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FINAL PROJECT REPORT

Supplying California with Renewable Energy through Advanced Biomass Gasification

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Prepared by:

Primary Authors:
Scott Cheney
W. David Thompson

Diversified Energy Corporation
2020 W. Guadalupe Rd.
Suite 5
Gilbert, AZ 85233
Phone: 480-507-0297 | Fax: 480-507-0780
http://www.diversified-energy.com

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Prepared for:

California Energy Commission

Prab Sethi
Contract Manager

Aleecia Gutierrez
Office Manager
Energy Generation Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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- Renewable Energy Technologies
- Transportation

Supplying California with Renewable Energy through Advanced Biomass Gasification is the final report for the Reducing California Industrial Natural Gas Consumption through Advanced Biomass Gasification project (contract number PNG-07-005) conducted by Diversified Energy Corporation. The information from this project contributes to Energy Research and Development Division's Renewable Energy Technologies Program.

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ABSTRACT

This report summarizes recent operations of the OmniGas reactor technology, representing the culmination of over eleven years of developmental work and more than $10 million of public and private funding ($500,000 provided by the California Energy Commission). Through this research, a comprehensive prototype system design was completed, including extensive refractory testing, thermal analysis and engineering schematics. The OmniGas reactor was installed at at Wyle Laboratories in San Bernardino, California, heavily instrumented and integrated with the necessary auxiliary components. The integrated biomass gasification demonstration project then converted waste wood fines into dilute carbon monoxide and carbon dioxide through partial oxidiation. Due to unexpected complications with the feed system, total feed rate and final reactor temperature were affected, thus affecting the quality of the gas produced, gas that ideally could be used for process heating or be converted into higher value products. The gasification reactions are based around common commercial smelting practices to generate synthesis gas, using a molten iron-based slag that catalyzes the reaction, provides thermal inertia to tolerate inconsistent feedstocks and captures feedstock ash as added slag. The primary recommendation from this study is to develop a more robust and efficient feed mechanism; one designed specifically for low-pressure, high-moisture and large-particle feedstock expected in OmniGas reactor applications.

Keywords: Biomass, Gasification, Energy, California, OmniGas

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EXECUTIVE SUMMARY

Introduction

The majority of gasification efforts within the United States are focused on large gasification systems (>250 MWe) using coal to generate electrical power. While this may be an attractive endeavor given the coal resources within the U.S., it overlooks the potential market for smaller biomass gasifiers for industrial applications. The interest in this emerging market had previously been fueled by current industrial consumers of natural gas who were competitively disadvantaged due to increasing gas costs, a fuel supply that can easily be replaced by renewable syngas. The crash during this contract in natural gas prices and the spike in petroleum prices has shifted product demand, but the need for industrial-scale, low-cost, renewable energy has persisted and is the principle target market for the OmniGas gasification process.

This report summarizes recent operations of the OmniGas reactor technology, representing the culmination of more than eleven years of developmental work and more than $10 million of public and private funding ($500,000 provided by the California Energy Commission). Through this research, a comprehensive prototype system design was completed, including extensive refractory testing, thermal analysis and engineering schematics. This prototype unit was a 50x scale-up over previous units and termed the "0.5m OmniGas Reactor" due to the internal diameter of the gasification chamber. The reactor and additional upstream and downstream components were shipped to Wyle Laboratories in San Bernardino, California and assembled after significant design and fabrication work. The integrated biomass gasification demonstration project then converted waste wood fines into usable gases that could be used for process heating or be converted into higher value products.

Background

Gasification is partial-oxidation process of converting carbon-based materials (such as biomass, coal, petroleum coke, and waste) into a mixture carbon monoxide, carbon dioxide and hydrogen gases. These are conditioned into a "synthesis gas" (hydrogen (H_2) and carbon monoxide (CO)) that can then be used for a myriad of applications including the production of liquid fuels, synthetic natural gas, electricity and hydrogen. While the concept and practice of gasification is well-known and established, existing gasification technologies have clear limitations in areas such as feedstock flexibility, capital costs, and the ability to scale economically for industrial and distributed operations. OmniGas is a breakthrough advanced gasification technology that leverages expertise and know-how from the established molten-metals industry for the conversion of multiple carbon-based feedstocks to a wide variety of energy products.

OmniGas is an advanced molten metal gasifier using common commercial smelting practices to generate a synthesis gas (syngas) suitable for steam, power, process heating and liquid fuel or chemicals production (Figure 1). Steam, carbon, and oxygen are injected into the molten bath where two primary reactions occur to produce hydrogen and carbon monoxide. Steam reacts with the pure iron to produce iron oxide and hydrogen; carbon reacts with the resulting iron

Figure 1: OmniGas Technology Overview

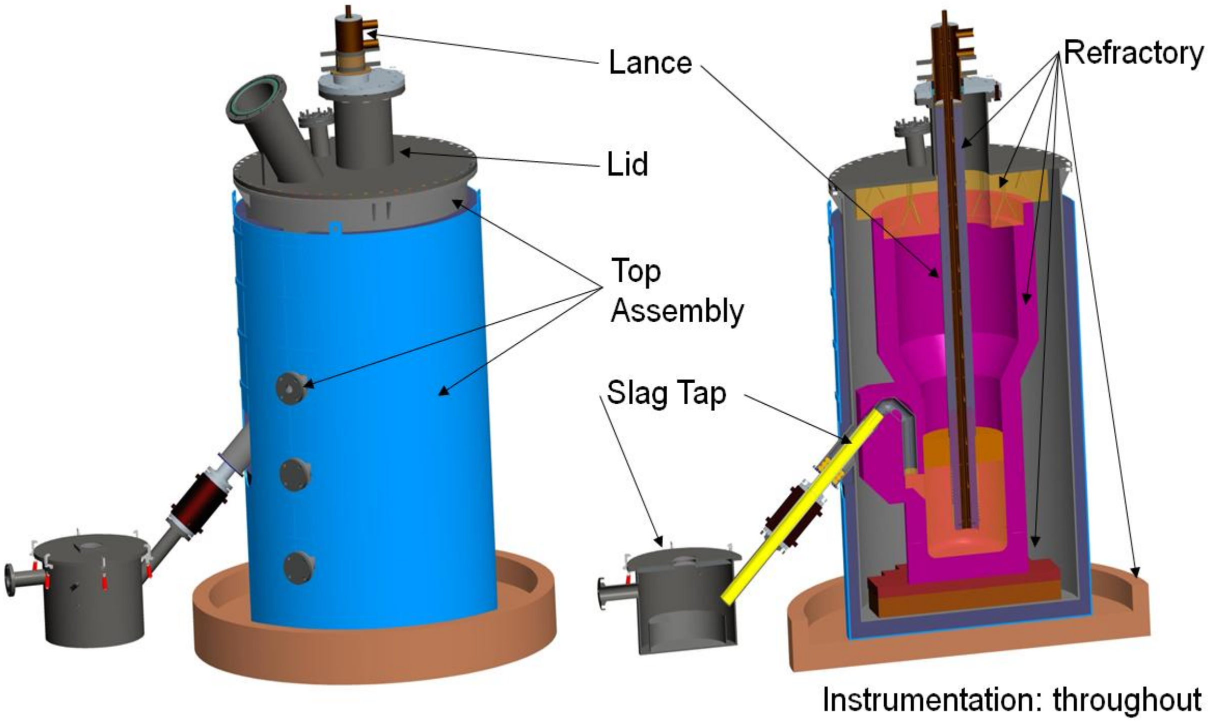


Photo Credit: Mike Sarin, Empowertech

producing carbon monoxide and returns the oxidized iron to its pure state. Oxygen is added to combust some of the carbon to maintain thermal balance within the reactor vessel.

Additionally, the high thermal inertia associated with the molten metal bath makes the OmniGas reactor tolerant to an array of biomass feedstocks with varying moisture contents without retarding the reaction rates or shutting down altogether. As molten slag, the ash content of entering feedstocks is directly captured in the molten bath and does not contaminate the syngas as it would in other technologies. As a result, the amount of slag material grows over time and is periodically removed with a patented slag-tap system that avoids direct contact of the operators with the 1300C material. The molten metal nature of the gasifier also enables modular and scalable reactors, and thus lower expected capital costs.

Years of testing at smaller scale have proven that OmniGas can efficiently gasify any biomass, in addition to waste products, such as discarded tires and high moisture content Municipal Solid Waste (MSW). This, along with the inherent end use flexibility of syngas, makes OmniGas an ideal candidate for industries looking to reduce or alleviate their natural gas or liquid transportation fuel consumption. The flexible feedstock advantage enables industries to utilize the most plentiful, lowest cost fuel for that region; whether it's high moisture content wood waste, or agriculture field waste.

Process and Results

Under the initial proposed project, the OmniGas gasifier was to be operated in conjunction with an existing industrial site. The first partner in this endeavor was Evergreen Pulp (EPI) that owned and operated a Kraft pulp mill in Eureka, California where waste wood fines would be used to generate syngas for replacing a portion of their natural gas use. Project agreements and plans were in place when, in 2008, EPI declared bankruptcy and shut down its plant.

After multiple discussions with other potential partners an alternative local site was established with Wyle Laboratories. Setup and operational testing of OmniGas was conducted and completed at this California facility using local low-cost sawdust – a by-product of wood chip manufacturing by West Coast Forest and Cinder Products, based in Arvin, California.

Preparations for gasifier operations were extensive; the test site provided the basic infrastructure and auxiliary support systems, but integration with the gasifier and this site was a major accomplishment of the project. Resulting from the site development and integration is a complete set of procedures, piping runs, instrumentation, feed preparation and heat exchange systems. The integrated system that has now been carefully dismantled is ready for reassembly and additional operations in conjunction with future investors and commercial partners. In addition, Diversified Energy has formed strong partnerships with various California businesses that provided many of the services or equipment used to complete this technology testing and validation.

The success of developing and integrating the gasification reactor was somewhat complicated by malfunctions with the biomass feed system which limited the maximum achievable temperature and gasification runtime duration. Issues with non-uniformity of, and contaminants in, the feed material resulted in reduced feed flow rates and frequent maintenance shutdowns. Additional research and development is necessary to advance robust and efficient feed systems for OmniGas system.

The summary outcomes from this OmniGas activity were:

- A complete System Design Report, including detailed analyses
- A fully fabricated and integrated ½ meter diameter prototype system
- A fully operational test facility and procedures
- California biomass gasification at scale
- Comprehensive collected data
- Future improvement recommendations

Benefits

This test demonstrated the OmniGas gasifier's ability to successfully integrate with other subsystems and proved for the first time the ability to heat up in the field by internal combustion.

As the OmniGas technology is applied in various market segments in California, it can provide more fuel security making the state less vulnerable to outside energy source price fluctuations and reducing fossil fuel imports. This biogasifier can also offset fossil sources of CO_2 emissions, improving California's air quality and helping to reach environmental targets. Additionally biogasification has can increase California's competitive position to attract new industry in the manufacturing and renewable technology sectors.

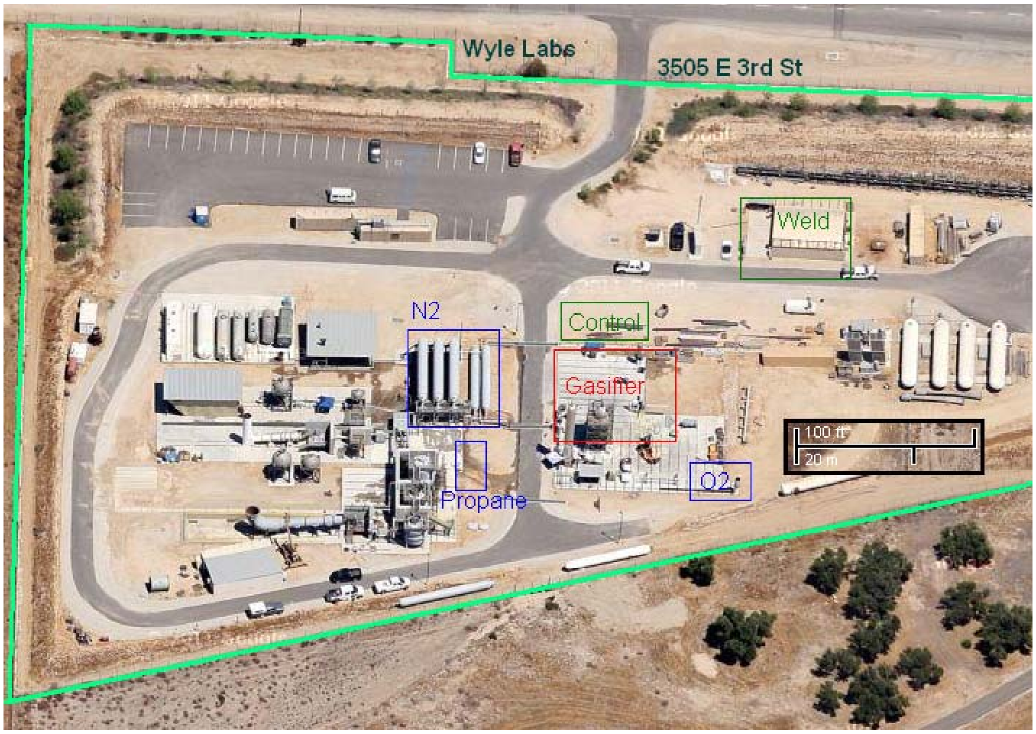
CHAPTER 1: Test Site Preparation and System Installation

1.1 Test Site Location, Capabilities

The location chosen for hosting operation of the OmniGas unit was a site maintained by Wyle Laboratories and located in San Bernardino, California. The site is close to the old Norton Air Force Base, which has been used extensively in the past for propulsion testing and high-pressure steam control testing. The site houses multiple concrete pads, high-pressure nitrogen tanks, liquid oxygen, a weld shop, data acquisition and control systems and site compliance with all regulatory agencies and permit requirements.

In addition to the impressive site capabilities, Wyle staff and personnel have past experience housing high-temperature and largely developmental projects such as our own. Their team included a full-time EHS manager, program manager and an instrumentation manager who had previously worked on developing biomass gasification in partnership with UC Riverside. Their welding and pipefitting crew proved extremely creative and efficient throughout setup and testing and thus helped control unexpected installation costs.

Figure 2: Arial View of Wyle Laboratories Site, Marked with Location of Pertinent Items



The Gasifier, piping and equipment were located on the central concrete pad (Red Box), connected to the gas supplies (Marked in Blue). The Control Room was located directly north of Gasifier operations. A weld shop, located on site, was frequently used during piping and integration.
Photo Credit: Google Earth 2013.

Figure 3: High Pressure Nitrogen Tanks

Eight high-pressure nitrogen tanks that contain nitrogen compressed at 5000 psig.

Photo Credit: Scott Cheney

Figure 4: Liquid Oxygen Tank

Photo Credit: Scott Cheney

Figure 5: Propane Tank

A 500-gallon propane tank was rented specifically for this testing and was refilled multiple times during testing to sustain the fuel required by the start-up burner.
Photo Credit: Scott Cheney

Figure 6: Gasification Control Room

This trailer was rented for this project and converted to a full-functioning control room with break room, computer screens and workbench. It is situated directly north of the pad.
Photo Credit: Scott Cheney

1.2 Gasifier Shipping, Unloading and Siting

The OmniGas unit was shipped from Diversified Energy HQ to Wyle Laboratories on February 28, 2013. Extensive transportation analysis and planning were completed before shipment to ensure that the unit would stay within major highway clearances and weight tolerances as well as ensuring proper equipment was in place at both ends for safe transfer of the unit to/from the flatbed. The gasifier (without lance or slag pot) weighs approximately 18,500 lbs and was 12 feet tall (including crating around the bottom of the unit). Transfer of the unit was slightly complicated by unexpected parking lot repairs outside the Diversified Energy high-bay, but that ultimately had no impact on final test date.

The gasifier was successfully unloaded at Wyle in March 2013 using a 10-ton crane and situated on the east-most site with easy access to needed gas inputs. The gasifier was later repositioned and shimmed on one side due to a slight slope in the concrete pad that was not identified until a difficult connection with the slag pot revealed this inconsistency. The lance was inserted later and without difficulty.

1.3 Integration of Unit to Gas Supplies

Integrating the OmniGas gasifier with Wyle's gas supply capabilities was initialized as soon as the unit was situated on site. The gasifier was connected to Wyle's nitrogen, oxygen, steam and cooling water supplies. These connections consisted primarily of an actuated control valve, manual shut-off valve, check valve and an instrumentation tree, as well as the tubing to connect the gasifier to the source through these items on each line. The details for these connections can be found in Appendix A: P&IDs. The orifice-style flow meters were designed and provided by Millennium Space Systems and included the bulk of the instrumentation (pressure, temperature and flow rate) for each of the gas inputs. Photos of the gas line connections are shown in Figures 7 - 9.

Figure 7: Incoming Pipe Lines and Instrumentation

All the incoming gas lines can be seen here, as well as the water supply line.
Photo Credit: Scott Cheney

Figure 8: Nitrogen Supply Control Valves and Instrumentation

The nitrogen supply comes through one main shutoff valve (right) and proceeds to a header from which the nitrogen goes to three different eductors, feed wash-down, hopper purge, slag pot purge and outer annulus of the lance (left shutoff valve). Also shown in this photo are the flow meter and additional instrumentation.
Photo Credit: Scott Cheney

Figure 9: High Pressure Steam Generator

This Sussman steam generator provided the 60 psig steam needed for gasification operations.
Photo Credit: Scott Cheney

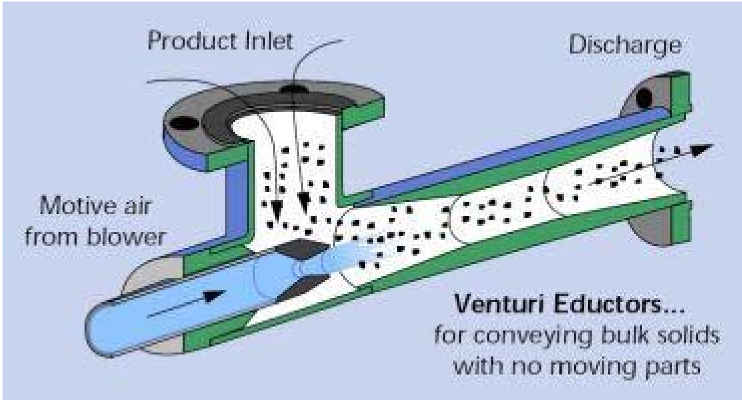
Several modifications were made in the field to the nitrogen and water lines for safety purposes, adding to the complexity and cost of the unit integration; however, the addition of an in-line quench is a major process improvement for this system compared to a separate quench reactor and will be implemented in future versions of the reactor. Additionally, the addition of two separate venturi eductors for the quick/effective reduction of pressure in the gasifier and slag pot (separately) is likewise a significant process and safety improvement over the initial embodiment of the OmniGas system.

Integrating the gasifier with the feed system was perhaps the most difficult activity and underwent several major revisions throughout integration and operation. The feed system employed had been previously developed for this unit in conjunction with smaller-scale testing at Pittsburg Mineral and Environmental Technologies (PMET). The basic concept is that a bulk feedstock (in this case, sawdust) is fed from a hopper to a screw feeder (at a specified rate) to a venturi eductor (which uses a high-pressure motive gas to create suction at the inlet and pressure at the outlet) that injects the gas-entrained solids into the gasifier (Figure 10). A schematic of eductor operation and principles is shown in Figure 11.

Figure 10: Penberthy 1/2A LL Eductor in Use at PMET Facility

The eductor used at PMET is a Penberthy model and has ½” suction and discharge fittings; it is the smallest version commercially available. It is shown here discharging biomass feedstock into a shopvac hose.
Photo Credit: Jonathan Hiltz (PMET)

Figure 11: Schematic of Eductor Operation Theory



Fox Valve is one of the most widely known and recommended suppliers of specialized eductor systems. However, they do not provide eductors at the small scale which the OmniGas system would be operating, thus engineering and procurement of the eductor were done independently of Fox.
Photo Credit: Fox Valve

For the 0.5m OmniGas unit operated at Wyle Laboratories, a twin-screw feeder was employed and a larger eductor was selected. The screw feeder size was selected from the measured bulk density of the sawdust and desired volumetric feed range; additionally, a unit was selected that has a hopper agitator to prevent any bridging of the feedstock in the hopper. The eductor size (3/4" in this system) was determined through a series of calculations based on documentation provided for liquid slurry transportation using Penberthy eductors – calculations for gas-entrained particle transportation are not available, but have proven to be similar enough via small-scale testing at PMET. See Figures 12-14 showing the screw feeder employed as well as the connection to the eductor.

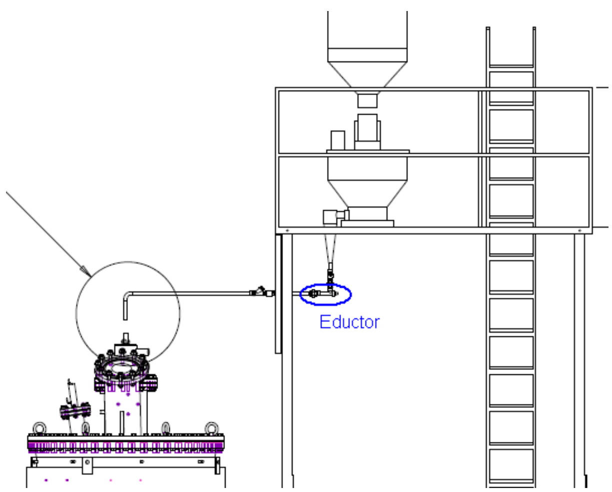
Figure 12: Unconnected Feeder Photo, Dimensions of Hopper

Photo Credit: J&M Industrial

Figure 13: Auger Comprised of Twin Screws, Shown Exposed

These twin screws normally discharge into a 4” pipe that is open on top and bottom. The material drops down from this point through a series of reducers and finally into the ¾” inlet of the eductor.
Photo Credit: Scott Cheney

Figure 14: Schematic for Mounting Auger to Eductor



This engineering schematic shows the feed supply assembly, from the initial silo through the hopper, auger, reducers, eductor and feed piping finally going into the inner annulus of the lance.
Photo Credit: Mike Sarin, Empowertech

After the hopper/screw/eductor system was connected on site, various calibration and limit tests were performed, using both the California fir sawdust and a small sample of petcoke. This provided an exact correlation between the feeder settings, RPM and volumetric rate which would later be used to control and measure the solids feed rate into the gasifier (calculated in conjunction with the bulk density of the material being conveyed). This testing also revealed a particle size and moisture content limitation on sawdust conveyance – although the eductor worked as expected for the petcoke powder, the sawdust would frequently bridge, clog and otherwise stop the eductor from functioning. For this reason, all of the sawdust had to be screened down to 10-minus and dried to roughly 20 percent moisture (down from the 36 percent as received). It is apparent that these issues are particularly problematic at this scale, where the small pipe size and eductor "neck" size create ample opportunity for the feedstock to stick and clog.

The calibration testing also allowed for measurement of the required "suction" or "wash-down" flow – that is, the gas flow required to accompany the feedstock at the suction of the eductor. When open to atmosphere, this is no issue because the eductor simply pulls in as much excess air as it needs to maintain proper operation, but for the gasification system, this wash-down flow is to be supplied with nitrogen. Testing revealed that this nitrogen flow must be controlled at near-atmospheric pressure or else it interferes with eductor operation and also impedes solids flow from the auger. A basic pressure regulator system was designed and constructed for this test, although a more sophisticated and robust solution would need to be designed for a larger and more permanent operation.

Another critical component of the feed system was the method for keeping the feed hopper filled: the hopper itself holds only enough material for roughly 20 minutes of operation at full rate. Initially, the sawdust was going to be delivered in one bulk load and thus a "silo system" was developed wherein the sawdust would be scooped (via skid loader) into 110-gallon silos, these silos would be hoisted into place above the main hopper and a slide gate opened to allow for continuous feed from the silo to hopper to auger to eductor to gasifier. The silo would be changed out and refilled when a low-level sensor was activated. A working platform was designed to support the feeder system above and to the side of the gasifier as well as allow access to the hopper/silo for easy change out.

A more elegant solution to the hopper filling problem came through the feedstock supplier who was able to load the sawdust into "totes" that hold 2.5 cubic yards each. These totes are essentially large square plastic cubes with hoisting straps on the top. The totes were lifted into place above the silo/hopper and the bottom of the tote cut open such that the material flowed from the tote to the silo and thus onto the rest of the feed system. This provided a much longer run time between changing out totes and avoided safety and contamination issues associated with transferring material to silos via skid loader. See Figures 15-17 of the platform structure, silo and feed totes.

