon	N/A	250000	N/A	10000	350
Chloromethane	74-87-3	9400	4500	9000	371
2-Methyl-1-propene	115-11-7	100000	44000	10000	391
Acetaldehyde	75-07-0	340000	180000	10000	407
C3-C5 Hydrocarbon	N/A	100000	N/A	10000	416
Furan	110-00-9	23000	8300	10000	498
1,3-Pentadiene	504-60-9	48000	17000	10000	499
C4-C6 Hydrocarbon	N/A	700000	N/A	10000	524
Pyridine	110-86-1	45000	14000	10000	713
C4-C6 Hydrocarbon	N/A	31000	N/A	10000	747
Phenylethyne	536-74-3	53000	13000	10000	818
a-Methylstyrene	98-83-9	15000	3100	10000	896
C9-C11 Hydrocarbon	N/A	67000	N/A	10000	910
C9-C11 Hydrocarbon	N/A	26000	N/A	10000	914
2,3-Benzofuran	271-89-6	64000	13000	10000	923
Phenol	108-95-2	62000	16000	10000	942
Indene	95-13-6	250000	51000	10000	955
C9-C11 Hydrocarbon	N/A	14000	N/A	10000	987
C10-C12 Hydrocarbon	N/A	13000	N/A	10000	1010
C10-C12 Hydrocarbon	N/A	12000	N/A	10000	1016
1-Methylnaphthalene	90-12-0	17000	3000	10000	1108
Acenaphthylene	208-96-8	35000	5500	10000	1206
Fluorene	86-73-7	14000	2000	10000	1297

Table 14. Thermal Desorption Tube 1 Syngas VOC and SVOC Concentrations

Thermal Desorption Tube 2					
Compound		Sample Concentration		Reporting Limit	
Total VOCs		8.70E+06		200	
Quantitative Results					
		Sample Concentration		Reporting limit	
Compound	CAS	ng/L	ppb	ng/L	Additional Information
1,3-Butadiene	106-99-0	2.30E+06	1.00E+06	50	J*
Ethanol	64-17-5	6700	3500	500	
Acetone	67-64-1	300000	130000	250	J*
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	77	10	50	
Carbon Disulfide	75-15-0	110	33	50	
Acetonitrile	75-05-8	180000	100000	100	J*
Acrylonitrile	107-13-1	130000	57000	50	J*
Propionitrile	107-12-0	21000	9300	50	
Methacrylonitrile	126-98-7	9400	3400	50	
Tetrahydrofuran	109-99-9	250	83	50	
Benzene	71-43-2	1.10E+06	340000	50	J*K*
Isooctane	540-84-1	670	140	50	2,2,4-Trimethylpentane
Toluene	108-88-3	770000	200000	50	J*K*
Ethylmethacrylate	97-63-2	190	40	50	
Chlorobenzene	108-90-7	83	18	50	
Ethylbenzene	100-41-4	40000	9100	50	J*
m,p-Xylene	108-38-3; 106-42-3	220000	50000	100	J*
o-Xylene	95-47-6	78000	18000	50	J*
Styrene	100-42-5	330000	77000	50	J*
Isopropylbenzene	98-82-8	180	37	50	
trans 1,4-Dichloro-2-butene	110-57-6	1000	200	50	
n-Propylbenzene	103-65-1	590	120	50	
4-Ethyltoluene	622-96-8	2500	500	50	
1,3,5-Trimethylbenzene	108-67-8	4300	860	50	
1,2,4-Trimethylbenzene	95-63-6	14000	2800	50	
Naphthalene	91-20-3	97000	18000	100	J*
2-Methylnaphthalene	91-57-6	17000	2900	100	

Semiquantitative Results					
Compound	CAS	ng/L	ppb	ng/L	RI
Propylene	115-07-1	1.10E+06	640000	9900	329
C2-C4 Hydrocarbon	N/A	250000	N/A	9900	351
2-Methyl-1-propene	115-11-7	130000	57000	9900	391
Acetaldehyde	75-07-0	690000	380000	9900	407
C3-C5 Hydrocarbon	N/A	200000	N/A	9900	416
C2-C4 Hydrocarbon	N/A	11000	N/A	9900	481
Furan	110-00-9	16000	5600	9900	498
1,3-Pentadiene	504-60-9	66000	23000	9900	499
C4-C6 Hydrocarbon	N/A	800000	N/A	9900	525
2-Methylfuran	534-22-5	11000	3200	9900	579
Pyridine	110-86-1	51000	15000	9900	713
C4-C6 Hydrocarbon	N/A	42000	N/A	9900	747
2-Methylpyridine	109-06-8	10000	2600	9900	768
Phenylethyne	536-74-3	65000	15000	9900	818
a-Methylstyrene	98-83-9	18000	3600	9900	896
C9-C11 Hydrocarbon	N/A	74000	N/A	9900	910
C9-C11 Hydrocarbon	N/A	29000	N/A	9900	914
2,3-Benzofuran	271-89-6	70000	14000	9900	923
Phenol	108-95-2	69000	18000	9900	942
Indene	95-13-6	280000	58000	9900	955
C9-C11 Hydrocarbon	N/A	16000	N/A	9900	987
C10-C12 Hydrocarbon	N/A	17000	N/A	9900	1010
C10-C12 Hydrocarbon	N/A	15000	N/A	9900	1016
1-Methylnaphthalene	90-12-0	16000	2700	9900	1108
Acenaphthylene	208-96-8	29000	4500	9900	1206
Fluorene	86-73-7	12000	1800	9900	1297