Figure 15: Feed Support Platform

The feeder support platform, 10' square, with the top platform at 14' above ground. The top level provides access to the feeder, hopper, silo and feed totes. The bottom level provides access to the eductor and nitrogen flow control. The motor control for the auger is located at the electrical box on ground level at the right of the image (by the ladder).
Photo Credit: Scott Cheney

Figure 16: Hoisting the Barrel Lifter with Crane

The barrel lifter (the yellow metal item) being lifted by the crane was used at times for moving full barrels of screened feedstock up to the top level for use.
Photo Credit: Scott Cheney

Figure 17: Bulk Sawdust Material Totes

Photo Credit: Scott Cheney

1.4 Integration of Unit to Downstream Gas Handling

Downstream of the gasifier several different elements were installed for appropriate gas handling. Of initial importance is cooling the syngas down to acceptable levels such that it will not significantly weaken the integrity of the stainless piping, flanges and bolts. For this requirement, a simple gas quench nozzle system was employed. A water line passes through the exhaust pipe at the exit of the gasifier; the flow is sufficient such that the water does not boil, but passes through to the outlet (in this case, a drain) and keeps the stainless tubing at a suppressed temperature. Installed onto the tubing are two spray nozzles which are activated upon adjusting the downstream water discharge valve – thereby creating backpressure to force water through the nozzles. Thus the flow through the nozzles is controlled to the amount needed to bring the syngas temperature from 1200C to approximately 900 C. In a commercial-scale model, this may be further developed or may be converted to a traditional quench "reactor" that includes a separate, refractory-lined and instrumented vessel.

After the quench nozzles, the syngas travels down a length of stainless piping to an experimental bundle of water-cooled heat exchanger tubes. The initial design was a fin-fan approach that utilizes ambient air blown over a bundle of finned tubes; this was deemed to be too inefficient and unreliable and so the water-cooled style was used. The heat exchanger is shown in Figures 18 and 19. In a commercial-scale design, the water used to cool the syngas is not sent to the drain (as it is in this version) but rather is converted to steam to be used in power generation via steam turbine.

Figure 18: Spray Water-Cooled Heat Exchanger, Before Operation

The stainless steel heat exchanger was built to withstand the roughly 900C incoming syngas and cool to below 200C. The top of the unit stands about 6 feet off the ground and end-to-end is roughly 20 feet long.
Photo Credit: Adam Weidner

Figure 19: Spray-Cooled Heat Exchanger Close-Up

The PVC water distribution system consisted of two levels of 24 nozzles each which could be turned on and off individually. The heat exchanger bundle routes the main flow through six parallel tubes down and back again where the lines recombine in a header and flow on to instrumentation and then to the flare.
Photo Credit: Scott Cheney

The heat exchanger cools the syngas to 200C at which point the flow, pressure and temperature are measured. Also, the gas composition is analyzed by a gas chromatograph (GC) which pulls a sample of the gas and analyzes it every 30 minutes. The frequency of the gas sampling is a result of the GC technology which uses the varying elution time of various compounds to identify them. Real-time gas analyzers (based on thermal conductivity and Near Infra-Red measurement) are preferred, but are expensive to purchase and unavailable for rental and thus not implemented in recent operational testing. The gas chromatograph unit is shown in Figure 20, along with the sample pump and filter.

Figure 20: SRI Instruments' Gas Chromatograph Unit; Filter and Sample Pump

A small vacuum sampling pump was connected to the main syngas line by 1/8" tubing and continuously pulled a slip stream from the main line through the GC and discharged back to the syngas line, further downstream.
Photo Credit: Scott Cheney

Finally, the gas is sent to a flare (thermal oxidizer) which combusts any and all combustibles in the syngas (predominantly the H_2 and CO, as well as any trace methane). The flare unit was rented from Callidus and includes a "knock-out pot" for separating any water condensate entrained in the syngas flow prior to sending it up the flare stack. At the tip of the flare stack are propane-fired pilots that are continuously lit and through which all the syngas passes. Figure 21 shows the flare stack and knock-out pot; Figure 22 shows the flare operating at night.

Figure 21: Configured Syngas Flare Unit

The 25’ tall syngas flare was rented from Calldius Technologies, was delivered on a trailer and was erected on site at Wyle. The knock-out pot is the gray-colored tank at the bottom and right of the flare. The flare control panel is also visible in the bottom right and covers up a portion of the knock-out pot.
Photo Credit: Scott Cheney

Figure 22: Operational Flare, Lit at Night

The pilots are monitored with “flame lit” indicators and gave an alarm in event of pilot failure: the pilot flames were not visible during daylight hours.
Photo Credit: Adam Weidner

1.5 Instrumentation and Control System

For instrumentation, a variety of sensors were placed throughout the system in the field and the output signal brought back to FieldPoint Input Cards, then to PXI Data Acquisition Cards and finally to a complete LabView program interface. The data was displayed in real-time on computer monitors and recorded in log files by LabView and stored on the Wyle server. A complete list of the instrumentation installed for this test is shown in Table 1.

The gas analyzer data was also pulled into the control room and data acquisition computers; however, the electronic signal that was transferred by Ethernet cable from the analyzer was converted and analyzed with specialized PeakSimpleTM software. The raw data and results from this software were stored on the Wyle servers.

There were only few instrumentation outputs (listed as the first five items in the below table). These are safety mechanisms for immediate or emergency shutoff of the various gas flows. These actuated valves were set to either fail-open or fail-close, depending on the valve, in case of power or instrument air failure. Additionally, control of these valves was hard-wired to a red Emergency Stop (E-Stop) button located in the control room. Upon pressing the E-Stop, the system would default the valves such that the system would be in the safest orientation possible – nitrogen purge of the vessel through the inner and outer annuluses of the lance.

Installomg the instruments went quickly and without much complication. Debugging the instrumentation, however, took a considerable amount of extra, unexpected time. The thermocouples especially proved problematic and took days to troubleshoot. In several cases, the thermocouples had false junctions which skewed the results; in other cases the thermocouples needed special resistors for correct operation. Ultimately even the entire Thermocouple Analog Input Card had to be replaced for some of the thermocouples to transmit their values correctly.

This lengthy debugging process, along with some last-minute modifications in release of the finalized LabView package, caused delay in the start date of operation by one or two days. At start-up, all of the instrumentation was functioning correctly, with the exception of one thermocouple that was damaged upon start-up of the quench system. Figure 23 shows an example of the LabView program interface (the full set of screens can be found in Appendix B). Figures 24-26 show various other elements of the instrumentation and control system.

Table 1: Complete List of Instrumentation Inputs and Outputs

#	Description	P&ID #	Manuf P/N	Manuf	Type
1	Fuel Feed Isolation Valve	FXV_F_01	15-39-SW	Flowserve	24 VDC
2	Nitrogen Feed Isolation Valve	FXV_N_01	15-39-SW	Flowserve	24 VDC
3	Oxygen Feed Isolation Valve	FXV_O_01	15-39-SW	Flowserve	24 VDC
4	Steam Feed Isolation Valve	FXV_W_01	15-39-SW	Flowserve	24 VDC
5	Water Feed Isolation Valve	FXV_W_02	15-39-SW	Flowserve	24 VDC
6	Nitrogen Lance Outer Shell Bypass	FXV_N_02	15-39-SW	Flowserve	24 VDC
7	Steam Feed Temperature	TI_W_01	KQXL-18G-6	Omega	K TC
8	Oxygen Feed Pressure	PI_O_01	PX329-150GI	Omega	mA
9	Nitrogen Feed Pressure	PI_N_01	PX329-150GI	Omega	mA
10	Steam Feed Pressure	PI_W_01	PX329-150GI	Omega	mA
11	Fuel Feed Pressure	PI_F_01	PX329-150GI	Omega	mA
12	S1-Lower Chamber	TE_S_01	SAT-24-4	Omega	S TC
13	S2-Upper Chamber	TE_S_02	SAT-24-4	Omega	S TC
14	S3-Process Exit Exhaust	TE_S_03	SAT-24-4	Omega	S TC
15	K1-Lower Chamber Bottom	TE_K_01	XCIB-K-4-3-10	Omega	K TC
16	K2-Lower Chamber	TE_K_02	PTRA-31614-4-1	Omega	K TC
17	K3-Upper Chamber	TE_K_03	PTRA-31614-4-1	Omega	K TC
18	K4-Containment Vessel Inner Surface	TE_K_04	CHAL-020	Omega	K TC
19	K5-Containment Outer Surface	TE_K_05	CHAL-020	Omega	K TC
20	K6-Containment Upper Flange	TE_K_06	CHAL-020	Omega	K TC
21	K7-Slag Tap Pipe	TE_K_07	XCIB-K-4-3-10	Omega	K TC
22	K8-Lance Head	TE_K_08	NB1-CAXL-14G-12	Omega	K TC
23	K9-Heat Exchanger Outlet	TE_K_09	CHAL-020	Omega	K TC
24	K10-Burst Disk	TE_K_10	CHAL-020	Omega	K TC
25	K11-Slag Pot	TE_K_11	CHAL-020	Omega	K TC
26	K12-Clamshell Heater	TE_K_12	TC-K-NPT-U-72	Omega	K TC
27	Syngas Flow Meter ΔP	DPIT_S_01	PX429-005DWUI	Omega	4-20mA
28	Syngas flow pressure	PIT_S_01	PX329-005GI	Omega	4-20mA
29	Pressure transducer 0-15 PSIG	PI_G_01	PX309-030G5I	Omega	mV
30	Pressure transducer 0-15 PSIG	PI_G_02	PX309-015A5I	Omega	mV
31	Oxygen Flow Meter ΔP	DPIT_O_01	PX429-100DWUI	Omega	4-20mA
32	Oxygen Flow Temp	TT_O_01	0.250-K-U-8"-PJ	Wilcon	4-20mA
33	Oxygen Flow Pressure	PIT_O_02	PX329-150GI	Omega	4-20mA
34	Nitrogen Feed Flow Meter ΔP	DPIT_N_01	PX429-100DWUI	Omega	4-20mA
35	Nitrogen Flow Temp	TT_N_01	0.250-K-U-8"-PJ	Wilcon	4-20mA
36	Nitrogen Flow Pressure	PIT_N_02	PX329-150GI	Omega	4-20mA
37	Steam Flow Meter ΔP	DPIT_W_01	PX429-100DWUI	Omega	4-20mA
38	Steam Flow Temperature	TT_W_02	0.250-K-U-8"-PJ	Wilcon	4-20mA
39	Steam Flow Pressure	PIT_W_02	PX329-150GI	Omega	4-20mA

Figure 23: Feed Gases Panel for LabView Program Interface

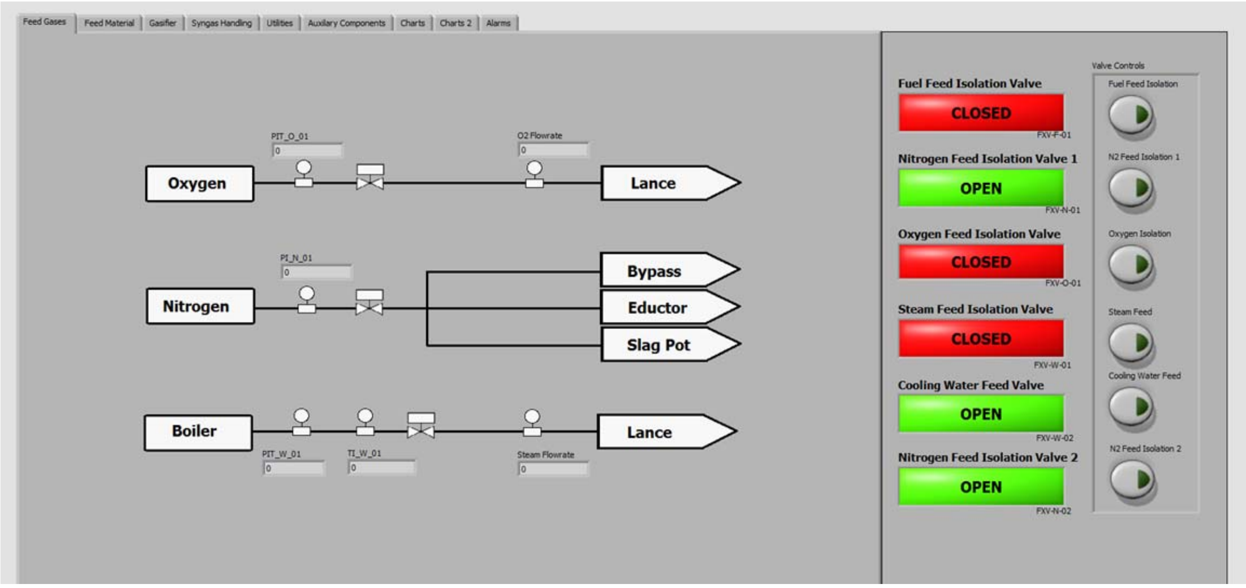
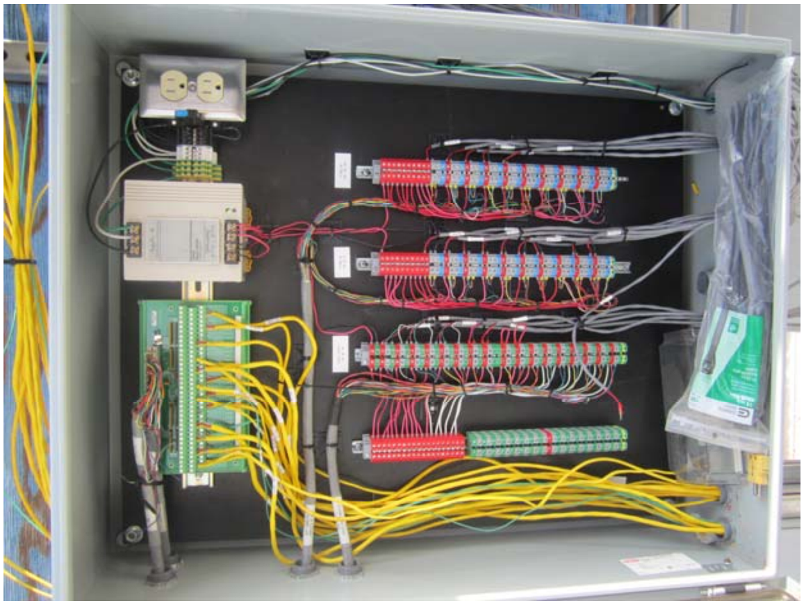


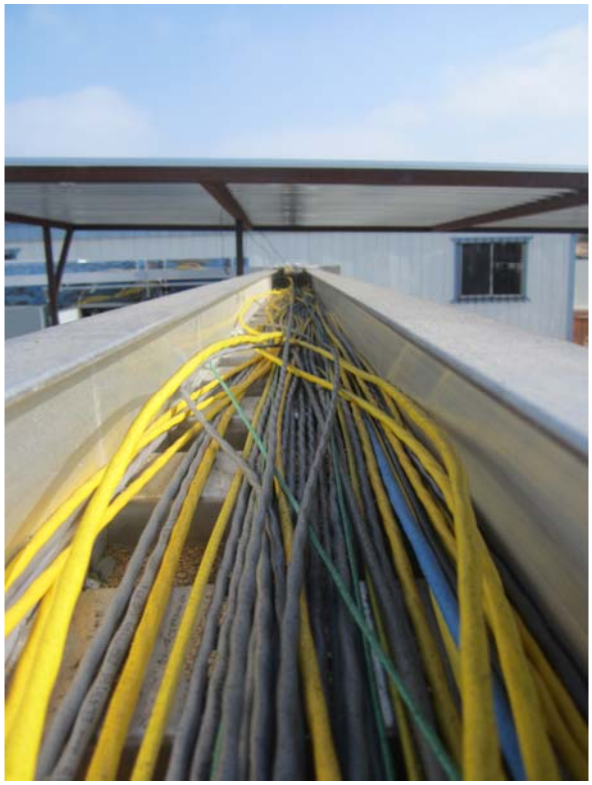
Photo Credit: Trishana Prater, Millennium Space Systems

Figure 24: FieldPoint Input Cards



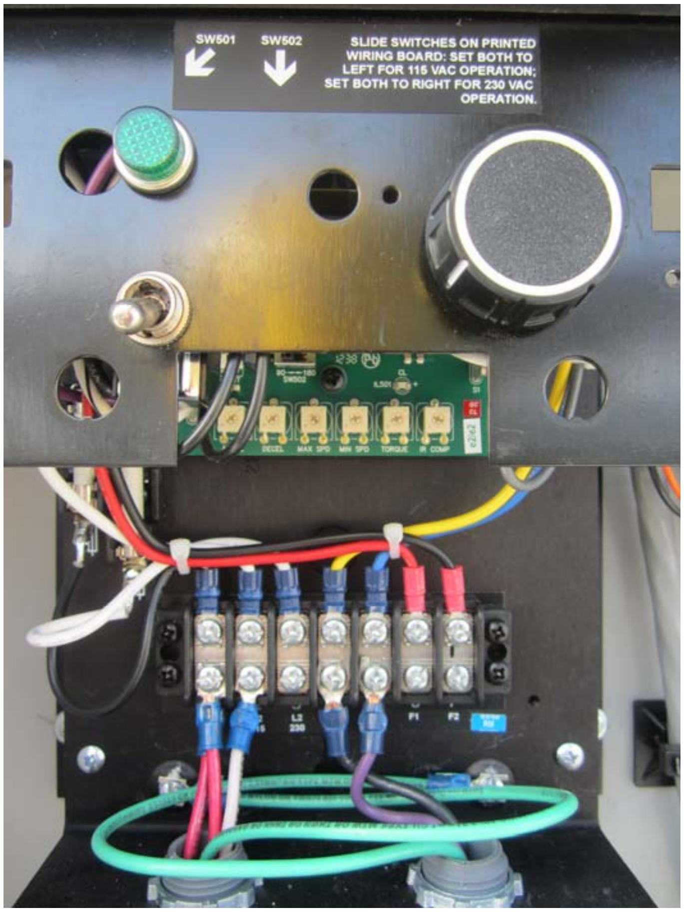
All of the system instrumentation wiring came back to this box where the signals are converted by National Instruments' FieldPoint Input Cards and sent to the control room PXI Data Acquisition system.
Photo Credit: Scott Cheney

Figure 25: Cable Tray Carrying Wires to Input Cards



Various types of extenders and wires were used for the various types of instrumentation used in the field.
Photo Credit: Scott Cheney

Figure 26: Feeder Motor Control Wiring



The feeder motor control proved to be more complex than anticipated and actually created problems later on during operation (which will be discussed later). The knob on the right controls the motor speed and auger RPM; the cover for this box has markings such that the current setting of the knob can be noted and recorded. The green panel in the center has feeder tuning parameters such as “torque” and “IR comp”.
Photo Credit: Scott Cheney

CHAPTER 2:
Slag Preparation

2.1 Ideal Slag Mixture and Challenges

The OmniGas technology operates using the principle of a molten/liquid slag intermediate which facilitates the gasification reaction and promotes production of cleaner, higher quality syngas. Previous research and testing has shown that the correct composition of this slag is necessary for proper stability, slag fusion and melt temperature. The ideal slag composition is shown in Table 2.

Table 2: Ideal OmniGas Slag Composition

Component	Base Mineral	Common Name	Percentage
FeO	Iron	Wüstite	50%
SiO_2	Silicon	Silica	28%
CaO	Calcium	Quicklime	22%

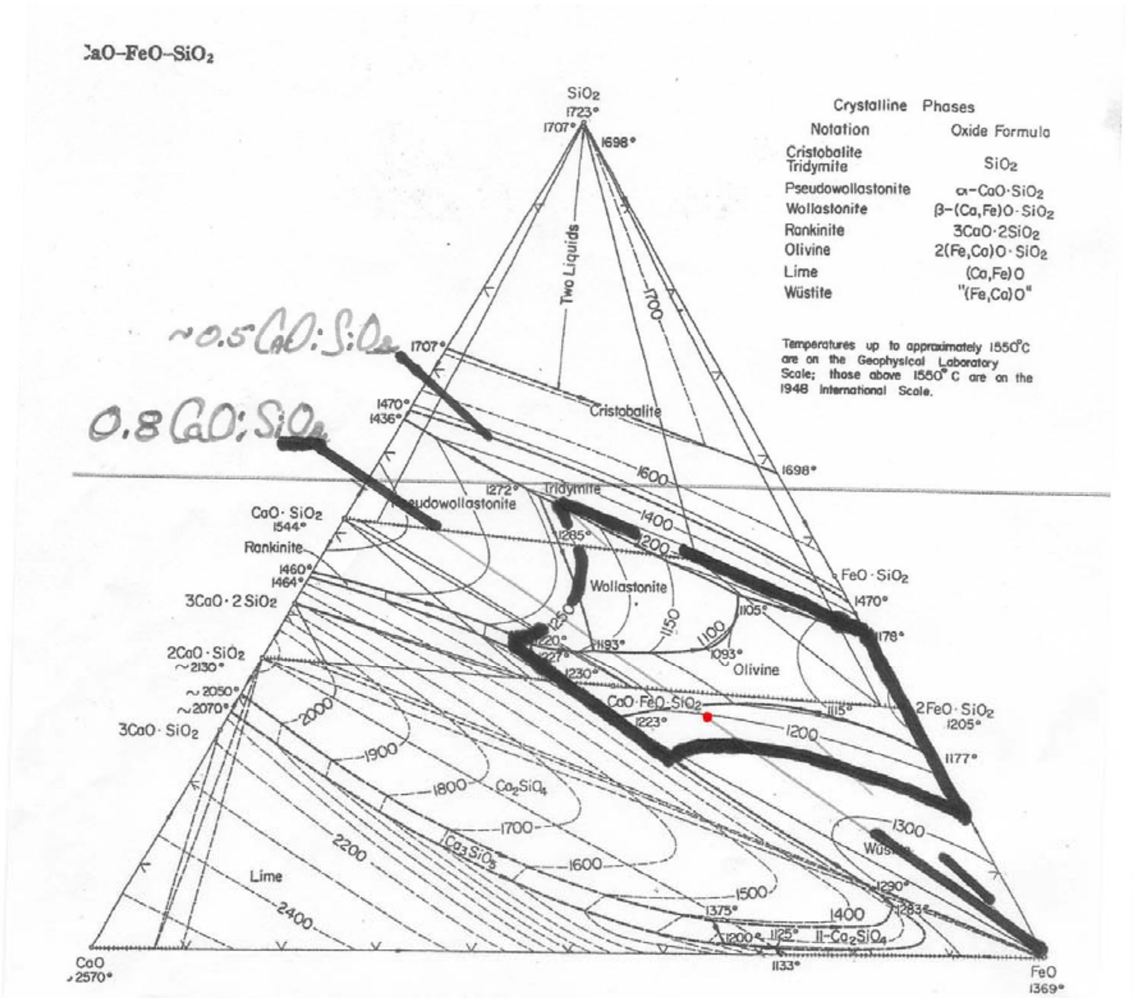
Source: Diversified Energy

The FeO content is kept as high as possible while keeping the melting point of the mixture below 1250C: the higher the iron content, the more efficient the gasification reaction. The silicon and calcium comprise the remainder of the mixture and are the two most common components found in carbon feedstocks (coal and biomass). The crucial parameter with these components is their ratio to each other and is ideally set just below 0.8 CaO:SiO2; above 0.8 the slag mixture will start to foam and create problems in the headspace of the reactor; below 0.8 the slag mixture starts to become more and more "glassy" and is not as molten/liquid.

However, there are multiple problems getting this ideal slag mixture procured and melted. First, Wüstite is not a commonly occurring compound and is only naturally found in certain meteorites. Therefore, one must start with a higher form of iron oxide Fe_2O_3 (hematite) or Fe_3O_4 (magnetite) and reduce it to produce FeO. Magnetite is readily available and so was used for the mixture used in this test. Then, at elevated temperature, the slag is put into a reducing atmosphere by adding petcoke with insufficient oxygen. The petcoke (basically pure carbon, C) is converted to CO and the Fe3O4 is reduced to FeO. If too much carbon is added, the FeO will reduce further to pure iron (Fe) and be basically unusable in the reaction until sufficient oxygen is added again to bring the metal back to its oxidized FeO state. This can be a delicate balancing act and is managed through precise addition of oxygen and petcoke (carbon).

The second issue with producing this ideal mixture is that each of the compounds melts at a much higher temperature than the composite. This is seen most clearly in Figure 27. Therefore, the materials must either be pre-melted and combined or must be made to be in such close proximity with each other that mass transfer effects take over at the desired melting temperature and the components fuse naturally at 1200-1250C. Both approaches were used in the preparation for the recent test.

Figure 27: Ternary Phase Diagram for the CaO-SiO_2-FeO System



The phase diagram is marked with the 1250C melting point outlined in black and CaO:SiO_2 ratios also marked. A small red dot denotes the target composite composition in the recent test.

Photo Credit: E.F. Osborn and Arnulf Muan, American Ceramic Society, 1960 – Edited by PMET and DEC

2.2 Slag Analysis, Mixing, Briquetting and Pre-Melting

In previous experiments, the best source of starter slag material has been from Harsco, a corporation that operates a coal power plant and produces slag as a byproduct from its process. This slag has, at times, had a near-perfect distribution of the desired components. The batch that was received from Harsco in preparation for testing had the distribution shown in Table 3.

Table 3: Slag Received from Harsco

Component	SEM Analysis	Conti Labs
FeO	26.70%	15.27%
SiO_2	38.47%	50.12%
CaO	13.25%	9.82%
Al_2O_3	19.11%	

Source: Diversified Energy

Due to the larger sample size used by Conti Labs and since they used wet chemistry instead of SEM, their analysis was the deemed the most reliable and used for additional calculations. To adjust for the iron and calcium deficiencies, additional Fe3O4 and CaO were added to the Harsco material; both of these materials were easily procured by PMET. To reduce the iron, a calculated amount of petcoke, procured from Exxon, was added to the mixture. A final mixture using the Harsco material was created and shipped out for additional pre-melting. A second mixture was created just out of the raw, individual materials and compacted prior to shipment. Both of these mixtures are shown in Table 4.

Table 4: Slag Mixtures Used in CA PIER OmniGas Testing

Component	Mix #1	Mix #2
Harsco	100 lb (25.4%)	
SiO_2		196 lb (26.3%)
CaO	39.8 lb (10.1%)	154 lb (20.7%)
Fe3O4	241 lb (61.3%)	376 lb (50.4%)
C (petcoke)	12.5 lb (3.2%)	19 lb (2.6%)
Total	393 lb	745 lb

Source: Diversified Energy

The first mix was sent to Peat International, a company that had the capability and willingness to pre-melt the entire 400 lb mixture in their furnace (albeit in two batches). The slag was melted in a nitrogen purged reactor and reached a temperature just under 1350C before tapping the melt onto a concrete slab and letting it cool. However, the results from this pre-melt were not as expected – the iron oxide had reduced all the way to iron and the various components appear to have layered/segregated instead of fusing together (see Figures 28-29). The only likely possibility is that too much carbon was added. This would seem to have required a significant slip-up in the amount extra carbon added (up to 50 lbs to reduce all the Fe_3O_4 to pure Fe); however, no other possibilities are forthcoming.

Figure 28: Slab of Metallic Iron from Peat Pre-Melt

The material shown above was clearly iron and not iron oxide, as proved by the magnetic properties of the material. The technician responsible for melting the mixture noted that the slag seemed to come out segregated/layered.
Photo Credit: Scott Cheney

Figure 29: Chunk of CaO/SiO_2 from Peat Pre-Melt

The rest of the material was brittle and much lighter density compared to the slag of iron. However, even this material seemed to be segregated in layers. One layer was glassy, greenish and brittle. The other was grey, rough and seemed to have flecks of shiny material.

Photo Credit: Scott Cheney

The other 750 lbs of pre-mixed slag material was compressed into bricks, roughly 4”x6”. This material was not to be pre-melted, but the close contact of the various compounds with each other (due to compression) enabled easier mass transfer and fusion of the components into one slag melt.

2.3 Loading of Slag into Gasifier

Various strategies were assessed for getting the slag mixture into the gasifier and ultimately the safest option was chosen. The first issue with loading the unit was size: both the pre-melt and bricks were much too large to fit through the feed lance of the gasifier. The only route for the material to be added was through a 4” port on the top of the gasifier unit. Still, the materials had to be size-reduced to fit through this port, but this was easily done on site with hammers of various weights.

The second issue was temperature. The start-up burner gets the reactor to 600 C at which point the top of the vessel is too hot to safely work on or around for any prolonged time period. Therefore the largest quantity of slag – the bricks – was loaded into the unit by hand prior to preheating the unit. The smaller quantity of (smaller chunk size) pre-melted slag was added via funnel to the pre-heated unit at minimal safety risk. From this point on, all the slag had been added and the unit could be taken up to maximum temperature.

This approach led to issues with the heat-up duration and project timeline. By pre-loading the slag into the unit, free airflow of the start-up burner was impeded and the vessel did not heat evenly or quickly. Two solutions to this issue could be implemented in future development of the unit. First, a separate feed system will be designed that will be able to introduce the slag material once the unit is at full temperature – without impeding the operation of the gasifier or lance. Second, all of the slag may be pre-melted and fritted or pulverized such that it doesn’t need to be added by hand. These are all issues associated with the prototype unit that can easily be modified in future commercial units. As expected, this testing proved invaluable for identification of such operational issues not normally seen in a small “laboratory environment”.

CHAPTER 3:
Feedstock Analysis and Pre-Conditioning

3.1 Suppliers Assessed and Samples Analyzed

Finding a supply of California-derived woody biomass was a lengthy process. Commercially available sawdust is provided by several vendors throughout the state of California, most who provide the material as a soil amendment or as bedding for animals. However, due to the size restriction of the prototype gasifier lance (must be 1/8″-minus) many of the suppliers could not provide feedstock in this range. Other potential suppliers were not interested or did not return inquiries.

Three suppliers made it to the final round of selection: West Coast Forest & Cinder Products, United Forest Products and Reuser Inc. West Coast sent samples of their fir bark and fir chips, United sent samples of their fir bark material, and Reuser unfortunately responded too late with availability to send samples of their redwood material. After these samples were analyzed by Conti Labs for composition, moisture and BTU content the fir chip sawdust material (#162145b) from West Coast was ultimately selected for use as the main feedstock at Wyle. The analyses are shown in Tables 5 and 6.

Table 5: Feedstock Sample Analysis

Parameter	West Coast Fir Bark	West Coast Fir Sawdust	United Forest Fir Bark
Sample #	162148	162145b	162356
Moisture %	33.58	47.63	16.51
Ash %	13.82	0.62	9.23
Volatile Matter %	37.93	43.45	49.67
Fixed Carbon %	14.67	8.29	24.58
Btu/lb (HHV)	4881	4596	6135
Dry Btu/lb	7348	8777	7348
MAF Btu/lb	9279	8883	8262
Moisture wt.%	33.58	47.63	16.51
Ash wt.%	13.82	0.62	9.23
Hydrogen wt.%	2.70	2.83	4.1
Carbon wt.%	31.17	29.35	44.39
Nitrogen wt.%	0.65	0.57	0.96
Sulfur wt.%	0.01	0.01	0.03
Oxygen wt.%	18.06	18.99	24.77
Density lb/ft3	17.8	23	21.6

Source: Diversified Energy and Conti Labs

Table 6: Feedstock Ash Analysis

Parameter	West Coast Fir Bark	West Coast Fir Sawdust	United Forest Fir Bark
Sample #	162148	162145b	162356
SiO2 wt.%	70.92	34.10	60.65
Al2O3 wt.%	12.7	7.75	14.13
Fe2O3 wt.%	3.15	3.10	7.45
CaO wt.%	4.83	33.59	7.6
MgO wt.%	1.34	4.38	2.9
TiO2 wt.%	0.35	0.30	0.77
SO3 wt.%	0.17	1.25	0.62
Na2O wt.%	2.56	1.62	1.42
K2O wt.%	2.53	8.69	2.28
BaO wt.%	0.09	0.19	0.09
MnO2 wt.%	0.08	0.97	0.43
SrO wt.%	0.04	0.20	0.05
P2O5 wt.%	0.34	3.07	0.85
V2O5 wt.%	0.00	0.02	0.02
CaO:SiO2	0.07	0.99	0.13

Source: Diversified Energy and Conti Labs

3.2 Fir Sawdust Screening and Drying

Before the sawdust is shipped, West Coast attempted to dry the material from 47 percent to a more acceptable target. They spread the sawdust out to let it dry from sunlight and air for about two weeks before packaging and shipping the material. This reduced all of the material to about 36 percent. With this material the feed system (hopper, auger and eductor) was tested and assessed for reliability with the given feedstock. Multiple locations were found where the feedstock was getting stuck and clogged, including various ridges within the pipe where fittings occurred. These ridges were smoothed out and trouble points debugged, but the feedstock would still eventually get clogged in the eductor.

To overcome the small orifice size of the eductor, an elaborate screening mechanism was designed and built in real time at Wyle. The sawdust screener was built of 2x4s and plywood, but the key components were two screens, of different mesh sizes, and two vibrators. The top screen had the largest hole size and the steepest angle – this screened out the particularly large pieces of biomass in the sawdust material. The second screen ran underneath the top one, and at an opposing slant direction, such that the material passing through the top would fall onto the bottom for further screening. The material of desired size (roughly 10-minus, or < 2mm) would pass through this second screen into the center section of the mechanism and accumulate before collecting. The unacceptable material was placed into the back of a dumpster for future disposal. Figure 30 shows the mechanism from the side, figure 31 shows accumulation under the mechanism, and Figure 32 shows the feed and size distribution.

Figure 30: Sawdust Screening Mechanism

Photo Credit: Adam Weidner

Figure 31: Accumulation of Screened Sawdust Material under Mechanism

The vibrator was a simple electric motor-powered unit that was attached to the underside of each screen; it is the orange device seen in this picture. The acceptable sawdust would accumulate in a pile and periodically be scooped out with a shovel back into a tote bag.
Photo Credit: Scott Cheney

Figure 32: Screened Materials

The top line of material is the bulk fir sawdust, as received. The bottom-left pile is the material passing over the top screen. The bottom-center pile is the material passing over the bottom screen. The bottom-left pile is the good material, passing through the 10-mesh bottom screen. The actual composition of these size groups in the bulk feed is roughly 10:50:40.
Photo Credit: Scott Cheney

The screened sawdust performed much better through the feeder and eductor, but still proved unreliable and would still clog the eductor, especially at elevated feed rates. To overcome this challenge, the sawdust was further dried, with the goal of eliminating bridging and sticking of the material to itself. The method for drying the material was to simply spread the material out in the dry air and hot sunlight, stirring it periodically. In this way the moisture content was reduced from 36 percent to below 20 percent. The dried material was much less dense, less sticky and flowed much more reliably through the feed system and eductor. Figure 33 shows the eductor still getting clogged with wet biomass. Figure 34 shows the drying process. Figure 35 shows the comparison between the wet and dry screened material.

Figure 33: Eductor Clogging with Wet Biomass

The sawdust got clogged in multiple places in the eductor at different times. In this case, the wet material actually built up around the high-pressure nitrogen nozzle.
Photo Credit: Scott Cheney

Figure 34: Sawdust Drying Process

Sawdust was laid out on multiple black plastic tarps and stirred periodically with a rake. This method was dependent on warm, sunny weather, which was common during the period of testing in San Bernardino.
Photo Credit: Adam Weidner

Figure 35: Comparative Photo of Wet and Dry Screened Sawdust

The size of piles is not indicative of moisture lost, but the color shows the obvious different in the amount of moisture removed from the screened sawdust.
Photo Credit: Scott Cheney

CHAPTER 4: Gasifier Operation

4.1 Pre-Heat and Dry Out

Operations commenced subsequent to all the gasifier integration and instrumentation check-out. The initial phase of gasifier start-up was the pre-heat and dry out schedule. Since the gasifier runs solely on solid feedstocks, an external source of energy was needed to heat the unit up to 700^{o}C, at which point heating could be continued through auto-ignition of coal and biomass in the presence of oxygen. The procedures used for the gasifier can be found in Appendix C.

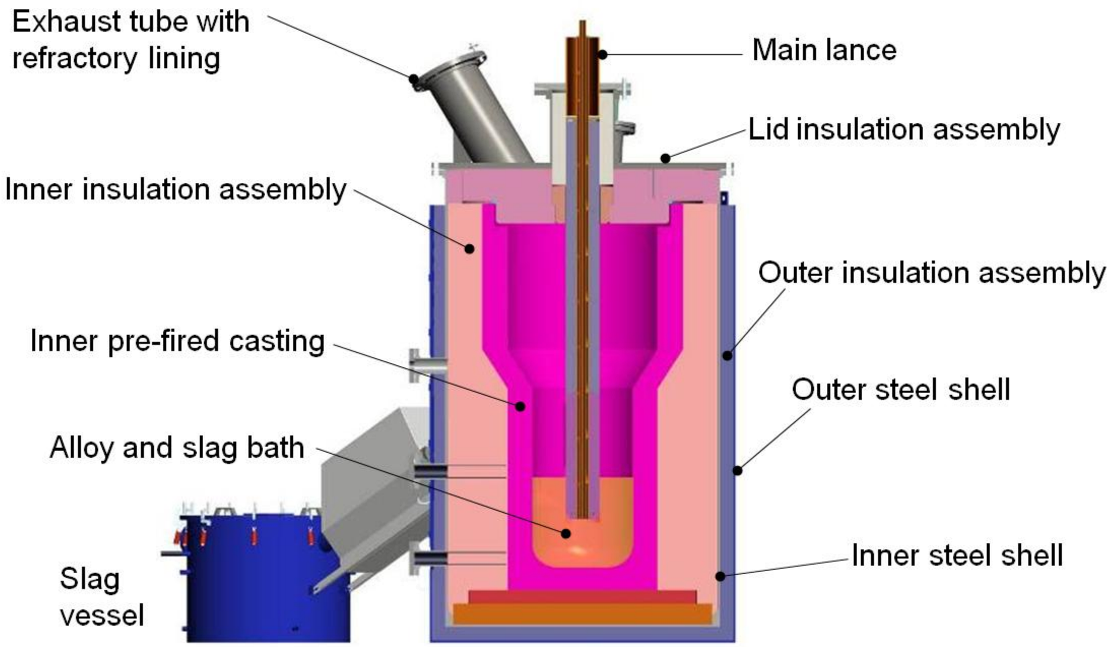
A propane-fired burner was used for this pre-heat operation, procured through the service company Hotwork that specializes in refractory dry out and heating. Hotwork provided the equipment needed as well as two technicians to operate the start-up burner 24/7. The burner nozzle was inserted into the gasifier via the top 4" flange (Figure 36).

Figure 36: Hotwork Burner Inserted into Gasifier and Pre-Heating

The Hotwork system consists of a main blower unit that generates airflow down through the nozzles and into the gasifier. A second, smaller line carries propane through a flow control valve and into the nozzle combustion chamber. The amount of propane is controlled based on two temperature sensors located near the tip of the nozzle.
Photo Credit: Scott Cheney

It is important to note that the gasifier has three layers of refractory (Figure 37). The innermost refractory was pre-cast and pre-dried. The outermost refractory was a brick material and placed in-between the inner and outer steel shells of the gasifier. The middle refractory was poured around the pre-cast pieces and secures them in place within the inner steel shell. This pourable refractory was still fairly wet when pre-heat commenced; after safety reviews, this resulted in extra safety caution (so as to not evaporate water too fast and create a steam explosion) and resulted in a significantly longer heat-up time (since the initial added heat went to evaporate water instead of heating up the refractory). This is a normal and expected aspect of refractory installation and use, but there was no way of knowing how much water had to be evaporated, or how quickly it would occur, and ultimately led to a longer pre-heat timeline than originally anticipated.

Figure 37: Engineering Drawing of Gasifier with Refractory Layers



The purple refractory is the pre-cast sections. The pink section is the pourable refractory. The blue border is actually the outer brick refractory. The yellow/orange fill inside the unit is the expected slag depth *after* the slag has melted (prior to melting the slag is much less dense and fills nearly ¾ of the reactor.

Photo Credit: Mike Sarin, Empowertech

The Hotwork burner has two thermocouples near the tip, to gauge hot gas temperature and allowed the operators to control the temperature ramp speed. A precise heat-up schedule was followed, based on the schedule provided by Resco (the refractory vendor). In general, the schedule involved ramping nozzle temperature by 28C every hour, with several instances of holding temperature constant for 14 hours. This is specified up to 542^{o}C, after which point heat-up was safely continued at a moderate rate to the desired 700^{o}C setpoint (Figure 38).

Figure 38: Burner Temperature during Pre-Heat Operations

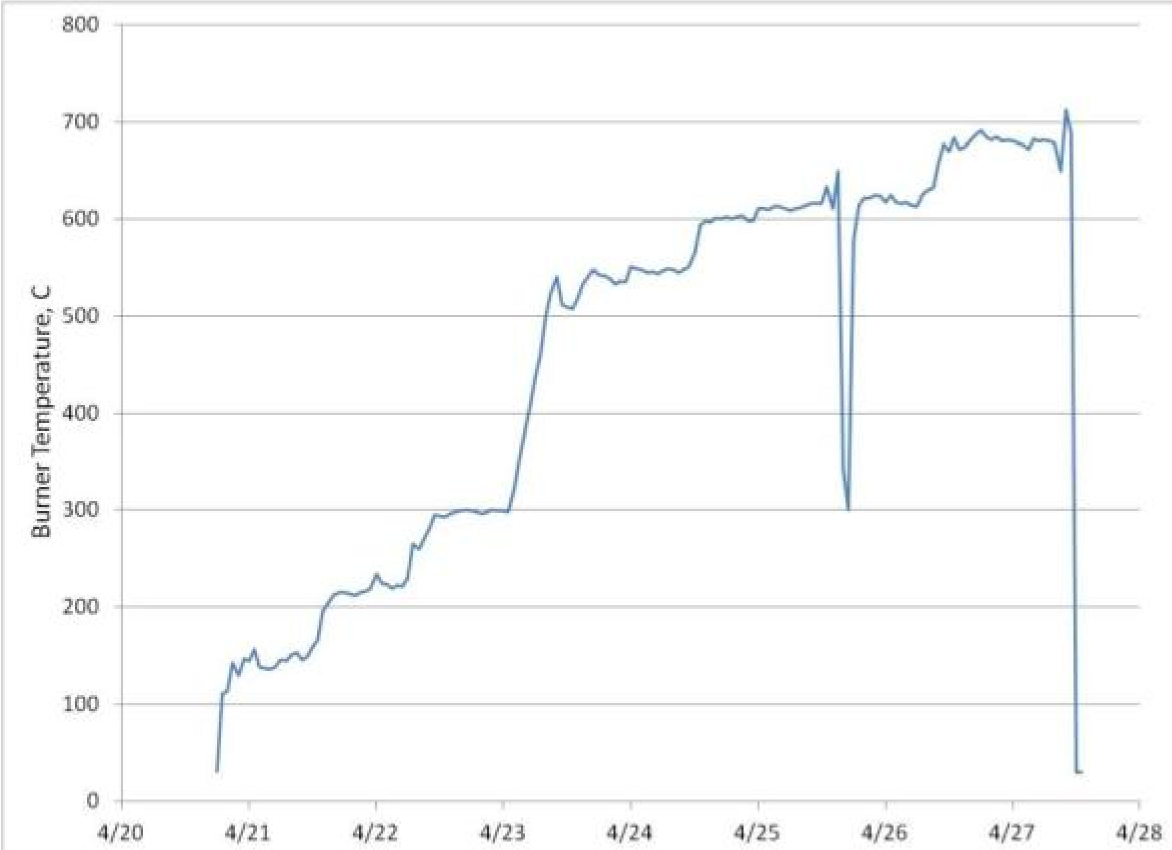


Photo caption here (optional) Arial 10 point.
Photo Credit: Scott Cheney

The original pre-heat schedule (provided by Resco) was complete after 3.5 days. However, the refractory temperature did not rise as fast as the burner, and so additional pre-heat duration was needed until the bottom section reached an adequate temperature (Figure 39). Once the lower section of the refractory reached 150°C, the pre-heat operations were stopped – at this point it was fairly certain that the temperature of the slag bricks was at least 250°C (the temperature necessary for auto-ignition of petcoke).

Figure 39: Gasifier Temperatures during Pre-Heat Operations

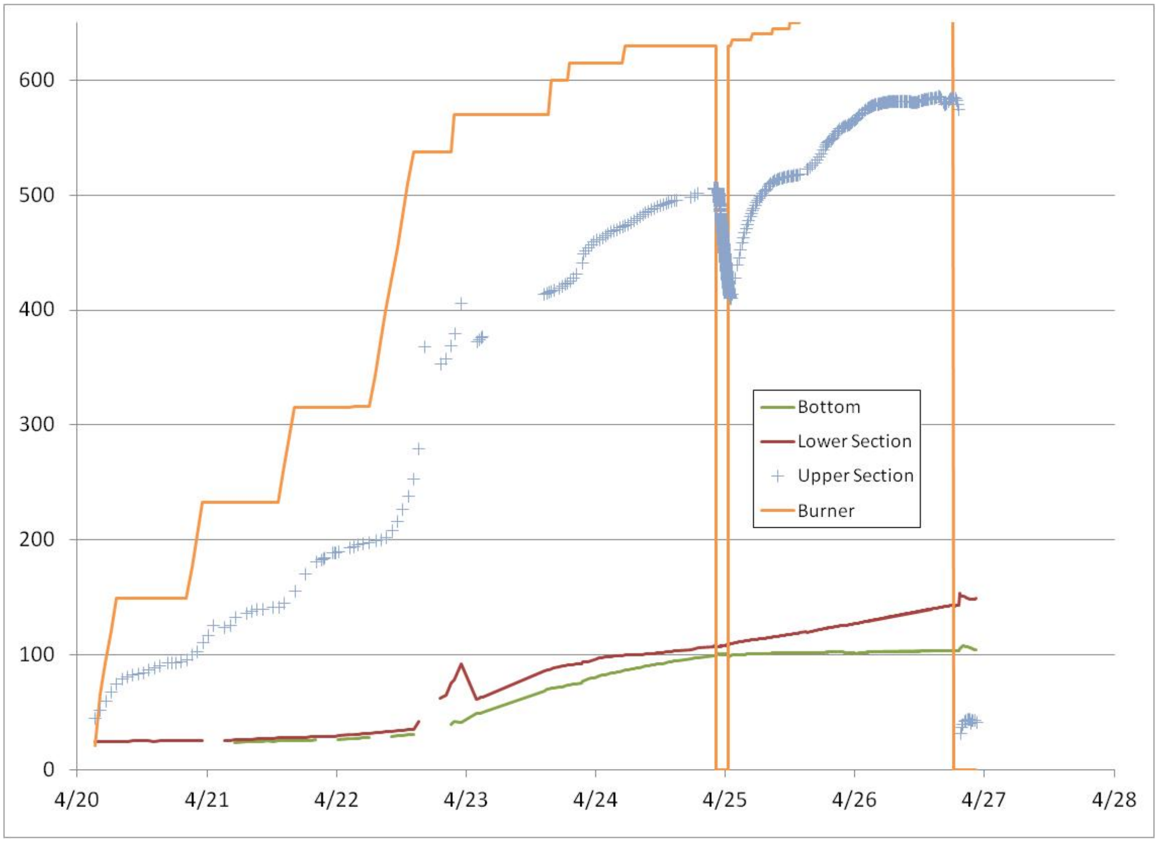


Photo Credit: Scott Cheney

The primary reason for the slow and non-uniform heating of the refractory is that the pre-loaded slag bricks impeded airflow from burner to the entire refractory surface. This is proved in part by the difference in temperature between the upper and lower section temperatures. The upper section was not covered by slag material and therefore reached elevated temperatures in direct correlation with the burner temperature. The lower section, although also trending with burner temperature, was much lower than the burner temperature. This effect was compounded by the fact that amount of water to be driven out of the pourable refractory was greater at the bottom of the unit where that refractory is thickest. Throughout the entire pre-heat process, steam was seen venting at various ports along the side of the gasifier (open for the reason of noting steaming).

Initially, the gasifier main vent was open and the vast majority of the air (and therefore, heat) simply reflected off the top of the slag bricks and escaped out the vent. This issue was identified and the downstream syngas valve was closed, forcing the airflow down to the bottom of the gasifier and out through the slag pot or through the inner annulus of the lance (although a large portion of the air also escaped back out the 4" port around the nozzle tip). Additionally, an eductor was installed backwards on the line going to the inner annulus in order to pull more airflow through the lance. Although these changes improved refractory heating, there was channeling of the burner's hot air through the slag bricks to the escape points and the walls of the refractory still did not see actual hot air. Instead, the refractory was heated via conduction of heat from the heating slag bricks outward.

The temporary shutdown mid-way through heat-up was intentional in order to take care of some maintenance and modifications. It was during this 2.5hr shutdown that eductor nitrogen piping was finished so that the feed system was ready to introduce the petcoke needed for heating the unit to full temperature.