Table 15. Thermal Desorption Tube 2 Syngas VOC and SVOC Concentrations

Thermal Desorption Tube 3					
Sample Concentration		Reporting Limit			
Compound	ng/L			ng/L	
Total VOCs	7.60E+06			200	
Quantitative Results					
		Sample Concentration		Reporting limit	
Compound	CAS	ng/L	ppb	ng/L	Additional Information
1,3-Butadiene	106-99-0	1.60E+06	720000	50	J*
Ethanol	64-17-5	6100	3200	500	
Acetone	67-64-1	210000	87000	250	J*
Carbon Disulfide	75-15-0	82	26	50	
Acetonitrile	75-05-8	150000	88000	100	J*
Acrylonitrile	107-13-1	92000	42000	50	J*
Propionitrile	107-12-0	17000	7300	50	
Methacrylonitrile	126-98-7	6000	2100	50	
Tetrahydrofuran	109-99-9	220	72	50	
Benzene	71-43-2	1.00E+06	310000	50	J*K*
Toluene	108-88-3	700000	180000	50	J*K*
Ethylmethacrylate	97-63-2	160	34	50	
Chlorobenzene	108-90-7	60	13	50	
Ethylbenzene	100-41-4	30000	6800	50	J*
m,p-Xylene	108-38-3; 106-42-3	180000	40000	100	J*
o-Xylene	95-47-6	62000	14000	50	J*
Styrene	100-42-5	280000	65000	50	J*
Isopropylbenzene	98-82-8	140	27	50	
trans 1,4-Dichloro-2-butene	110-57-6	780	150	50	
n-Propylbenzene	103-65-1	440	88	50	
4-Ethyltoluene	622-96-8	1900	370	50	
1,3,5-Trimethylbenzene	108-67-8	3300	660	50	
1,2,4-Trimethylbenzene	95-63-6	10000	2100	50	
Naphthalene	91-20-3	130000	25000	100	J*
2-Methylnaphthalene	91-57-6	35000	5900	100	J*

Semiquantitative Results					
Compound	CAS	ng/L	ppb	ng/L	Ri
Propylene	115-07-1	930000	530000	10000	329
C2-C4 Hydrocarbon	N/A	210000	N/A	10000	351
2-Methyl-1-propene	115-11-7	75000	32000	10000	391
Acetaldehyde	75-07-0	240000	130000	10000	407
C3-C5 Hydrocarbon	N/A	160000	N/A	10000	416
Furan	110-00-9	16000	5800	10000	498
1,3-Pentadiene	504-60-9	38000	13000	10000	499
C4-C6 Hydrocarbon	N/A	590000	N/A	10000	525
Pyridine	110-86-1	41000	13000	10000	713
C4-C6 Hydrocarbon	N/A	28000	N/A	10000	747
Phenylethyne	536-74-3	49000	11000	10000	818
a-Methylstyrene	98-83-9	13000	2600	10000	896
C9-C11 Hydrocarbon	N/A	55000	N/A	10000	910
C9-C11 Hydrocarbon	N/A	21000	N/A	10000	914
2,3-Benzofuran	271-89-6	53000	11000	10000	922
Phenol	108-95-2	290000	73000	10000	942
Indene	95-13-6	250000	52000	10000	955
C9-C11 Hydrocarbon	N/A	17000	N/A	10000	987
p-Cresol	106-44-5	19000	4300	10000	991
C10-C12 Hydrocarbon	N/A	21000	N/A	10000	1010
C10-C12 Hydrocarbon	N/A	19000	N/A	10000	1015
1-Methylnaphthalene	90-12-0	34000	5800	10000	1108
Biphenyl	92-52-4	20000	3100	10000	1138
C12-C14 Hydrocarbon	N/A	15000	N/A	10000	1178
Acenaphthylene	208-96-8	79000	12000	10000	1206
Acenaphthene	83-32-9	20000	3100	10000	1220
Fluorene	86-73-7	41000	5900	10000	1297
C15-C17 Hydrocarbon	N/A	24000	N/A	10000	1322
C15-C17 Hydrocarbon	N/A	21000	N/A	10000	1333

Table 16. Thermal Desorption Tube 3 Syngas VOC and SVOC Concentrations

APPENDIX C - A list of Separate Reports

Table Of External Lab Reports	
Lab	Analysis
BEL Laboratories	Feedstock
BEL Laboratories	Ash
BEL Laboratories	Bed Material
Element One	HCN
Element One	HCL
Element One	NH3
Element One	Metals
ENCO Laboratories	Condensate
Enthalpy	TD Tube (3 Reports)
Intertek	GC-SCD
Intertek	GC-NCD
Intertek	GC-FID/TCD

Table 17. A List of External Lab Reports