4.2 Lance Heating and Slag Melting

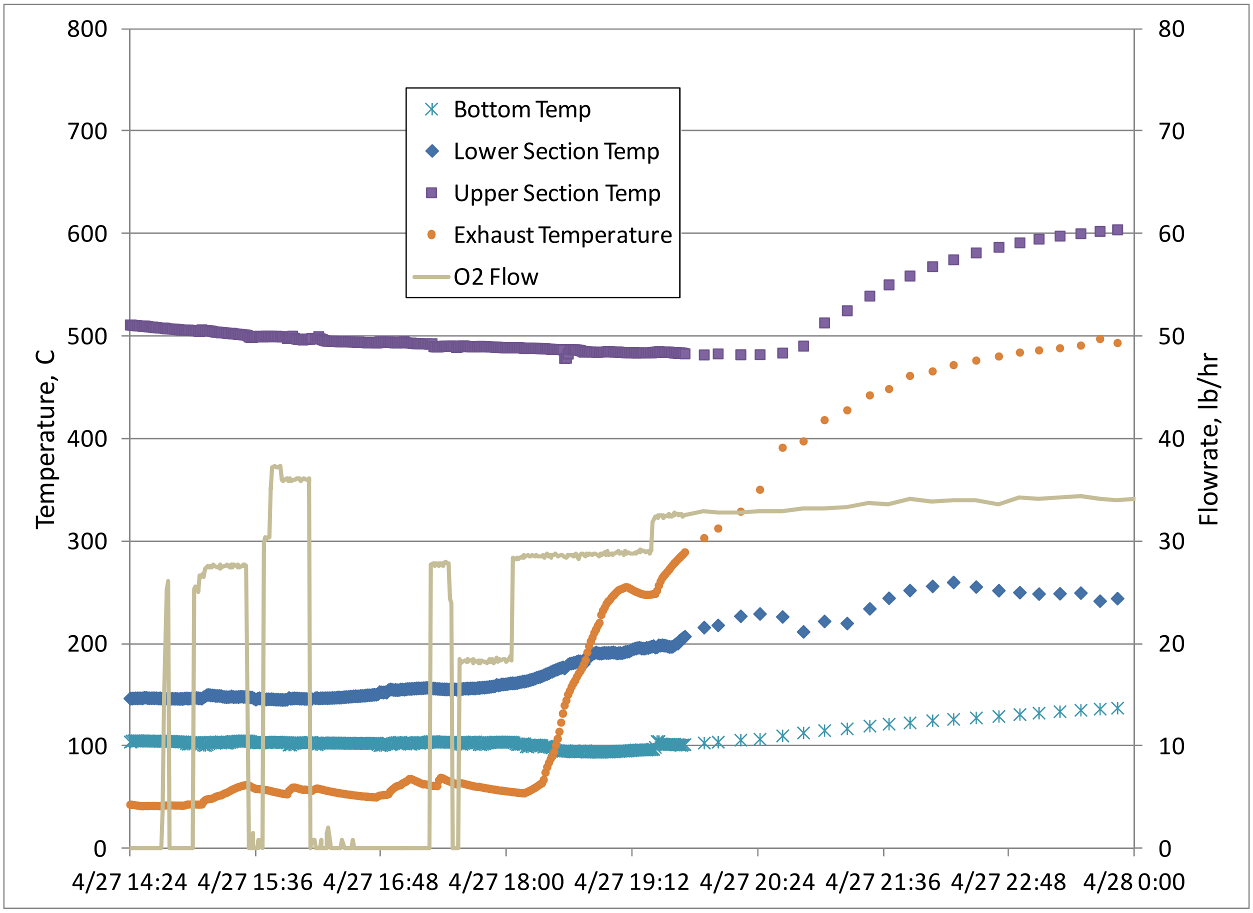
The start-up burner was then shut off and removed from the top port. Immediately, operators added the pre-melt slag mix with a funnel through this 4" port and then sealed the port with a blind flange. From this point on there was no going back to the start-up burner and the auto-ignition method for heating was used to bring the gasifier to full temperature. Introduction of petcoke through the lance was started at the lowest possible rate (5 lb/hr) and oxygen feed was likewise started – the oxygen rate was calculated to provide an exact stoichiometric amount (15 lb/hr; no excess oxygen and complete combustion of the petcoke).

Initially, combustion was observed, as indicated by small wisps of grey smoke emanating from the flare, and a slight increase in the exhaust temperature. However, almost immediately after starting up lance heating operations, the feed had to be shutdown in order for maintenance to the exhaust line thermocouple. The ceramic sheath on the thermocouple had shattered from temperature shock from the quench nozzles and had to be pulled out and replaced with an inconel sheath to maintain safe operations. This led to significant exhaust flowing out of the thermocouple port. Although the sheath was replaced, the thermocouple never functioned quite properly after that repair.

Upon re-starting the petcoke and oxygen feed, no auto-ignition was observed. It is most likely that in the space of those two hours of downtime, the slag had cooled enough that the petcoke was not being heated sufficiently as it traveled through the reactor and was no longer reaching the auto-ignition temperature. Various methods were attempted to overcome this, including a "batch-mode" start-up where an amount of petcoke was added under nitrogen purge, some time passed to allow for increase in petcoke temperature and then pure oxygen added to try and light up the material. When this proved unsuccessful, the reactor was in danger of dropping further in temperature and auto-ignition being completely out of reach.

At this point, a decision was made to switch to feed sawdust, which has as lower density and BTU content but a lower ignition point. This was started with an oxygen rate at 1.25 times that of the entering sawdust (15 lb/hr). Initially, there was still no combustion, but oxygen and feed rates were increased until there was auto-ignition and an increasing gasifier temperature. This was proved by increasing exhaust and lower section temperatures (Figure 40).

Figure 40: Failed Attempts and Final Success with Auto-Ignition



Oxygen was turned on and off through the attempts at petcoke combustion. Oxygen flowrate increased with biomass addition before reaching steady-state.
Photo Credit: Scott Cheney

Sawdust combustion was continued through the night until about midnight when the auger started having problems and would not run consistently or at the same rate as before. Exhaust temperature started to drop, even though the operators worked to keep the system going through the night by manually adding feedstock to the eductor (bypassing the auger). During this feeder downtime, the bottom refractory temperatures continued to rise – a function of the heated slag material continuing to conduct heat outward to the refractory walls. See Figure 41 for the temperature profile during this time.

Figure 41: Continued Refractory Temperature Rise during Feeder Downtime

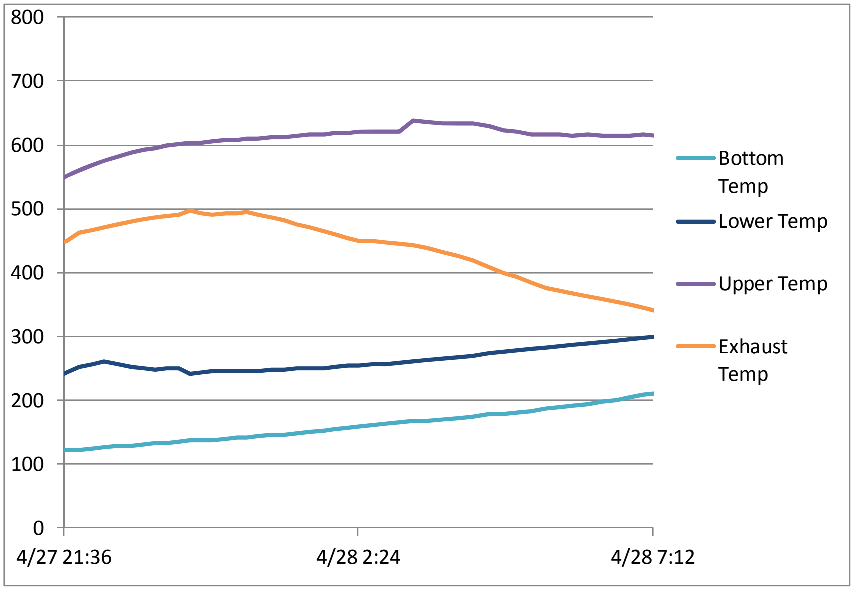


Photo Credit: Scott Cheney

The next morning, daylight and additional operators allowed for troubleshooting the auger system. After several unsuccessful attempts at restoring the unit in-situ, the entire feeder (hopper and screws) was removed from the platform and the machine dismantled. The lone culprit causing the issue was a small wood screw that had gotten mixed with the sawdust and was causing the auger screws to spin erratically (Figure 42). The feeder was re-assembled and re-positioned on the platform; sawdust feed and auto-ignition commenced anew.

Figure 42: Severed Wood Screw the Jammed Auger

While smaller than a quarter, this little screw caused additional friction and scratched the auger screws.
Photo Credit: Scott Cheney

The feeder again operated smoothly until roughly midnight the same day when it started showing similar symptoms of a lodged foreign object. Now familiar with these symptoms, the auger was again dismantled and feed restarted; the problematic object was a wood finishing nail – likely swept up with the dried sawdust material at the origin, and accidentally fed to the auger. A screen was placed over the silo to better capture future foreign objects and heat-up operations continued.

Unexpectedly, the screws continued to have issues and behave erratically, even after verifying they were clear of debris. Further examination of the unit revealed the possibility of damage to the gearbox (from previous jams) was the most likely possibility. The electrician made some adjustments at the motor control box, and by adjusting the torque and IR comp settings, the auger screws seemed to get back to normal functioning levels, but only after considerable time had been lost to unexpected maintenance downtime. The previous two jams seemed to have damaged the gearbox, motor or otherwise thrown off the previous motor control tuning.

Shortly thereafter, the screw feeder was working normally again, dispensing a 50/50 v/v mixture of petcoke and sawdust to the reactor for auto-ignition and heat-up and resulting in a dramatic increase in temperature in the refractory. This continued with the refractory slowly plateauing due to changes in the sawdust/petcoke ratio as well as continued steaming/drying of the refractory at the bottom.

Figure 43: Lance Heating

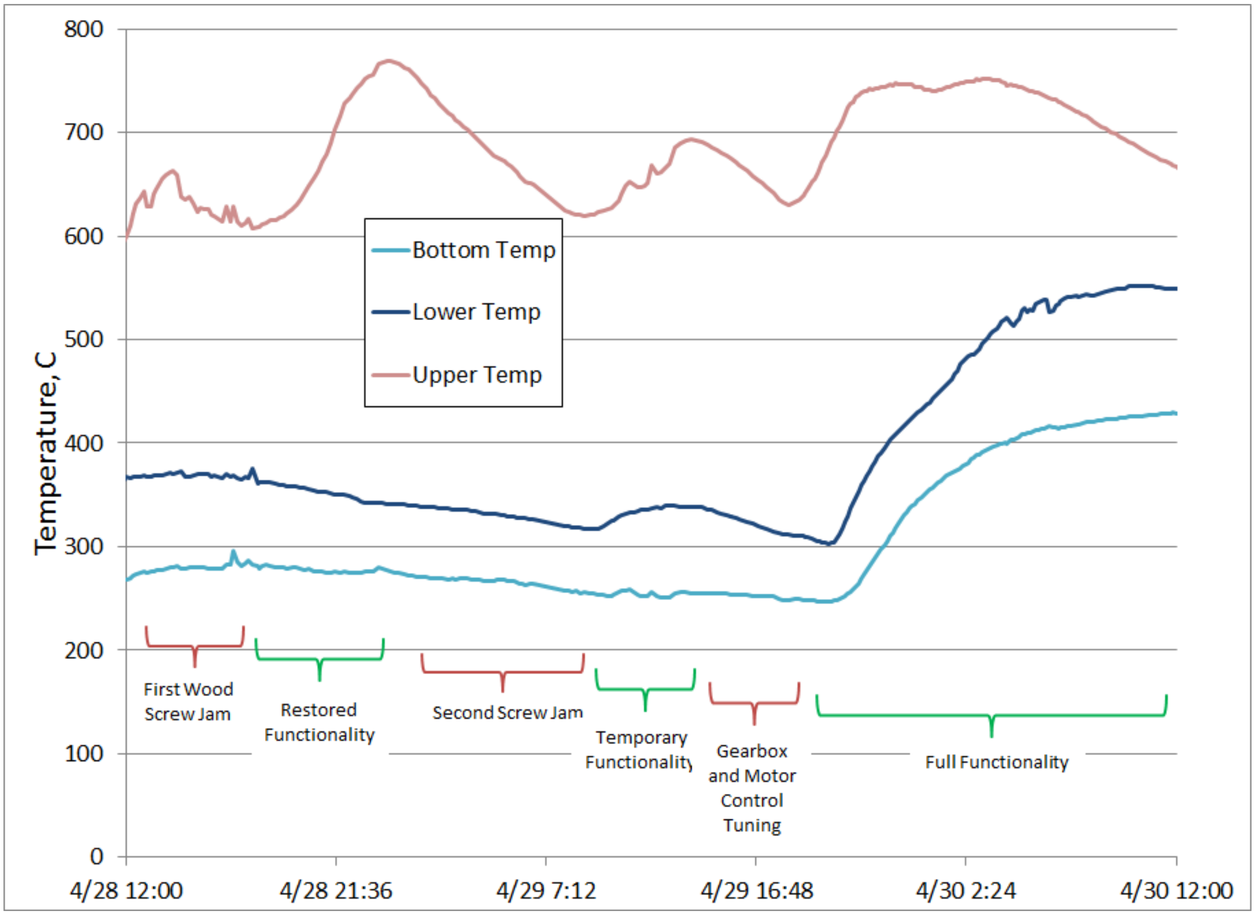


Photo Credit: Scott Cheney

It seemed at this point that the feeder issues had been solved because overnight the temperatures had risen significantly. However, the feeder had deteriorated again overnight (and had to "babysitted" in the later hours of the night) and two new maintenance issues came up that had to be fixed immediately. The team had earlier identified a leak around the piping that connects the gasifier to the slag pot. This pipe was intentionally left loose upon installation so that the inconel pipe could grow with changes in temperature during slag taps. However, through the pre-heat and lance heating operations, the seal around the pipe deteriorated and was creating an unsafe environment around the gasifier (and would have leaked significant amounts of hazardous syngas during gasification).

Figure 44: Burnt, Leaking Slag Pot Connection

Photo Credit: Scott Cheney

Initially a stainless bellows was proposed as a seal around the pipe, but the lead time on the proper bellows was too far out, and it was consider unsafe to weld the thin-wall bellows with the unit already in operational mode. So instead a quick fix was proposed and completed – simply to weld a stainless plate/ring from the inner pipe to the inner pipe. The completed fix is shown in Figure 45.

Figure 45: Fixed Slag Pot Connection

Photo Credit: Adam Weidner

This fixed the leaking slag pot connection, but another equipment issue was even more problematic and difficult to fix. The pipe upstream of the syngas valve was packed full of wet petcoke. The piping upstream of this valve includes the entire heat exchanger, and all twelve 1" tubes (24' long) had some amount of petcoke material coating the walls of the piping.

Figure 46: Petcoke Material Clogged in Syngas Piping

Photo Credit: Scott Cheney

The source of the petcoke was most likely the material that was first fed to the gasifier when auto-ignition was attempted for the first time. The material is such a small particle size (i.e. powder) that it was easily carried through with the nitrogen purge and started getting clogged at the various bends and fittings in the tubing. This clogging was then compounded by the moisture being released while drying out the refractory, which then condensed as the gas cooled in the heat exchanger. All of this piping had to be manually unclogged and cleaned out, which added unexpected downtime. Again, the prototype testing proved invaluable "lessons learned" for future commercial reactors.

When the system was cleaned out and ready for start-up again, the feeder was restarted with the previously used sawdust/coal mixture. Immediately the feeder was inconsistent no matter what setting the control knob was set to. At this rate, the reactor would likely not be able maintain its current temperature, let alone go up further in temperature. Having already debugged the unit and eliminating the previous failure modes, it was concluded that the problem was most likely in the gearbox or the motor (especially given the strain, wear and tear that they had been subjected to through the previous failures). It was possible to have the operators hand-feed feedstock into the eductor inlet at an adequate rate; however, this was not considered safe to continue for extended periods. After considering all safety aspects, a decision was made to move immediately to sawdust gasification.

4.3 Sawdust Gasification

The process began to gasify sawdust while the localized slag at the tip of the lance was still hot and molten. One operator fed pure sawdust to the eductor inlet and excess oxygen was added to the unit. The steam generator was turned on and steam began to be introduced to the process. Gradually, the oxygen rate was decreased, thereby reducing combustion and encouraging the gasification reactions to occur at the localized molten slag. Twenty-five pounds of sawdust by hand was added during each hour (below the ideal feed rate but sufficient for the reactions to occur).

Oxygen feed was reduced to 0 lb/hr through the flowmeter to "oxygen-starve" the gasifier and promote the gasification reactions; however, due to hand-feeding the eductor, roughly 50 lb/hr of air is pulled in as "wash down" instead of nitrogen (adding 10 lb/hr of oxygen and combusting roughly 8 lb/hr of the feedstock). Steam was increased to 9 lb/hr, which is in excess of the actual steam requirement, but useful in driving the reaction to completion. A graph of the gasification operations is shown below.

Figure 47: Temperatures and Flowrates during Sawdust Gasification

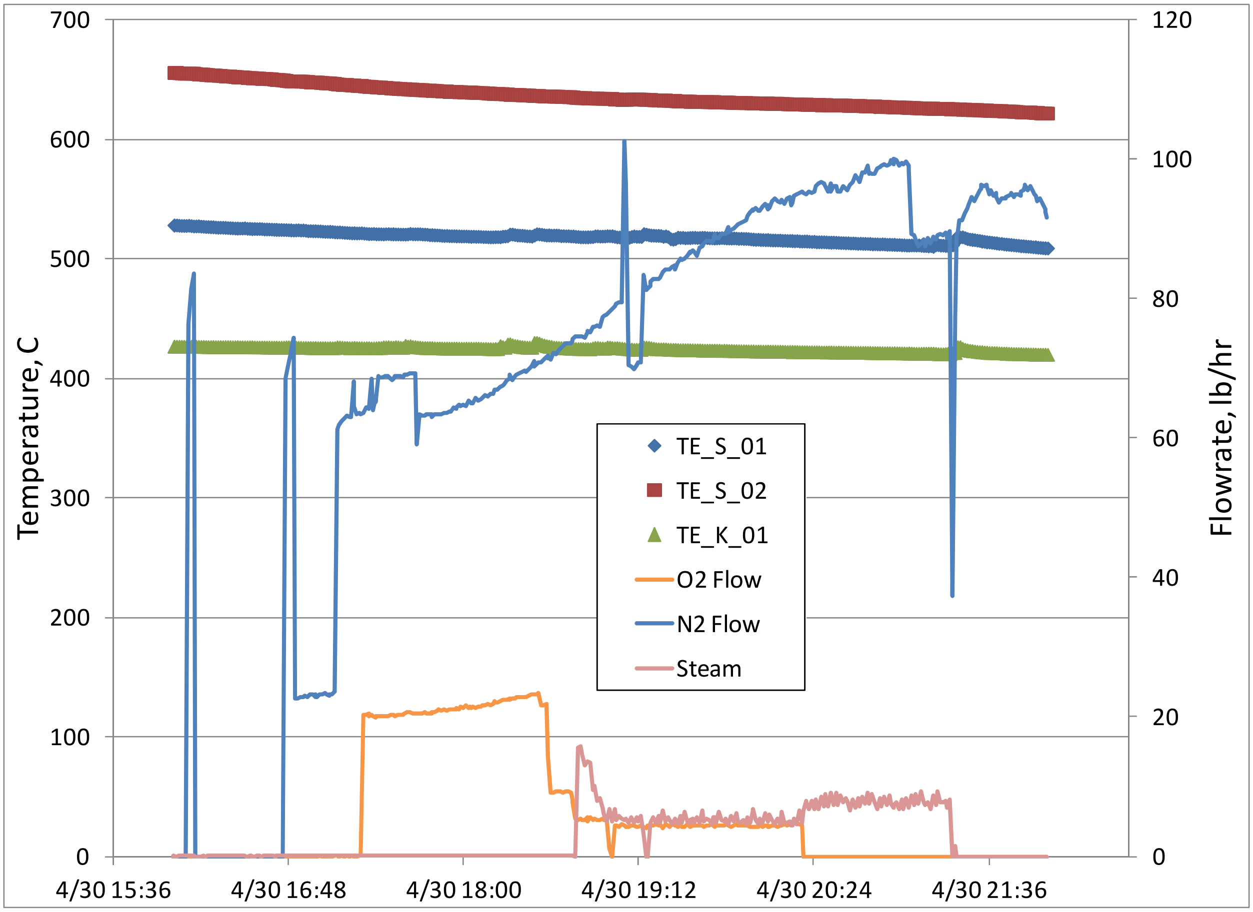
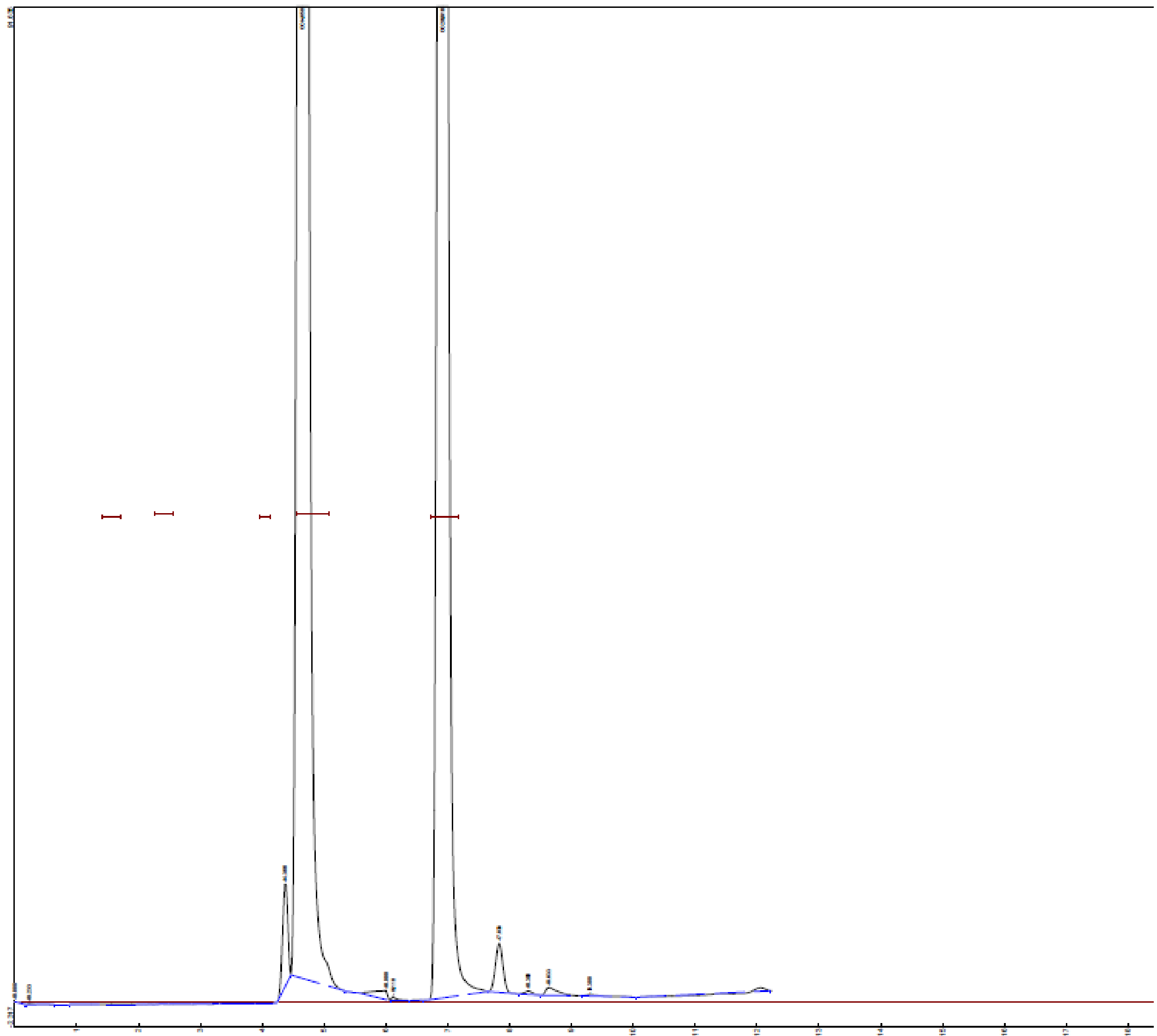


Photo Credit: Scott Cheney

During this time, the gas analyzer was running and collecting data on the reaction products. Gas Chromatographs (GC) generate a graph of a series of peaks, of varying height and width. Each peak is generated by a specific compound. The area under each peak can be used in conjunction with calibration charts (Appendix D) to determine the percentage of the incoming gas of each compound in the syngas. One of the GC graphs from the gasification run (742.CHR) is shown below in Figure 48, another can be found in Appendix D (where two other GCs from heat-up are also included). The calculated gas composition, based on this graph is shown in Table 7.

Figure 48: Gas Chromatograph Data taken during Gasification



The peaks are measured by integration. The two main peaks here are CO (left) and CO_2 (right). There is no detectable H2 peak (would be on the far left). The other peak of interest is the one directly to the right of the CO_2 peak: it appears in many of the other graphs generated during gasification, but has not yet been identified.
Photo Credit: Scott Cheney, PeakSimple software

Table 7: Composition of Gasifier Output during Sawdust Gasification Mode

Component	Heading
H_2O	7.7%
CO_2	9.3%
CO	4.1%
H_2	ND
N_2	78.9%

Source: Scott Cheney

Hydrogen may not have been detected because the signal was washed out by nitrogen concentration, or because it had escaped out of the piping prior to the GC or because it was not produced in large quantity (or at all): the large amount of nitrogen used compared to the small amount of feedstock made the resolution of the peaks more difficult to see; the long length of pipe, large number of fittings and small molecular size of hydrogen may have resulted in H2 leakage; or the lower than ideal temperature of the gasifier melt may have prevented hydrogen production from the biomass.

4.4 Shut Down and Cool-Down

Final shut down and cool down of the unit took several days. This was a fairly simple procedure wherein feedstock addition was stopped, as well as the oxygen and steam feeds; the only input to the unit was a nitrogen purge through the inner and outer annulus of the lance. After 15 minutes of purge the flare was shut down and the unit left overnight to cool under nitrogen purge.

Figure 49: Cool Down Temperature Data

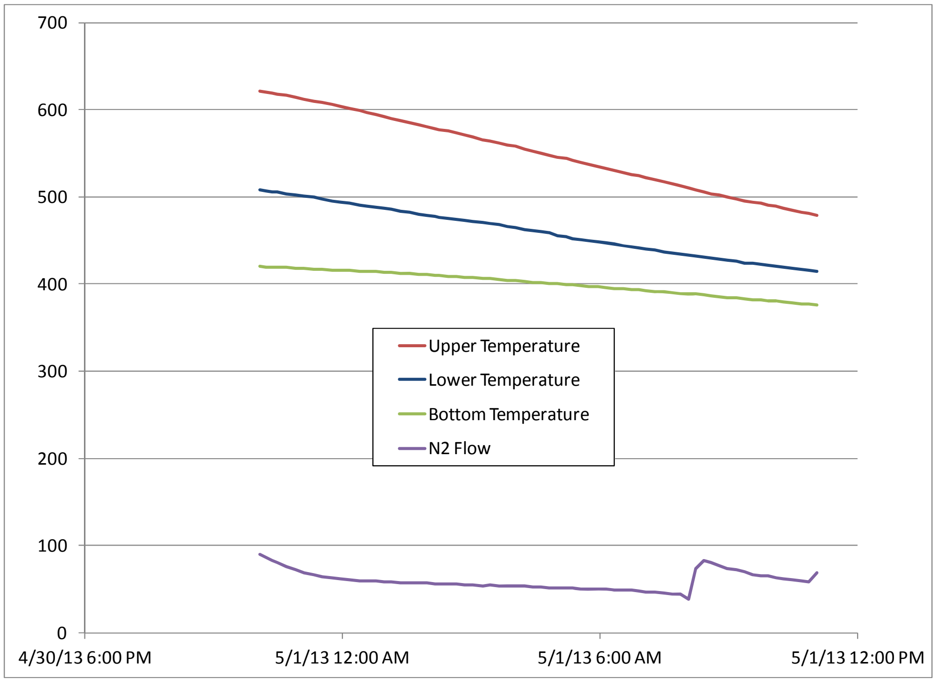


Photo Credit: Scott Cheney

As evidenced by the chart above, the temperature of the refractory fell consistently, but very gradually. The large mass of hot slag and refractory stored considerable energy that was only dissipated through the cold nitrogen purge gas or out through multiple layers of refractory to the ambient air. This was also a positive testimonial to the excellent thermal design and insulation of the unit. After 12 hours, the nitrogen purge was shut off so that the unit could be disassembled and the pad cleared (except for the gasifier) in a timely fashion. After a week of cooling down just by sitting in ambient air, the internal temperature of the refractory was 43°C. At this point the gasifier was ready for shipment to Diversified Energy headquarters for additional disassembly and post-mortem of the slag mix and refractory.

CHAPTER 5: Results and Discussion

5.1 Post-Mortem

As mentioned above, the post-mortem on the gasifier has not yet been completed; this evaluation, when complete, will include various visual observations and a compositional analysis of the final slag melt.

A post-mortem on the feed system (motor, gearbox and screws) was completed shortly after the test shutdown in order to ascertain the condition and failure mode of this subsystem. The auger screws were easily accessed and found to bear the markings of scratching damage caused by the earlier debris. No obvious bending or warping of the screws could be observed at the time, and more precise measurements of this possibility are needed. The gearbox (the most likely culprit in feed system erratic performance) was disassembled and examined, but no damage or problems were found.

With everything disconnected but the power, the next component examined was the motor, and this was where the major issue was found. While the motor itself was still intact and in working order, the motor controller tuning (torque and IR comp) was completely misaligned – adjustment of these settings allowed the motor to work normally again. However, it is clear that these motor tuning parameters are not a fixed setting, and are heavily influenced by the load on the screws – this load itself a factor of feedstock density and moisture, as well as any damage to the auger screws that may have created new rubbing spots against the screw housing. Sustained operation of the feed auger is simply too dependent on the motor tuning and was not capable of tolerating slight changes in feedstock composition or minor damage to the screws. An alternative feed system is recommended for subsequent operations.

A post mortem on the heat exchanger was also performed, during disassembly of the system. It was mostly clear, a vast improvement compared to the earlier coating/clogging with petcoke dust. However, there was some residual dust, potentially ash from the sawdust or some residual petcoke that still was getting blown through into the exhaust. In the next embodiment of this system, a particulate capture subunit is recommended (either a full quench reactor or hot candle filter) to accommodate any operational upsets that would result in ash/petcoke being carried to the heat exchanger and creating major problems and downtime.

5.2 Results and Recommendations

Given the conditions of operation, the OmniGas gasifier functioned as intended: the larger thermal mass of the slag maintained the internal temperature of the unit throughout various interruptions in the feed system; sawdust was partially oxidized in the chamber, despite lower than anticipated temperatures, evidenced by considerable CO production (41 percent of all carbon feed converted to CO).

Instrumentation of the unit provided accurate readings throughout the test, which were accessible via LabView and successfully recorded in data historian log files for the entire operation. The only temperature probe that failed (syngas exhaust) was due to the shattered ceramic sheath which will be replaced with an inconel sheath in future units.

The feed system has the greatest need for modification and improvement before full commercial operations. With the powdered petcoke feedstock, the feed auger and eductor were both successful. However, with the irregular and larger sized sawdust feedstock, both the auger and eductor started to behave erratically and interfered with feed flow consistency. This is largely due to the prototype-scale of the unit tested and smaller tolerances throughout the feed system. As the flowrates and pipe sizes increase, an auger/eductor feed system would be able to handle more of the irregularities found in the sawdust; optimization and testing of this auger/eductor feed system is recommended at larger scales.

Additionally, investigation of other feed strategies is recommended. Since the OmniGas technology operates at low pressure, it does not require some of the complicated and high-cost feed systems employed on other gasifiers. Yet various lock-hopper, plug-flow and entrained-flow technologies could be substituted for the auger/eductor system currently in place. These feeder technology options could be licensed or developed internally, but additional research in the area is highly recommended.

Another key finding was the need for an efficient slag addition strategy that can meter pulverized slag into the gasification chamber after the reactor is already at full temperature. The most likely retrofit of the current prototype unit is a large feed hopper with rotary valve situated above the 4” top gasifier port. This would be actuated remotely and safely while monitoring gasifier temperature and continuing to add heat as required via combustion of petcoke through the lance. The challenge is having any such feed system capable of withstanding high temperatures. Additional development on the slag addition process is required prior to future testing.

Last, a real-time gas analyzer is recommended. The gas chromatograph was very accurate, capable and robust, but the long duration between sample analyses prevents real-time adjustments to the process. Nondispersive Infrared Sensors (NDIR) have widespread usage in many gas analysis applications, and provide virtually instantaneous results. Once purchased, such a unit could be used for tests at any scale and the data could be viewed and recorded with all other instrumentation for easy analysis.

The original technical objectives are shown below in Table 8. These project goals were based on targets for full prototype operation.

Table 8: Technical Project Goals

Goals	Actual Achieved	Comments
Generate syngas with a volumetric flow rate of > 5000 scf/hr and a heating value of >175 BTU/scf as a replacement biogas for industrial process heating and drying applications	Generated syngas at a volumetric rate of 2,100 scf/hr and an average heating value of 15 BTU/scf.	Unexpected issues with the biomass feed system limited biomass feed rates, thus reducing both the rate and energy content of the resulting syngas.
Demonstrate that the OmniGas process can use a variety of biomass feedstock with a heating value between 6,000-10,000 BTU/lb and moisture content between 0 and 50%.	A biomass feedstock with heating value of 6,880 BTU/lb and moisture content of 19% was used.	This is the heating value of the feedstock at the specified moisture. Moisture content above 20% resulted in some feeder clogging; However this is easily resolved with upgrades in the commercial unit.
Realize a syngas composition ratio of Hydrogen to Carbon Monoxide between 2.0 and 4.0 to accommodate back-end processes (i.e. methanation).	A syngas composition ratio of 0:1 H_2:CO was realized during the project	Hydrogen gas was below detection threshold during this test. However, the theoretical maximum is only 1.0 H_2:CO ratio for this feedstock without additional gas conditioning.
Realize a continuous nominal operating time of >168 hours for at least 1 test run.	The system operated for a total of 250 hours. Only for two hours of the test was the unit in gasification conditions	Feeder system maintenance and safety holds were the main factors leading to system variability. Basic reliability and containment were well-proven.
Realize a dry feedstock feed rate conversion efficiency of >75% with a flow rate heat yield of >875,000 BTU/hr.	100% of the feedstock was consumed in the gasifier. 35% of the feedstock was converted to CO. The heat rate was 31,200 BTU/hr.	The lower biomass feed rate (25% of expected) led to lower heat rate as well as a greater fraction of the feed needed to maintain gasifier heat balance.
Operate the OmniGas system to replace natural gas injection to the thermal oxidizer flare to realize reduction in natural gas consumption.	All OmniGas syngas was injected and combusted in the thermal oxidizer flare.	Syngas combusted in the thermal oxidizer as planned.
Realize a capital cost of <$19.50/kscf/year (analyzed operating continuously).	The CAPEX was approx $350,000 to build and produced 18,600 kscf/yr: CAPEX = $18.8/kscf/yr	Cost goal met. If the target syngas rate had been met, the relative capital cost would have been only $8/kscf/yr.
Realize an operation and maintenance cost of <$1.65/kscf/year (analyzed operating continuously).	Demonstrated O&M Cost extrapolated to one year based on non R&D test site were $6.77/kscf/yr	At full run rate of 5000 scf/hr, 43,800 kscf/year would have cost $2.88 per kscf/yr

Source: Diversified Energy Corporation

CHAPTER 6: Commercialization

6.1 Markets and Applications

As noted, the initial target market was to replace natural gas with syngas in various applications. At the time of this initial test planning, natural gas prices were as high as $12/MMBtu, and there was a strong appetite for alternatives. OmniGas provides this industrial scale solution to increasing operating costs because in many situations, low-BTU syngas can be used to substitute natural gas, particularly in drying and heating. Additionally, this gasifier is able to the use a company's own waste products as low-cost, renewable feedstocks for this syngas.

The recent discoveries of shale natural gas and development in extracting this resource has crashed the price of natural gas below $2/MMBtu (since then has risen to near $4/MMBtu). This has severely limited the market and the economic advantage for OmniGas to be used in replacing natural gas. There still may be opportunity with site-specific wastes and drying applications, but largely the value of syngas has been shifted into other applications.

For example, while the price of natural gas has fallen to historical lows, the price of fuel has risen to historic highs. Since syngas can be converted to liquid transportation fuels (using Fischer-Tropsch catalysis), this is a new strong market target for application of the OmniGas technology. For example, many municipalities have airports, school buses and fleets of police cars which must be fueled with shrinking state and local budgets. At the same time, many of these municipalities have a significant biomass resource in the form of waste biomass and municipal solid waste (MSW). This feedstock can be shredded or pelletized and fed to the OmniGas gasifier similarly to sawdust or petcoke and produces fuel that can be a "drop-in" replacement of the petroleum counterparts.

Also, the agricultural economies of the Midwest, long focused on ethanol produced from corn or biodiesel from soybeans, also have waste biomass resources. Corn Stover has been proven to be collectable at a reasonable cost and with little impact to farmland, and is currently being assessed by many in the ethanol industry as a viable feedstock for cellulosic ethanol. However, within the United States, the capacity for ethanol blending has already reached the maximum 10 percent and efforts to get this limit raised have so far proved unsuccessful. A market exists, therefore, to provide "drop-in" diesel fuel back to the trucking and farming demands of agriculture with a local, low-cost feedstock. Besides corn stover as a feedstock, OmniGas could utilize other waste products like poultry litter or cattle wastes, depending on the site-specific resources and needs.

Another potential market is within the Department of Defense. Already Diversified Energy has a contract with the U.S. Navy to investigate the application of OmniGas technology to gasify the solid waste generate at forward operating bases (basically the same as MSW in composition) and produce either electricity for the base or fuel for military vehicles. Not only is waste disposal an issue that the Navy wants to solve, but both electricity and fuel are paid for at a premium in many forward locations and alternatives are needed.

6.2 Process Economics

A preliminary commercial-scale system and economic evaluation has been completed for production of liquid transportation fuels from biomass. This analysis is based on expected results for the gasifier operating at design parameters, with no malfunction of the feed system. An economic evaluation of the system operating at conditions observed during the test run has not been completed due to the severely limited feed rate, lower reactor temperature and limited run time (data acquired)

At this time, production of syngas as a natural gas replacement is not generally economically viable, except perhaps in a certain case. The system analyzed at this time is more than 50 barrels per day that uses a 1.5m OmniGas reactor and produces gasoline and diesel fuels. The results from the model are shown below.

Figure 50: Synthetic Liquid Fuels Plant System Model Results

Pinewood Feedstock		Wheatstraw Feedstock	
Feedstock Input Characteristics	1700 kg/hr @ 15% moisture	Feedstock Input Characteristics	1700 kg/hr @ 15% moisture
F-T Liquids Produced	57 barrels/day	F-T Liquids Produced	53 barrels/day
Total Steam Production	3,833 kg/hr @ 253°C	Total Steam Production	3,559 kg/hr @ 266°C
F-T Light Ends Remaining	0 kg/hr	F-T Light Ends Produced	33 kg/hr
Power Consumption (kW)	965	Power Consumption (kW)	906
Power Production (kW)	117	Power Production (kW)	103
Required Power Input (kW)	848	Required Power Input (kW)	803
Required Water Input (kg/hr)	872	Required Water Input (kg/hr)	871

DEC000699-006

Photo Credit: Diversified Energy Corporation

Both pinewood and wheat straw were analyzed as potential biomass feedstock sources. Petcoke was also analyzed due to its low cost, availability and high energy density, although it would only be feasible in certain situations. Operational costs have been estimated, based around $25/ton biomass cost, a $0.05/kWh produced electricity cost, and other labor, maintenance and variable costs.

Figure 51: Synthetic Liquid Fuel Annual Costs

Pinewood Feedstock		Wheatstraw Feedstock		Petcoke Feedstock	
Item	Cost ($k)	Item	Cost ($k)	Item	Cost ($k)
Feedstock (16,437 tons annual)	$411	Feedstock (16,437 tons annual)	$411	Feedstock (16,437 tons annual)	$740
O&M Costs		O&M Costs		O&M Costs	
Electricity	$334	Electricity	$317	Electricity	$79
Operating Costs	$438	Operating Costs	$438	Operating Costs	$438
Equipment Maintenance	$100	Equipment Maintenance	$100	Equipment Maintenance	$100
Total Annual O&M	$872	Total Annual O&M	$855	Total Annual O&M	$617

DEC000699-008

Photo Credit: Diversified Energy Corporation

For the capital cost build-up, a combination of vendor estimates and published data was used. It is worth noting that the cost rollup represents a very comprehensive assessment by including such items as land and yard upgrades, buildings, contractor's fees, 10 percent contingency, and installation costs which are a large percentage of the overall purchased equipment costs. The baseline CAPEX cost is considered conservative. The gasifier itself is low compared to the rest of the system. This is consistent with the intended design and construction methods used in developing the prototype model. Most of the cost is actually a result of the downstream processing equipment, much of which has not yet been tailored to the specific OmniGas syngas output but is based mainly on parametric modeling. The breakdown is shown in Figure 52 and 53.

Figure 52: Liquid Fuels Plant CAPEX Results

Details	Item	Cost ($K)	Total Cost ($K)	Basis
Purchased Equipment	Storage Tanks	295	13,322	Estimate from similar system data
	Size Reduction Process	118		Estimate from similar system data
	Conveyor	118		Estimate from similar system data
	Feedstock Dryer	236		Estimate from similar system data
	Lock Hopper	200		Estimate from similar system data
	HydroMax Gasifier	1050		Gasifier cost rolled up from 4 items below
	• Reactor Vessel	500		Cost Estimate from supplier vendor
	• Refractory	350		Cost Estimate from supplier vendor
	• Injection Lances	100		Cost Estimate from supplier vendor
	• Cap/Vent Ports	100		Cost Estimate from supplier vendor
	Quench Reactor	150		Cost Estimate from supplier vendor
	Syngas to Air Hex	236		Chemical Engineering Handbook estimate
	Syngas to Water Hex	295		Chemical Engineering Handbook estimate
	Tin Roaster	413		Estimate from similar system data
	Zinc Oxide Guardbed	59		Estimate from similar system data
	Particulate Removal	236		Fabric filter, 4000 scfm
	Syngas Compressor	531		2300 scfm from 4-30 atmospheres
	Shift Reactor System	1,180		Chemical Engineering Handbook estimate
	Amine Scrubber System	1,475		Chemical Engineering Handbook estimate
	Startup Boiler	295		Chemical Engineering Handbook estimate
	Steam Turbine	500		Chemical Engineering Handbook estimate
	Air Separation Unit	4,000		Chemical Engineering Handbook estimate
	Ash/Spent Flux Handling	590		Chemical Engineering Handbook estimate
	Water Pump	50		Chemical Engineering Handbook estimate
	Cooling Tower	300		Chemical Engineering Handbook estimate
	F-T System	995		Velocys cost estimate
Equipment Installation			3,397	25.5% of purchased equipment cost
Piping			6,661	Factor from purchased equipment cost (50%)
Instrumentation			1,332	Factor from purchased equipment cost (10%)
Insulation			1,066	Factor from purchased equipment cost (8%)
Electrical			1,332	Factor from purchased equipment cost (10%)
Buildings			1,332	Factor from purchased equipment cost (10%)
Land and Yard Upgrades			1,332	Factor from purchased equipment cost (10%)
Utilities			1,998	Factor from purchased equipment cost (15%)
		Physical Plant cost	31,773	
Engineering and Construction			3,177	Factor from Physical Plant cost (10%)
		Direct Plant costs	34,950	
Contractors Fee			2,447	Factor from Direct Plant cost (7%)
Contingency			3,495	Factor from Direct Plant cost (10%)
		Total CAPEX Costs	**40,892**	

Photo Credit: Diversified Energy Corporation

Figure 53: Capital Cost and Overall Cost Breakdown Summaries

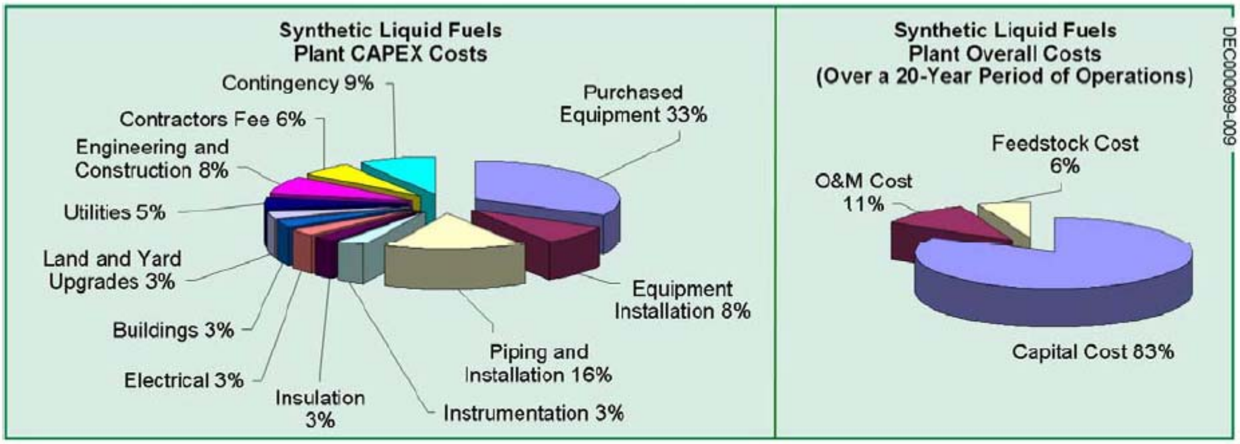


Photo Credit: Diversified Energy Corporation

The result of the analysis was a finished fuel product at $7/gallon, influenced heavily by the capital cost component. Once the capital cost has been paid for, the system produces fuel at $1.60/gallon, based solely on feedstock and O&M costs. Additionally, significant development work is ongoing in the downstream catalysis space that will improve efficiencies and yields of the water-gas shift and Fischer-Tropsch reactors, thereby increasing output while all other costs are held constant.

6.3 Benefits to California

Immediately this testing had a direct benefit to several California businesses that generated revenue by providing services or goods to Diversified Energy as the project progressed:

- Wyle Laboratories (San Bernardino, CA) – Host site and integration support
- Millennium Space Systems (Torrance, CA) – Engineering and fabrication support
- West Coast Forest and Cinder (Arvin, CA) – Feedstock supply
- SRI Instruments (Torrance, CA) – Gas Analyzer provider
- Air Liquide (Santa Fe Springs, CA) – Gas Analyzer carrier and calibration gases
- Recon Engineering (Los Alamitos, CA) – Gasifier refractory installation
- McMaster Carr (Santa Fe Springs, CA) – Parts, fittings, nozzles, scales, funnels and other equipment
- Local San Bernardino Businesses – Lodging, food for employees; last-minute hardware

More than 90 percent of the California funds for this project (more than $450,000) was spent in California.

Wyle Laboratories has mentioned that some of their other customers were very curious in the OmniGas unit as it sat on their test site. This is further evidence of the growing interest from the aerospace industry in technologies that produce renewable, low-cost gases. Additionally, the

OmniGas testing at their site benefits their development efforts as they seek to attract new customers, especially those in the renewable energy technology space.

On a larger scale, OmniGas has the potential to displace substantive volumes of petroleum or natural gas use by the state of California. Since OmniGas is uniquely able to accept a diverse variety of biomass-related feedstock, it can offer very broad appeal and market penetration to address this challenge. Most large municipalities have feedstock (MSW) and need (fuel use) for intermediate-scale gasification technology. Industrial targets in California include companies like California Portland Cement Company in Mojave and National Gypsum in Long Beach and Richmond that have substantial energy-related operating costs. Also, companies operating in Northern California near wood waste facilities, or those in the agriculture waste regions of the San Joaquin Valley, are particularly attractive.

As the OmniGas technology is applied in these various market segments within California, it will (1) make the state more secure and less vulnerable to outside energy source price fluctuations, (2) offset fossil sources of CO_2 emissions, improving California's air quality and helping reach environmental targets, (3) increase competitive position of the state to attract new industry in both the manufacturing and renewable technology sectors, and (4) improve California's balance of trade by importing less energy (who currently imports 85 percent of its natural gas and >60 percent of its petroleum).

6.4 Value Propositions

This value proposition section was developed initially to send to potential investors and partners and provides a good summary of the strengths of the OmniGas technology entering into the existing and emerging markets.

VP-1: The OMNIGAS Process provides broad input feedstock flexibility, converts nearly any carbon source into Syngas (Carbon Monoxide and Hydrogen) which can then be converted downstream into a fungible (drop-in replacement, "lookalike") fuel. Most other existing and planned gasifiers cannot do this, as they are limited to a single feedstock, and many of them require that feedstocks be very dry and that they be ground down to millimeter sizes.

Value to the investor/partner: The researchers believe that the molten metal gasifier can handle feedstocks with moisture levels as high as 30 percent (water is used in our process and can be part of the feedstock). Some competing gasifiers require pre-drying. The gasifier is believed to handle feedstock sizes up to ¼ inch or even ½ inch minus – some competing "entrained flow" gasifiers require that feedstocks be ground down to millimeter sizes in order to feed them. The top-fed, annular injection lance lets gravity can do the work and the waiting molten metal bath provides an instant chemical reaction interface for the feedstock.

VP-2: OMNIGAS combines metal-bath smelting technology with gasification to achieve higher reliability and availability.

Value to the investor/partner: The major weakness of all other historical gasifiers has been a low "availability" number and lower plant "up-time", (as low as the 70th percentile range), due to poor gasifier reliability. This stems from other gasifiers' complex feed mechanisms, internal components and grates, multiple-chamber designs, ash removal systems, etc. This system takes advantage of more than 100 years of history in developing and operating metal-bath smelters for the metals processing industry. Metal bath smelters in the metals industry routinely achieve operating Availabilities in the high 90 percent ranges.

VP-3: Industrial-Scale with Full Carbon-Chain Cracking and are positioned in the middle-market industrial-sized space for gasification. The system fully "cracks" all tars and oils in the feedstock, providing a "clean" Syngas.

Value to the investor/partner: Larger Utility-Scale entrained-flow gasifiers (such as GE's) are very large scale units optimized for thousands of tons of a single feedstock per day, (such as coal) but cost billions of dollars to implement in a "Utility Scale" energy plant, with years of planning, permitting, building etc. required. Lower-end "Mom and Pop" or "Garage Shop" gasifiers are lower in capacity and cost and operate at lower temperatures, but do not always fully "crack" all of the tars and oils in the feedstock, creating "dirty Syngas" which requires extensive gas cleanup downstream. The mid-sized gasifier is being optimized for the middle market at millions of dollars in cost, (not Billions), and its operation at 1300 degrees Centigrade fully cracks all tars and oils in the feedstock. Result is more customer applications deployed much more quickly.

VP-4: A Continuous Mode, Full Slagging Reactor is used to float "slag" off the top of the molten metal process.

Value to the investor/partner: Impurities in the feedstock, inert elements, and other byproducts are floated off the top of our molten metal bath in a "slagging" process. By monitoring, the slag composition can be adjusted to the process chemistry to optimize it. Other gasification processes which do not slag may build up contaminants or other impurities in the reactor chamber which affect the operations of the gasifier. Researchers believe that there are some new patentable features in the continuous-mode slag removal system. Slag can be processed downstream after cooling to make other valuable byproducts such as recovery of selected high value metals or conversion into building products, etc.

VP-5: Lower Cost to Build and Faster Assembly – The simplicity of a metal bath process leads to very simple construction geometries and simple materials assembly. The first demo ½ meter gasifier (60 inch diameter, ten foot height, 16,000 lbs) was assembled in less than 30 days using simple tools and semi-skilled labor.

Value to the investor/partner: Competing gasifiers can take years to construct onsite in a "stick-built" process. Many of the system components can be factory-assembled and shipped to the site. Processes include straightforward bricklaying, and the result is dramatically lower costs and faster deployment.

VP-6: Simpler Process Chemistry –Only two primary chemical reactions, the well-known "Steaming of Iron" and the well-known "Carbon Reduction" are used. Process is done in single reaction chamber, with the oxidizing and reducing reactions occurring simultaneously.

Value to the investor/partner: Competing gasifier processes use more complex chemistries, such as plasma arc interactions, pools of liquid glass with molten metals precipitating out, multiple reaction chambers, complex feed entrainment schemes, etc. Each of these steps adds complexity, requires more energy (plasma), and lowers reliability.

VP-7: Unique non-water-cooled injection lance – The injection lance is "air-cooled" by its own gases, not external water.

Value to the investor/partner – Competing gasifiers use water-cooled injection lances which carry away up to 30 percent of the energy in the gasifier as waste heat – to keep the lance from melting. The injection lance is designed with special materials, and similar to a NASA rocket engine nozzle – it is designed to use its own gases as coolants on their way to the reaction, without melting the nozzle (lance). Researchers believe there are possible patentable features in that design. Water-cooled lances are more complex; require external cooling equipment, waste water and thermal energy.

VP-8: High Thermal Inertia of Molten Metal Bath Requires Less Feedstock Temperature Control

Value to the investor/partner: The molten metal bath has a large mass and a "high thermal inertia" meaning that introducing cooler feedstock does not impact the reactor temperature. Other competing systems may require greater pre-heating or other drying of the feedstock to prevent the loss of thermal inertia in the reaction chamber. This process should be able to take a wider range of input feedstock temperatures without expending energy on pre-treating the feedstock.

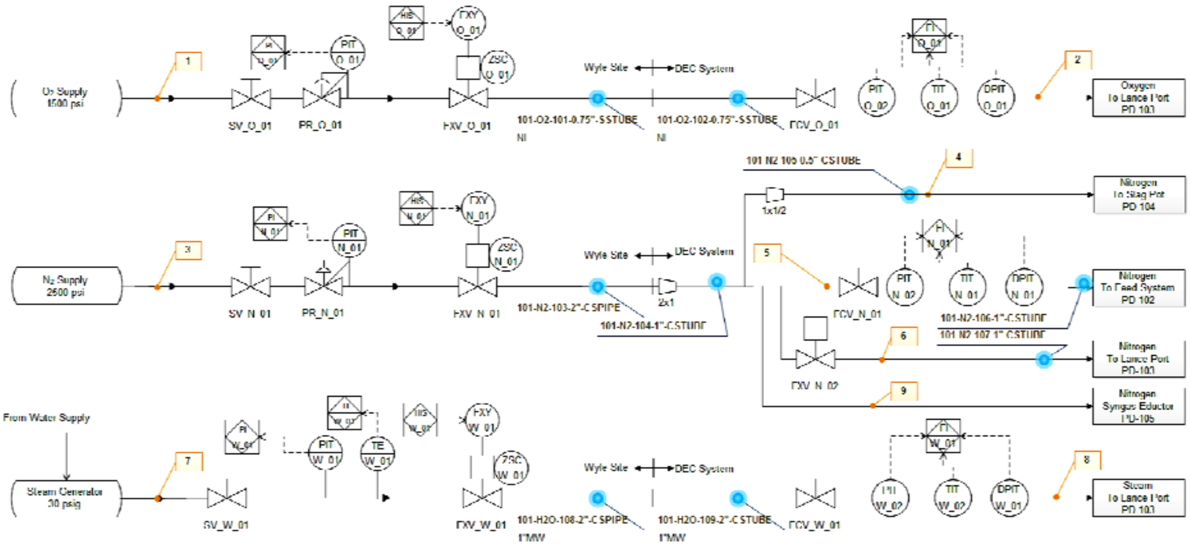
VP-9: Operation at Atmospheric Pressure, or Pressurized – This process can operate in many pressure regimes, with Atmospheric pressure planned

Value to the investor/partner: Competing gasifiers must operate "at pressure", anywhere from a few Atmospheres to very high pressures. Higher pressures require thick ASME-certified and welded metal pressure vessels, expensive and heavy flanges, gaskets, and bolting, pressurized lock-hoppers for feedstocks, etc. By operating at or near atmospheric pressure, this process reduces costs of materials substantially, decreases safety hazards, and simplifies construction, operations and maintenance.

VP-10: Highly Scalable – OmniGas is scalable to very large diameter reactors with straightforward scaling laws.

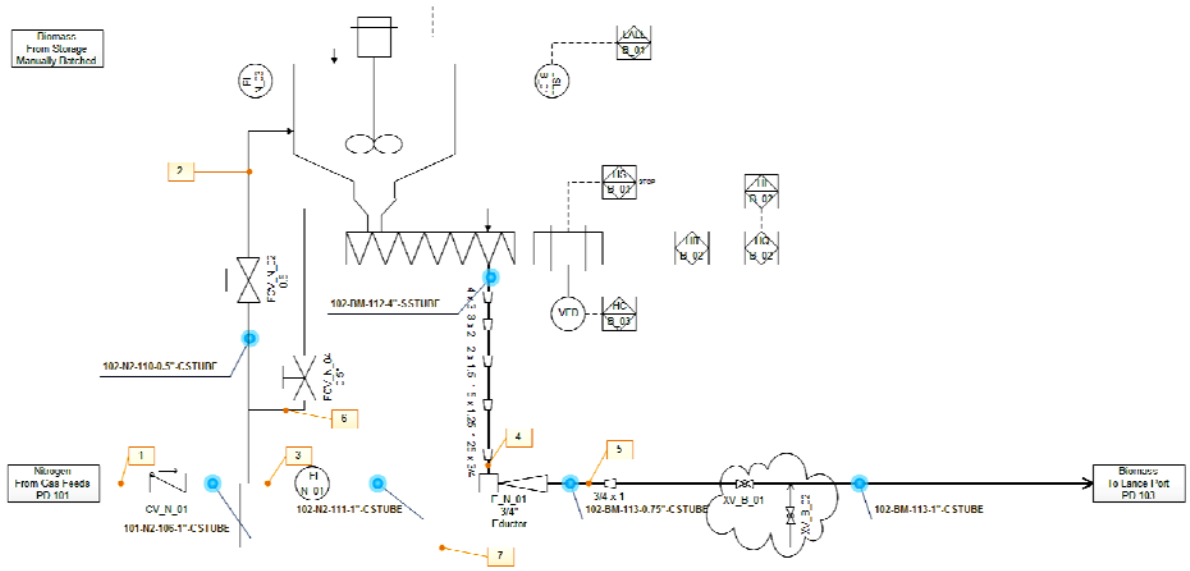
Value to the investor/partner: Because the main gasification reaction occurs in a pool of molten metals, larger "pools" should scale easily. Since the volume of the "melt' goes up faster than the diameter, a "geometric" increase is achieved in melt volume over surface area as the diameter increases. Even though the containment cost goes up as the diameter increases, the process is more cost efficient with the larger in diameter and processing more feedstock per unit dollar of reactor cost.

APPENDIX A:
P&IDs



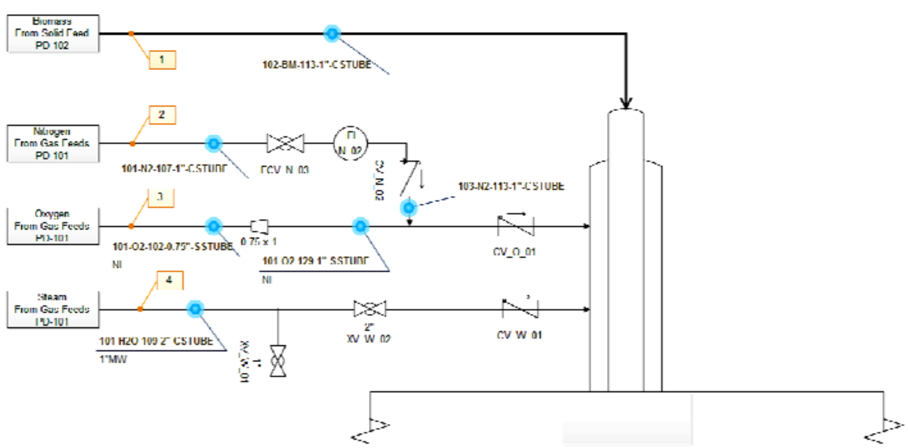
Flow #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temperature (F)	68	68	68	68	68	68	298	298	68										
Pressure (psig)	1500	30	2500	30	30	30	30	30	30										
Nominal Flowrate (lb/hr)	42	42	82	2	82	0	15	15	0										
Density (lb/ft3)	2.97	0.267	7.80	0.234	0.234	0.234	0.105	0.105	0.234										
Flow Range (lb/hr)	0-60	0-60	0-160	0-20	20-120	0-20	0-40	0-40	0-50										

Revision #: 6 Date: 4/8/13 Drawn By: SJC	**PD-101** OmniGas WTT Piping and Instrumentation Diagram Gas Feeds
Facility Loc: Wyle Labs	Diversified Energy Corporation Confidential and Proprietary



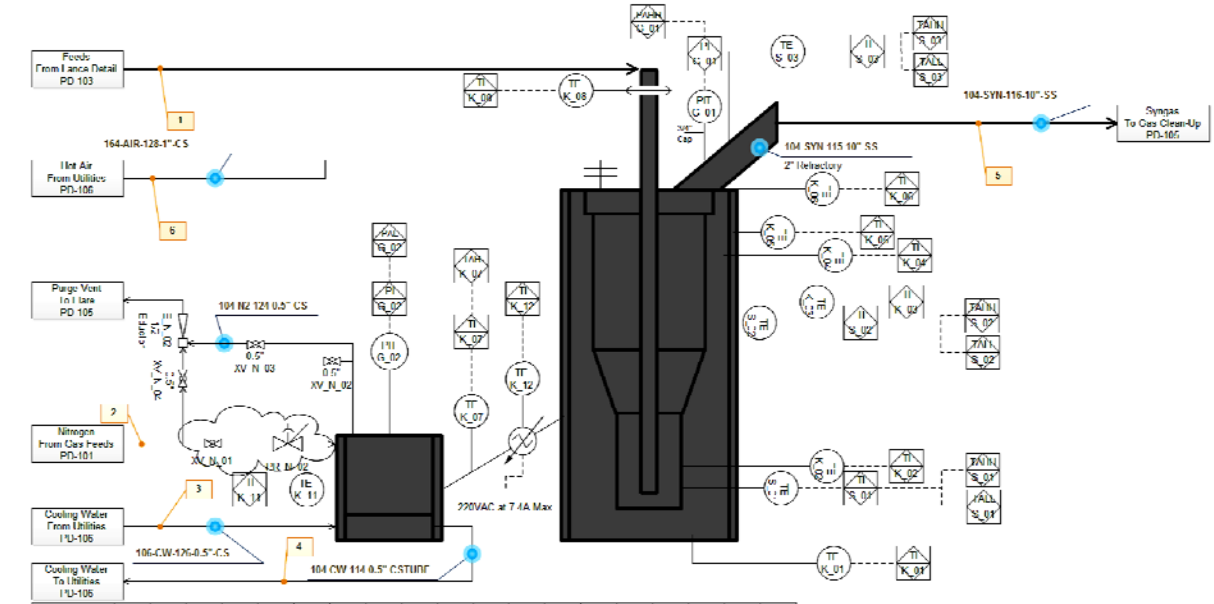
Flow #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temperature (F)	68	68	68	68	68	68	68												
Pressure (psig)	30	30	30	30	30	30	30												
Nominal Flowrate (lb/hr)	82	2	70	100	180	10	0												
Density (lb/ft3)	0.234	0.234	0.234	22	11	0.234	0.234												
Flow Range (lb/hr)	20-120	0-4	20-120	0-120	20-240	0-25	0-80												

Revision #: 6 Date: 4/8/13 Drawn By: SJC	**PD-102** OmniGas WTE Piping and Instrumentation Diagram Solid Feed
Facility Loc: Wyle Labs	Diversified Energy Corporation Confidential and Proprietary



Flow #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temperature (F)	68	68	68	248															
Pressure (psig)	30	30	30	30															
Nominal Flowrate (lb/hr)	180	0	47	15															
Density (lb/ft3)	11	0.234	0.267	0.105															
Flow Range (lb/hr)	20-240	0-20	0-60	0-40															

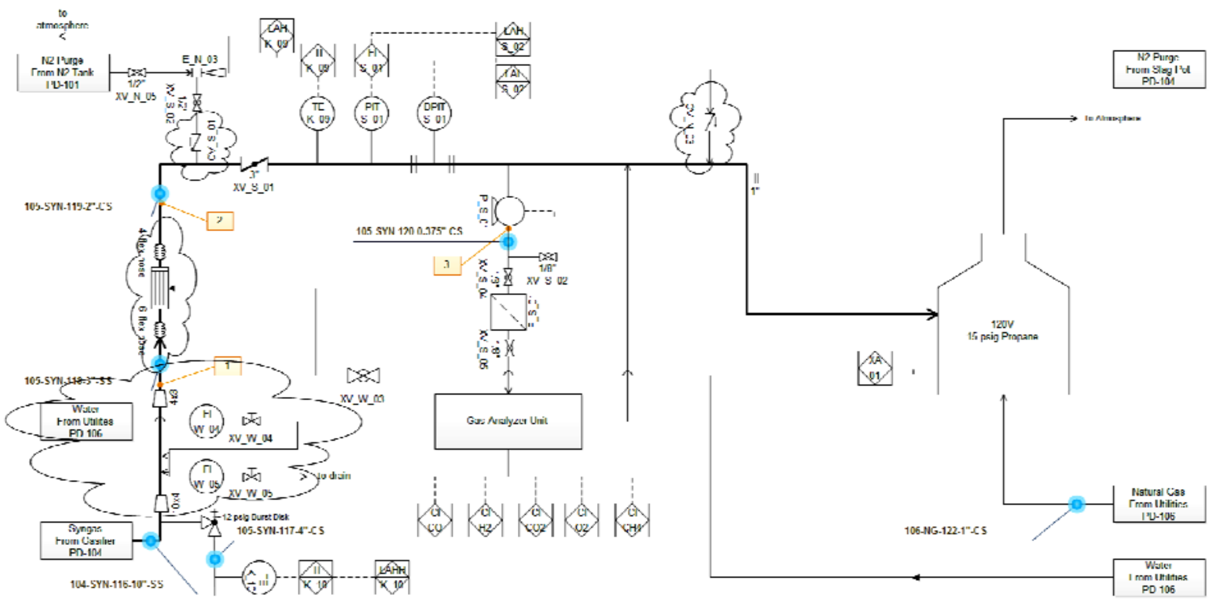
Revision #: 6 Date: 4/8/13 Drawn By: SJC	**PD-103** OmniGas WTE Piping and Instrumentation Diagram Lance Detail
Facility Loc: Wyle Labs	Diversified Energy Corporation Confidential and Proprietary



Flow #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temperature (F)	100	68	68	104	1,652	68	68												
Pressure (psig)	30	15	70	70	5	1	0.56												
Nominal Flowrate (lb/hr)	157	2	1000	1000	157	242	5.81												
Density (lb/ft3)	8	0.234	62.4	62.4	0.021	0.080	0.045												
Flow Range (lb/hr)	20-320	0-20	0-2,500	0-2,500	20-320	0-242	0-5.8												

Revision #: 6
Date: 4/8/13
Drawn By: SJC
Facility Loc: Wyle Labs

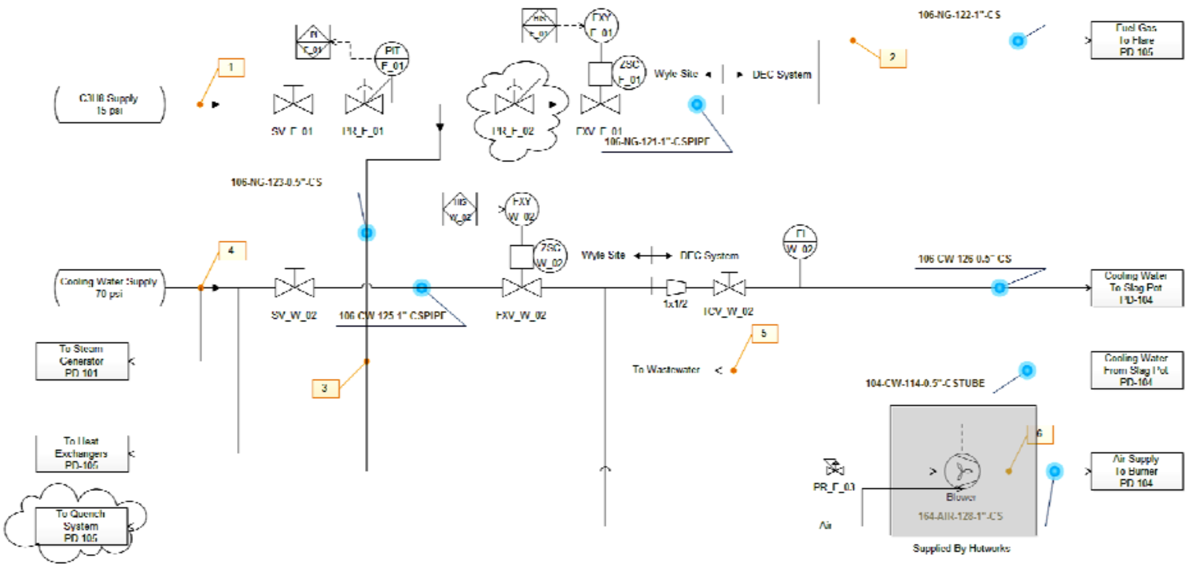
PD-104
OmniGas WTE
Piping and Instrumentation Diagram
Gasifier
Diversified Energy Corporation
Confidential and Proprietary



Flow #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temperature (F)	1,652	392	392																
Pressure (psig)	5	3	3																
Nominal Flowrate (lb/hr)	157	157	0.1																
Density (lb/ft3)	0.021	0.047	0.047																
Flow Range (lb/hr)	20-320	20-320	0-0.1																

Revision #: 6
Date: 4/8/13
Drawn By: SJC
Facility Loc: Wyle Labs

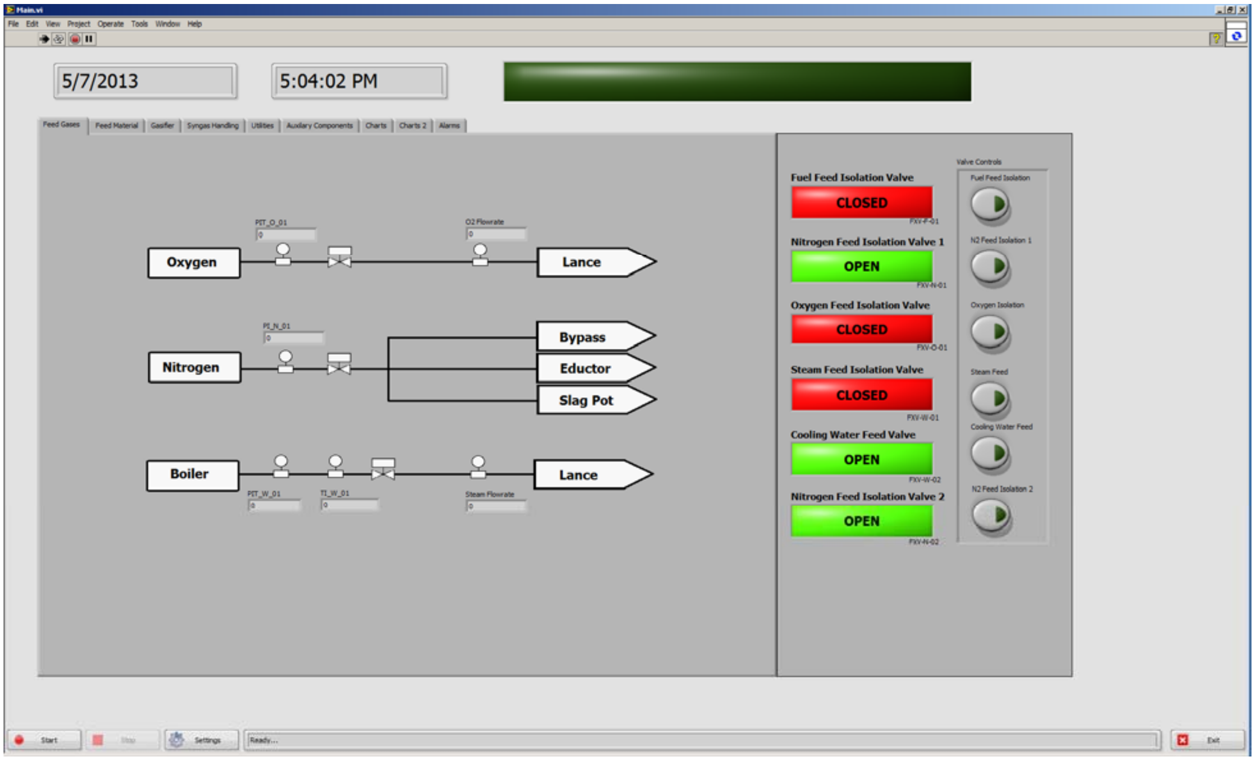
PD-105
OmniGas WTE
Piping and Instrumentation Diagram
Syngas Handling
Diversified Energy Corporation
Confidential and Proprietary

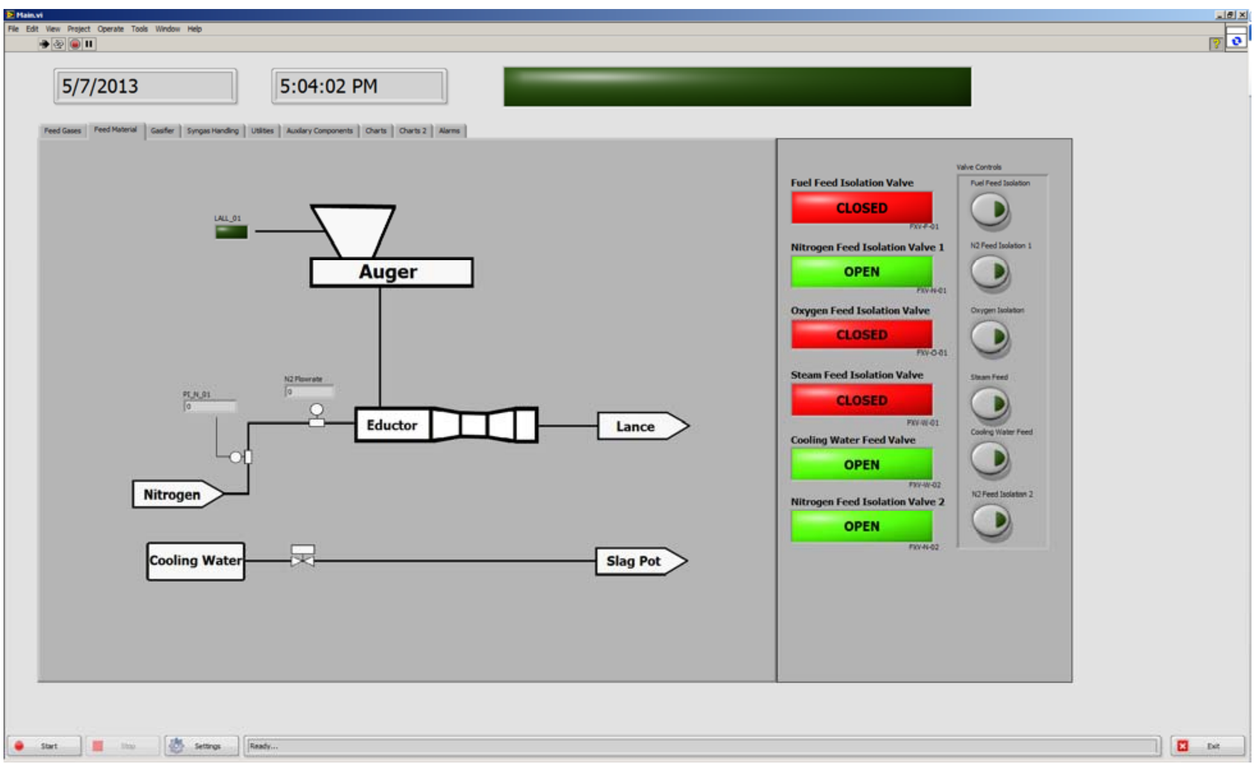


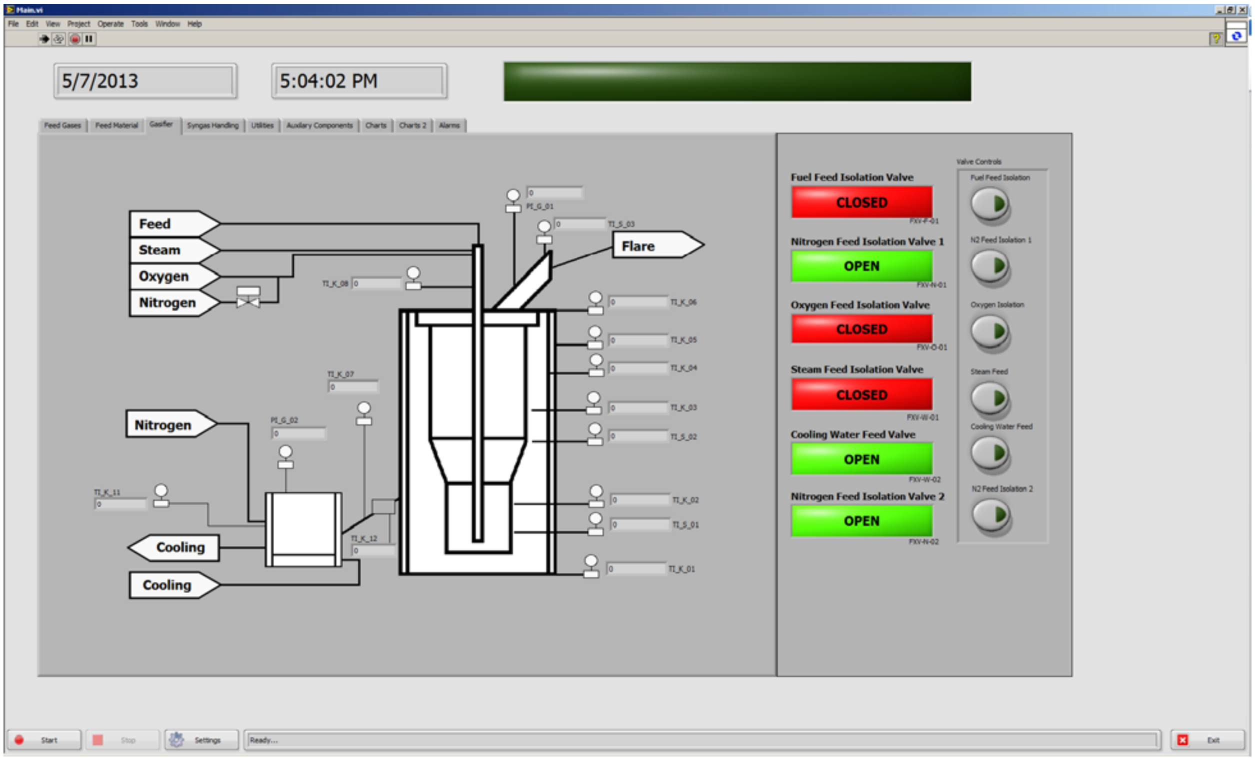
Flow #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Temperature (F)	68	68	68	68	104	68													
Pressure (psig)	15	15	0.56	70	70	1													
Nominal Flowrate (lb/hr)	3.80	3.80	5.81	1000	1000	242													
Density (lb/ft3)	0.136	0.136	0.045	62.4	62.4	0.08													
Flow Range (lb/hr)	0-10	0-4	0-8	0-2,500	0-2,500	0-242													

Revision #. 6 Date: 4/8/13 Drawn By. SJC	**PD-106** OmniGas WTE Piping and Instrumentation Diagram Utilities
Facility Loc. Wyle Labs	Diversified Energy Corporation Confidential and Proprietary

APPENDIX B:
LabView Screenshots



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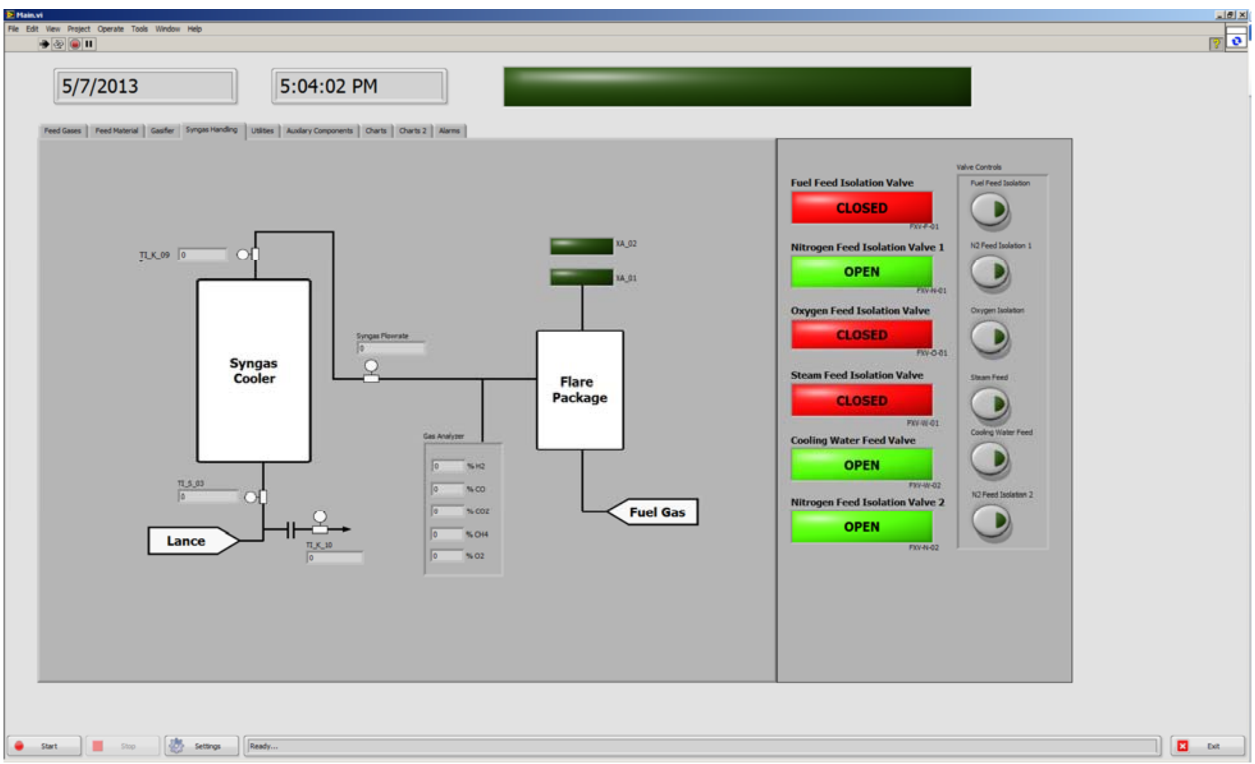
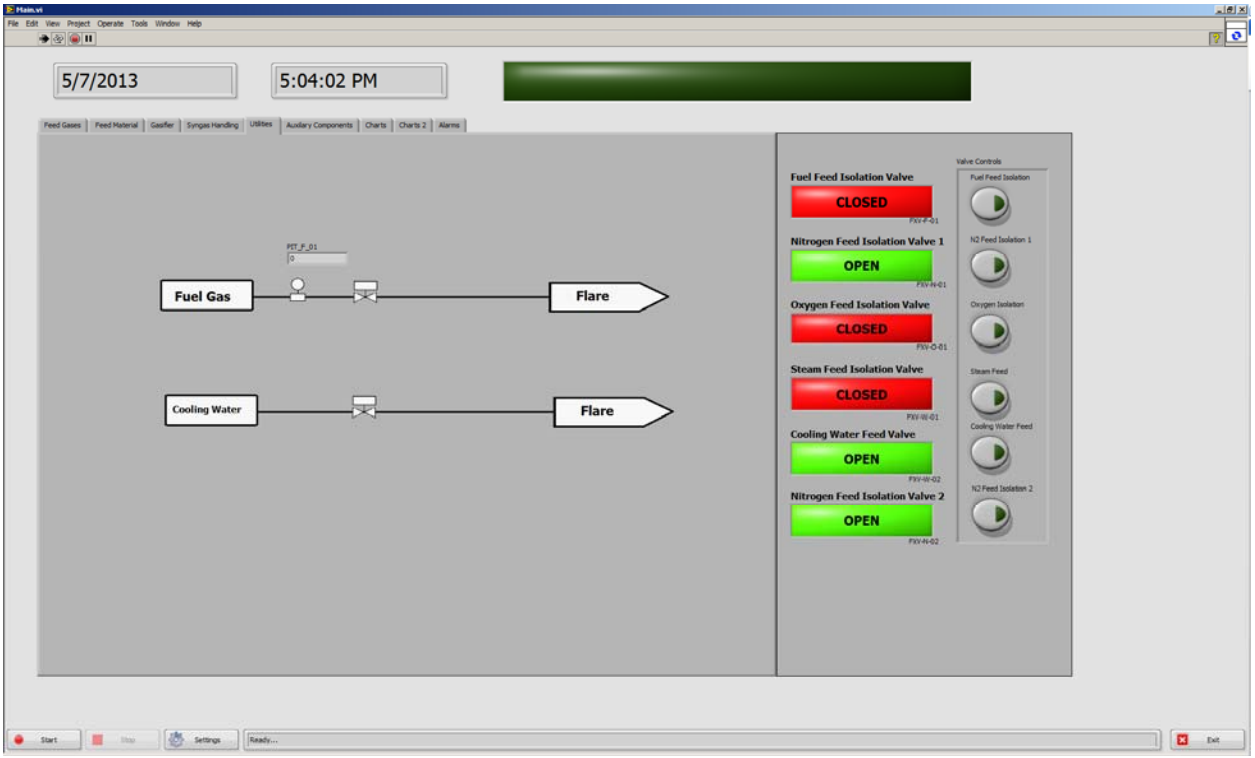
Feed
Steam
Oxygen
Nitrogen
Flare
Nitrogen
Cooling
Cooling
Fuel Feed Isolation Valve
CLOSED
Nitrogen Feed Isolation Valve 1
OPEN
Oxygen Feed Isolation Valve
CLOSED
Steam Feed Isolation Valve
CLOSED
Cooling Water Feed Valve
OPEN
Nitrogen Feed Isolation Valve 2
OPEN


5/7/2013
5:04:02 PM
Syngas Cooler
Flare Package
Fuel Gas
Lance
Fuel Feed Isolation Valve
CLOSED
Nitrogen Feed Isolation Valve 1
OPEN
Oxygen Feed Isolation Valve
CLOSED
Steam Feed Isolation Valve
CLOSED
Cooling Water Feed Valve
OPEN
Nitrogen Feed Isolation Valve 2
OPEN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5:04:02 PM
Fuel Gas
Flare
Cooling Water
Flare
Fuel Feed Isolation Valve
CLOSED
Nitrogen Feed Isolation Valve 1
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Oxygen Feed Isolation Valve
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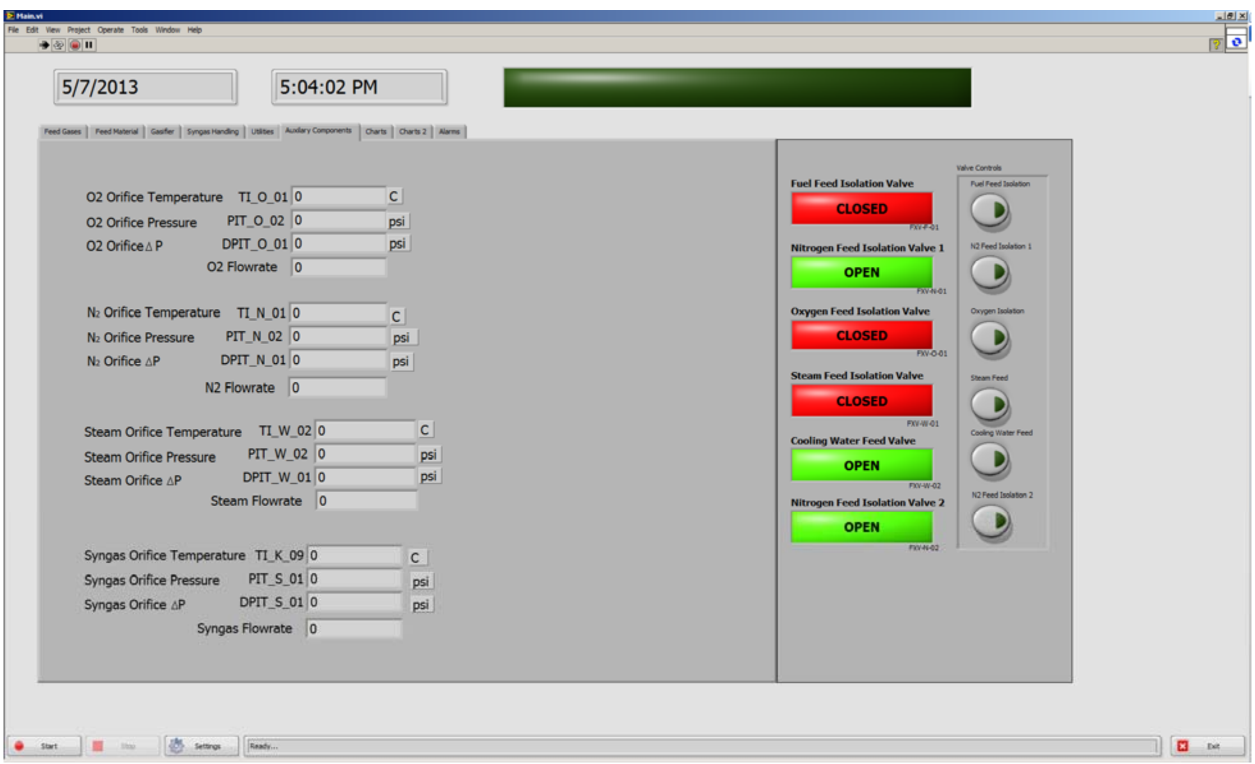
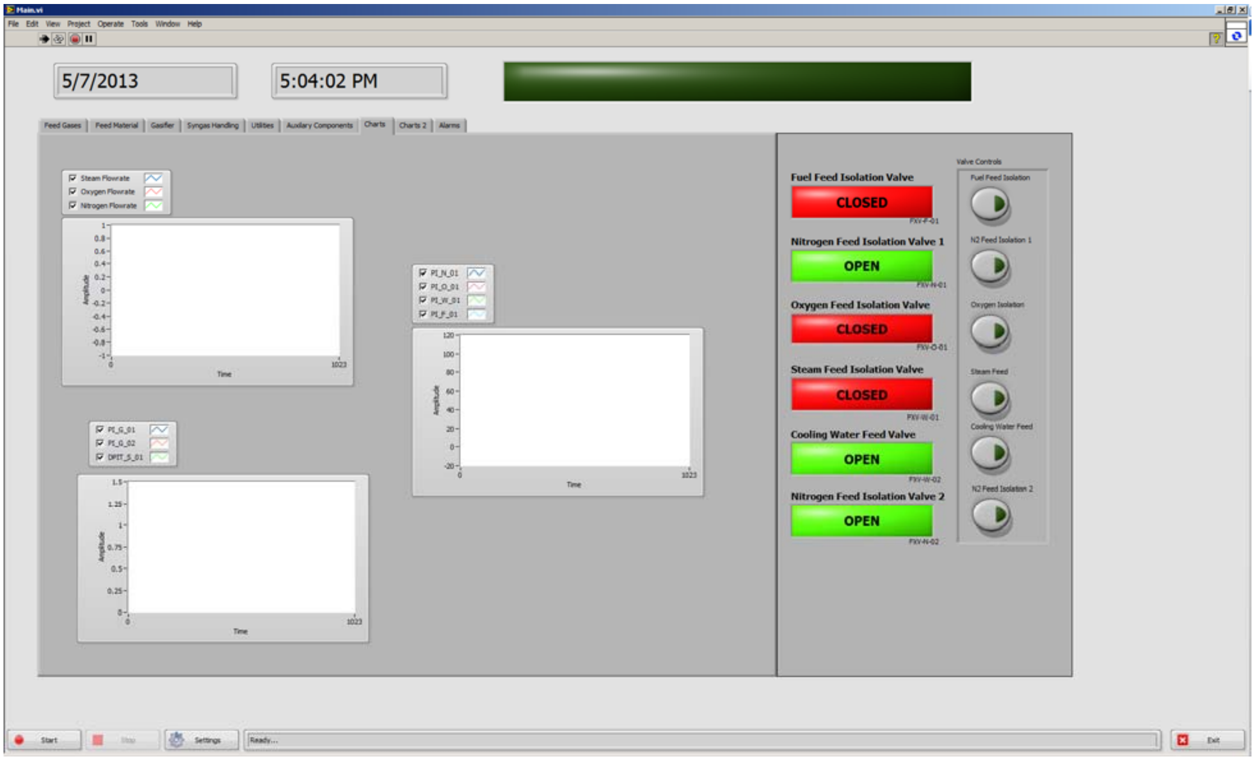
Cooling Water Feed Valve
OPEN
Nitrogen Feed Isolation Valve 2
OPEN


5/7/2013
5:04:02 PM
O2 Orifice Temperature TI_O_01 0 C
O2 Orifice Pressure PIT_O_02 0 psi
O2 Orifice ΔP DPIT_O_01 0 psi
O2 Flowrate 0
N2 Orifice Temperature TI_N_01 0 C
N2 Orifice Pressure PIT_N_02 0 psi
N2 Orifice ΔP DPIT_N_01 0 psi
N2 Flowrate 0
Steam Orifice Temperature TI_W_02 0 C
Steam Orifice Pressure PIT_W_02 0 psi
Steam Orifice ΔP DPIT_W_01 0 psi
Steam Flowrate 0
Syngas Orifice Temperature TI_K_09 0 C
Syngas Orifice Pressure PIT_S_01 0 psi
Syngas Orifice ΔP DPIT_S_01 0 psi
Syngas Flowrate 0
Fuel Feed Isolation Valve
CLOSED
Nitrogen Feed Isolation Valve 1
OPEN
Oxygen Feed Isolation Valve
CLOSED
Steam Feed Isolation Valve
CLOSED
Cooling Water Feed Valve
OPEN
Nitrogen Feed Isolation Valve 2
OPEN


5/7/2013
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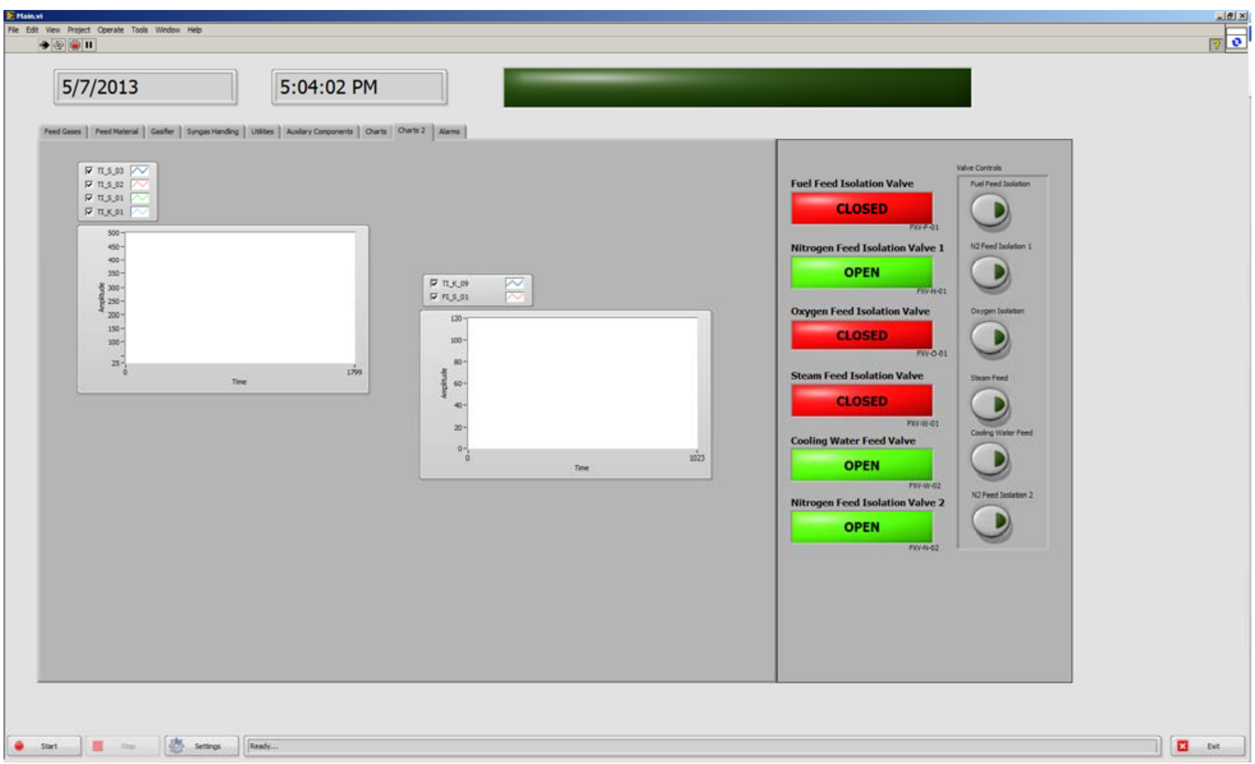
Feed Gases
Feed Material
Gasifier
Syngas Handling
Utilities
Auxiliary Components
Charts
Charts 2
Alarms
Steam Flowrate
Oxygen Flowrate
Nitrogen Flowrate
PI_N_01
PI_O_01
PI_W_01
PI_F_01
PI_G_01
PI_G_02
DPIT_S_01
Amplitude
Time
Fuel Feed Isolation Valve
CLOSED
Nitrogen Feed Isolation Valve 1
OPEN
Oxygen Feed Isolation Valve
CLOSED
Steam Feed Isolation Valve
CLOSED
Cooling Water Feed Valve
OPEN
Nitrogen Feed Isolation Valve 2
OPEN
Valve Controls
Start
Stop
Settings
Ready...
Exit


5/7/2013
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Feed Gases
Feed Material
Gasifier
Syngas Handling
Utilities
Auxiliary Components
Charts
Charts 2
Alarms
TI_S_03
TI_S_02
TI_S_01
TI_K_01
TI_K_09
FI_S_01
Amplitude
Time
Fuel Feed Isolation Valve
CLOSED
Nitrogen Feed Isolation Valve 1
OPEN
Oxygen Feed Isolation Valve
CLOSED
Steam Feed Isolation Valve
CLOSED
Cooling Water Feed Valve
OPEN
Nitrogen Feed Isolation Valve 2
OPEN
Valve Controls
Start
Stop
Settings
Ready...
Exit

Main.vi
File Edit View Project Operate Tools Window Help
5/7/2013
5:04:02 PM
Feed Gases
Feed Material
Gasifier
Syngas Handling
Utilities
Auxiliary Components
Charts
Charts 2
Alarms
Fuel Feed Isolation Valve
CLOSED
Nitrogen Feed Isolation Valve 1
OPEN
Oxygen Feed Isolation Valve
CLOSED
Steam Feed Isolation Valve
CLOSED
Cooling Water Feed Valve
OPEN
Nitrogen Feed Isolation Valve 2
OPEN
Valve Controls
Start
Settings
Ready...
Exit

APPENDIX C:
Operating Procedures

APPENDIX C:
Operating Procedures

Document Number: CA-SOP-001	Revision Number: #0
Creation Date: 3/8/13	Revision Date: NIL
Severity: 2/5 - Minor Risks COULD Exist	Frequency: 2/5 - Once Only

Task Name: Gasifier Instrumentation Check (N2 Cold Purge)

General Description:

Prior to heat-up and start-up, the gasifier will be purged with nitrogen in order to test the various flowmeters and temperature probes.

Step	Description	Hazards/Precautions
1	Prior to starting any testing on the unit, oxygen, steam and nitrogen supply valves *(SV_O/W/N_01)* should be locked out	
2	Unlock SV_N_01. Ensure FCV_N_01, FCV_N_02, FCV_N_03, FCV_N_04, XV_N_01, XV_N_04 and XV_N_05 are closed. Ensure XV_S_01 is open.	
3	Open SV_N_01. Open FXV_N_01. Slowly open FCV_N_01 to send nitrogen through the eductor system and through the lance. Adjust	
4	Adjust pressure on pressure regulator PR_N_01	
5	Check nitrogen orifice flowmeter and verify it matches analog meter.	
6	Check syngas orifice flowmeter and verify it matches nitrogen flow supply.	
7	Check gasifier pressure gauge and ensure it is operational	
8	Open FXV_N_02. Slowly open FCV_N_03 and adjust flowrate to 15 lb/hr. Check flow to eductor and adjust both flows until they are equal at 15 lb/hr.	
9	Open XV_N_01 to open nitrogen to slag pot. Adjust pressure regulator PR_N_02 to 5 psig. Ensure pressure gauge PI_G_02 is working.	
10	Open XV_N_04 and XV_N_03 to test slag pot venturi. Verify it is working correctly by the decreasing pressure in the slag pot. Test valve position vs. amount of vacuum pulled. Return valves to prior position.	
11	Open XV_S_03 and XV_N_05 to test syngas line venturi. Verify it is working correctly by the decreasing pressure in the gasifier. Test valve position vs. amount of vacuum pulled. Return valves to prior position.	
12	Purge entire system in this condition for 1 hour prior to start-up.	

Document Number: CA-SOP-002	Revision Number: #2
Creation Date: 3/8/13	Revision Date: 4/19/13
Severity: 4/5 - Major Risks Exist	Frequency: 2/5 - Once Only

Task Name: Gasifier Preheat

General Description:

This task will bring the gasifier from ambient pressure and temperature to full operating temperature. It involves use of a start-up burner that has additional specifications not listed here. During heat-up the refractory will also dry out, which may take considerable additional time. Major hazards here are the elevated work at the hot top face of the gasifier.

Step	Description	Hazards/Precautions
1	Preload hopper with powdered coal (hopper is 2.7 ft3, coal is 100 lb/ft3). Total amount of coal needed ~125 lb, so ~%50 full. Turn on nitrogen purge *FCV_N_02* after lid is sealed. Ensure that coal addition amount is recorded.	Elevated work and possible pinch points
2	Unbolt blind flange on 4" port on lid of gasifier.	Elevated work and possible pinch points
3	Preload gasifier with 300 lb pre-melted slag and 550 lbs of slag briquettes through the open port. This will require a crane to lift the materials to the 4" gasifier port and a manlift for a technican who will transfer the material in.	Elevated work and lifting hazards. Mobile equipment operation.
4	Install temporary start-up burner system per vendor specifications. This will require some elevated work and connections to propane and electrical connections	Start-up service company hired to do this work and will raise awareness of any burner hazards
5	Ensure downstream syngas butterfly valve *XV_S_01* is open	
6	Remove cap on 1/4" line (either by the pressure transducer off of the main vent above the gasifier or off the side gasifier itself, near the top). This port will be used to identify if refractory is steaming during heat-up.	Elevated work
7	**Operator #1** in the control room should ensure oxygen and steam actuated valves, *FXV_O_01* and *FXV_W_01* , are closed. Then open nitrogen supply actuated valve *FXV_N_01* and nitrogen bypass valve *FXV_N_02*.	
8	**Operator #2** in the field will slowly open nitrogen supply valve *(FCV_N_01)* . Nitrogen will flow through eductor to inner lance and through bypass valve to outer lance. Adjust valve such that total flow (*FI_N_01* & *FI _N_02*) is 20 lb/hr. Pinch back bypass valve *(FCV_N_02)* if needed to ensure roughly equal flow through both inner and outer annulus.	Watch pressure on gasifier so it doesn't overpressurize.
9	Purge unit for 10 minutes in this mode.	
10	**Operator #2**: Open quench water supply valve *XV_W_04* to 40 lb/hr. Open return valve *XV_W_05* all the way. Open water supply valve *XV_W_03* to heat exchanger but at minimal setting.	
11	Start-up burner company will ignite burner.	
12	Ramp up temperature across the gasifier at 50F per hour. Monitor via control room screens *(TI_S_01/02, TI_K_01-06)* . Burner will be adjusted in the field to meet this heat-up rate. There will be some gradient across the various temperature probes in the gasifier. Most critical is adequate heating of the bottom of the unit.	

13	Monitor 1/4" open line off the vent. If steam is venting, hold temperature until steaming stops. When all steaming is complete put cap back on this open line	Elevated work, hot gas exiting, use proper PPE and tools
14	Continue to ramp at 50F per hour until inner gasifier temperature reaches 800F. Hold at 800F for one hour or until temperaure gradient across gasifier reaches steady state or until day shift. Increase HX capacity as needed to keep downstream temperature < 200C. Keep quench flow on, but minimal.	
15	Remove start-up burner with a crane/lift	Mobile equipment operation
16	**Operator 2**: shut off main nitrogen supply via hand valve *(SV_N_01)* in the field.	
17	**Operator 1**: operate man-lift for elevated work **Operator 2**: attach blind flange back onto 4" port. PPE includes high temp gloves, face shield and flame resistant jacket.	The gasifier will be very hot and there will be significant radiant heat. No N2 purge will limit hot gas exiting port. Work is elevated.
18	Turn on nitrogen purge. Wait 5 mintues then test KOP outlet for O2 concentration. When below 8%, start up flare via vendor specifications	Review of flare documentation to ensure all safety precautions are taken
19	**Operator 1**: Ensure nitrogen supply and bypass actuated valves are open *(FXV_N_01/02)* . Adjust bulk density input for feeder to ~48 lb/ft3. **Operator 2:** Open main nitrogen supply *(SV_N_01)* and increase flow to eductor to 60 lb/hr *(FCV_N_01)* . Start feeder at 5 lb/hr coal addition *(HI_B_02)* .	Elevated work to adjust feed rate.
20	Immediately after starting feeder: **Operator 2**: Check main oxygen supply hand valve *(SV_O_01)* and flow control valve *(FCV_O_01)* are closed. **Operator 1**: Open actuated oxygen supply valve *(FXV_O_01)* **Operator 2**: Open supply valve *SV_O_01* . Gradually open oxygen flow control valve *(FCV_O_01)* and increase flowrate in the field to 3x the coal mass rate (flow rate will be visible in control room by Operator 1)	
21	**Operator 1**: Monitor temperatures across gasifier. Combustion will be proved by lower temperature probe. Ensure temperature continues to rise at roughly 50 C/hr (or ~1 degree C per minute). **Operator 2**: Adjust coal and oxygen flowrate as needed to meet temperature rise	
22	**Operator 1**: Check gas composition via gas analyzer inputs. Check for complete combustion - this will be indicated by O2, CO and CO2 percentages. **Operator 2**: Adjust oxygen flowrate up if there is incomplete combustion (CO); adjust down if there is oxygen in the flue gas. **Repeat**: Do this every 20 minutes (or as often as the gas analyzer returns new sample results) until oxygen balance is correct	Oxygen in the syngas could create risks at the flare
23	Allow temperature to rise to 1350C by increments of 50 C/hr. If coal runs out during this process, (as indicated by sudden reduction in downstream gas flow), refill feed hopper. Ensure coal addition amount is recorded.	Hopper will be under nitrogen purge, so ensure purge is shut off and use caution when opening hopper for refill.
24	**Operator 2:** During the heat-up time, increase quench supply flow *(XV_W_04)* to 100 lb/hr *(FI_W_04)* and close quench return valve *(XV_W_05)* such that return flow meter *(FI_W_05)* is 80 lb/hr. Increase water to heat exchanger *(XV_W_03)* such that downstream temp < 200C *(TI_K_09)* ; this is roughly 40% of the heat exchanger capacity	Refer to "Cooling Coordination" spreadsheet. Insufficient cooling at the quench or heat exchanger could lead to equipment or piping failures.

25	Upon reaching 1350C, **Operator 2** reduce coal such that temperature holds steady. **Operator 2** reduce oxygen flow in proportion (~3x coal lb/hr). Hold at this temperature until temperature profile across reactor stabilizes	
26	When ready, proceed to *CA_SOP_003* for introduction of biomass feed to the gasifier	

Document Number: CA-SOP-003	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 5/5 - Catastrophic Risks Exist	Frequency: 2/5 - Unlikely or Once Only

Task Name: Feed Start-Up

General Description:

After the gasifier has been heated up and charged with slag, the various feeds must be started to bring the gasifier to normal operation. This is a critical step. Starting up too slowly will allow the gasifier to cool and slag to harden. Starting up too quickly could shock the system with a spike in pressure and temperature.

Step	Description	Hazards/Precautions
1	Have at least one silo of biomass prepared/filled *(CA_SOP_004)*	
2	Ensure gasifier pressure is within appropriate limits via *PI_G_01* (< 7 psig)	
3	Gasifier has been preheated and charged with initial slag mix	
4	Coal, oxygen and nitrogen are being fed to the unit to maintain temperature until ready to introduce feed	
5	Bottom temperature gauge of the gasifier *(TI_S_01)* must stay above 1250 for slag to stay melted. If it starts to drop below this during startup, feed and oxygen flow must be increased and steam flow decreased until temperature is back within range	
6	Quench, heat exchanger, flare and steam generator must be all be operational	
7	**Operators 1 & 2:** Position silo with feedstock into place above hopper. Open slide gates to dump material from silo into hopper. If any coal remains in the hopper, it will be mixed with the feed and flow into the gasifier until it is eventually all biomass feed in the hopper	Elevated platform work
8	**Operator 1**: Adjust density of feed material on LabView screen (~15 lb/ft3). Note: this may be different based on remaining coal in hopper	
9	**Operator 2:** Slowly ramp up feeder to 30 lb/hr feedstock addition *(HS_B_02)* . This will require coordination with **Operator 1** looking at LabView screens	Elevated platform work
10	**Operator 2:** Adjust oxygen flow to 15 lb/hr addition *(FCV_O_01)* . This will require coordination with **Operator 1** watching *FI_O_01*.	
11	**Operator 2:** Decrease quench water return *(FI_W_05)* to 74 lb/hr via *XV_W_05* ; this will direct more quench water through the nozzles. Increase heat exchanger water to 52% of capacity (or sufficient to bring TE_K_09 < 200C) via *XV_W_03*.	Insufficient cooling at the quench or heat exchanger could lead to equipment or piping failures.
12	**Operator 2:** Blow out steam line at bleed valve near gasifier *(XV_W_01)* . Close bleed valve and open supply valve to gasifier *(XV_W_02)* .	Valves may be hot. Hot steam/condensate will exit bleed valve at high speeds. Insufficient line blow-out could lead to
13	**Operator 2:** Slowly increase steam flow to 5 lb/hr addition *(FCV_W_01)*. This will require coordination with **Operator 1** watching *FI_W_01*.	Valves may be hot.
14	**Operator 1:** Check temperature of gas coming out of gasifier - it should be ~1200 C. Check temperature of gas after the heat exchanger - it should be < 200C. Check syngas flowmeters to ensure they are	Over-temperature after the heat exchanger could lead to failure instrumentation, flare or gas analyzer.
15	Wait 40 minutes. The GC (gas analyzer) will have taken and analyzed at least one sample of the gas. Via LabView or Data Historian, check *CI_CO*	

16	With **Operator 2** in field and **Operator 1** watching indicators: Increase feed to 60 lb/hr, oxygen to 24 lb/hr, steam to 9 lb/hr.	Elevated platform work, hot valves.
17	**Operator 2:** Decrease quench water return *(FI_W_05)* to 62 lb/hr via *XV_W_05* ; this will direct more quench water through the nozzles. Increase heat exchanger water to 76% of capacity (or sufficient to bring TE_K_09 < 200C) via *XV_W_03*.	Insufficient cooling at the quench or heat exchanger could lead to equipment or piping failures.
18	Wait another 40 minutes and evaluate results from gas analyzer. If gasifier begins to overheat, reduce oxygen. If gasifier begins to lose heat, increase oxygen.	
19	Increase feed to 100 lb/hr, oxygen to 40 lb/hr and steam to 15 lb/hr.	Elevated platform work, hot valves.
20	**Operator 2:** Decrease quench water return *(FI_W_05)* to 40 lb/hr via *XV_W_05* ; this will direct more quench water through the nozzles. Increase heat exchanger water to 100% of capacity (or sufficient to bring TE_K_09 < 200C) via *XV_W_03*.	Insufficient cooling at the quench or heat exchanger could lead to equipment or piping failures.
21	Wait another 40 minutes and evaluate results from gas analyzer. If gasifier begins to overheat, reduce oxygen. If gasifier begins to lose heat, increase oxygen.	
22	After this point, the goal is to make small changes every 30 minutes or so. Since the initial feed will be some mixture of coal and biomass, operators will need to lower the bulk density of the feed, lower steam input (due to higher moisture of the biomass) and may need to adjust oxygen. Adjust cooling system accordingly.	
23	When the feed has stabilized (i.e. is pure biomass) the goal will be to continue to make changes every 30 minutes or so to reduce the steam and oxygen requirements. These changes will be based on maximizing CO/H2 production and minimizing CO2/H2O in the syngas. Adjust cooling system accordingly.	

Document Number: CA-SOP-004	Revision Number: #2
Creation Date: 3/8/13	Revision Date: 4/19/13
Severity: 3/5 - Minor Risks Exist	Frequency: 4/5 - Two Times per Day

Task Name: Fill and Change Feed Silos

General Description:

This process is for adding additional feed material to the elevated, and nitrogen-purged, feed hopper. Due to the weight of the feed bags, a crane will be used, and an operator will be on an elevated platform to change out the bags.

Step	Description	Hazards/Precautions
1	Double-check density of the material by taring, filling and weighing a 5-gallon pail. Change density number in LabView and other calculations if needed.	
2	Weigh empty silos and record weight with silo number on "Silo Spreadsheet".	
3	Operators will know when to change feed bag (or shake it loose) by the **Low Level Probe** *(LALL_B_01)* on the feed hopper - it will go into alarm, signalling that the bag and barrel are empty and feeder is operating solely on the feed hopper	
4	If the above method fails, an empty feed hopper will be indicated by a sudden drop in syngas flowrate (in which case, put gasifier into bypass/idle mode immediately	
	Every Hour:	
5	Go up and bang on feed bag to make sure material is still flowing. Check if it needs to be emptied. Check to make sure crane position hasn't drifted downward	
6	Add specied amount of materials to the feed. Add appropriate amount of magnatite (~3.2 lb) and silica (~0.25 lb) into silo. Use lab scale to ensure correct amount is added. Refer to "Slag Growth" spreadsheet for exact amount/calculations. Record amounts added onto Slag Spreadsheet.	Dust masks. MSDS for materials. If too much silica is added, slag will foam up in the unit.
	To Prepare Bags:	
7	Attach tension scale to cables. Attach tension scale to bag.	
8	Pick up bag with crane and record the weight and bag number on the "Silo Spreadsheet"	
9	Place bag back on the ground and remove the scale. Repeat for multiple bags and record.	
	To Change Silos:	
10	**Operator 1:** Ascend feed system platform	Elevated work
11	**Operator 2:** Use the crane to lower empty bag (on platform)	Mobile equipment operation.
12	**Operator 1:** Descend platform and detach empty bag. Attach full bag to crane	Elevated work
13	**Operator 2:** Hoist the full bag with the crane up to feed platform - above and near the feed hopper	Mobile equipment operation.

14	**Operator 1:** Ascend feed platform. Position bag into place	Elevated work
15	**Operator 1:** Open bag bottom with a knife, creating an "X" on the bottom	DO NOT get arm crushed between bag and hopper
16	**Opeator 1:** Shake bag to start flow of material into hopper	Mobile equipment operation.
17	Back in the control room, ensure the low level alarm probe *LALL_B_01* has cleared	
18	Refer to "Silo Spreadsheet" for weight added. A timer in the control room is reset to (silo weight, lb) / (feed rate, lb/hr) = time (in hours)	
19	This weight additionally needs to be added to the "Slag Growth" spreadsheet	

Document Number: CA-SOP-005	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 4/5 - Major Hazards Exist	Frequency: 2.5/5 - Once weekly

Task Name: Normal Slag Tap Sequence

General Description:

Due to the ash content of the incoming feedstock, the amount of slag in the reactor will gradually increase. For this reason, the reactor must be periodically tapped to remove a certain amount of the slag. This design incorporates a stand-alone, water-cooled slag pot into which slag is pushed through heated inconel tube. Multiple risks are present with hazardous gases, extremely hot material, pinch points and heavy lifting.

Step	Description	Hazards/Precautions
1	Determine when to perform tapping by using the "Slag Growth" spreadsheet to calculate slag growth (a function of feed rate, ash content and amount oxides fluxed). A tap should be performed when the added slag is approximately 7.5" above its base point.	The slag must not get more than 15" above the base point.
2	Prior to tap, continuous N2 purge into slag vessel should be verified at 1 psi differential above Omni-gas pressure.	Pressure transmitters on the slag pot and gasifier will ensure pressure differential
3	**The slag pipe heater should be switched on 30-60 minutes before slag tap and controlled to 1200C *(TI_K_12)* .**	Tapping slag into a cold pipe will cause it to freeze and block the pipe. Overheating the pipe will reduce pipe integrity and lead to pipe failure/rupture upon tapping.
4	Portable CO monitor(s) turned on and available for testing at slag vessel	
5	H2 and CO levels should be monitored and recorded in the Omni-gas exhaust via online gas analyzer	
6	Put gasifier into idle mode by opening nitrogen bypass and shutting off main feeds (See *CA_SOP_010*). Nitrogen flow will be 30 lb/hr.	
7	Purge via lance with N2 for 10-15 minutes — or as required to purge H2 and CO from the chamber to 0%. Test periodically with hand analyzer at sampling port outlet *(XV_S_02)* . Also test slag pot gas at *XV_N_02* . Move to next step once unsafe levels of CO are removed.	Gasifier CO Level ________ Slag Pot CO Level
8	**Operator 2:** In the field, turn on 3 GPM of cooling water to slag pot (adjusted with *TCV_W_02* and monitored with *FI_W_02*).	
9	**Operator 2:** Stop N2 purge of slag vessel by closing *XV_N_01* .	
10	**Operator 2:** Shut down flare. Refer to *CA_SOP_009* for instructions.	Insufficient purge flow to flare tap will create explosion risk at flare
11	**Operator 2:** Pinch back the main Omni-gas exhaust throttle valve *(XV_S_01)* thus allowing pressure in Omni-gas to build. When Omni-gas pressure is 7 psig *(PI_G_01)* , set valve position, then move to the next step.	
12	**Operator 1:** Ensure pressure remains constant. Field operator may have to re-adjust throttle valve again to keep gasifier pressure in desired range	
13	**Operator 2:** Turn off slag pipe heater.	

14	**Operator 2:** Open exhaust valve on slag vessel *(XV_N_03)* allowing slag vessel to be depressurized. Slightly open nitrogen motive gas *(XV_N_04)* to eductor to pull pressure on the slag pot to ~0 psig *(PI_G_02)* . Adjust exhaust valve as needed to make sure eductor doesn't pull too strong of vacuum	
15	Slag will flow from higher pressure Omni-gas to the lower pressure slag vessel	
16	**Operator 1:** Monitor slag tap temperature *(TI_K_07)* and slag vessel thermocouple *(TI_K_11)* for temperature rise. Verify flow through sight window if possible.	
17	When pressure level starts to rise in the slag vessel *(PI_G_02)* , indicating end of tap, shut off eductor *(XV_N_04)* .	
18	**Operator 2:** Start N2 purge of slag vessel (open *XV_N_01*) and continue for 3 minutes.	
19	**Operator 2:** Close slag exhaust valve *XV_N_03* .	
20	**Operator 2:** Completely open main Omni-gas exhaust (syngas) throttle valve *(XV_S_01)* .	
21	**Operator 2:** Ensure nitrogen purge to flare for > 5 minutes. Restart the flare.	Refer to flare instructions. Flare must be purged to remove any oxygen.
22	Refer to idle mode procedure *(CA_SOP_010)* to bring the gasifier out of idle mode	
23	Continue water cooling for at least 4 hours, or until kettle temperature is below 200 F, prior to kettle removal.	
24	Follow Slag Kettle Removal procedure *(CA_SOP_006)* to remove slag-filled kettle.	

Document Number: CA-SOP-006	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 5/5 - Catastrophic Risks Present	Frequency: 2.5/5 - Once Weekly

Task Name: Slag Kettle Removal

General Description:

The following steps are necessary to remove the slag kettle. This procedure should be performed as soon as possible after slag removal and cooling of the slag in the kettle. This promptness is required in order remove the slag kettle when the molten slag is as low as possible inside the Omni-gas reactor. Risks include hazardous gases, heavy lifting, forklift/crane operation and risk of molten slag entering slag pot while pot is open

Step	Description	Hazards/Precautions
1	A venturi system on the main chamber exhaust is used to reduce pressures inside the gasifier. The slag kettle should not be opened without the venturi in operation.	
2	There must be one operator watching LabView **at all times** during this procedure to ensure pressure on the gasifier *(PI_G_01)* is less than 1 psig and ensure temperature on the slag tap line *(TI_K_07)* remains constant . Alert personnel in the vicinity of the slag vessel in the event of any failure of the venturi system.	
3	The slag kettle should be removed as soon as possible after cooling of the slag. Ideally, the slag kettle will be removed in the range of 6-12 hours after the tap. This will provide some small slag growth to form a seal but also provide a safety margin to prevent burping of slag from the chamber into the slag pipe system	
4	Operators should make every effort to reduce exposure of any body part to the open end of the slag pipe within the slag vessel.	
5	Appropriate safety clothing for high temperature exposure must be worn at all times including gloves, face protection, boots and smock.	
6	Start by putting the gasifier into idle mode *(CA_SOP_010)* , this will involve opening the nitrogen bypass and shutting off main feeds. Purge with nitrogen for 10-15 minutes. Nitrogen flowrate should be 30 lb/hr.	
7	**Operator 2:** Check CO level in the gasifier exhaust at *XV_S_02* with handheld meter. If it is within limits, proceed to next steps.	CO Level ________
8	**Operator 1:** Check that the temperature of the slag vessel *(TI_K_11)* is below 100 C.	
9	**Operator 2:** Turn off the slag vessel cooling water flow (TCV_W_02) if not already done.	
10	**Operator 2**: Turn off the flare. Refer to *CA_SOP_09* .	
11	**Operator 2:** Pinch back the main syngas valve *(XV_S_01)* and open exhaust valve *(XV_S_03)* and motive gas *(XV_N_05)* to start venturi.	
12	**Operator 1:** Wait for pressure inside the gasifier to reach ~0 psig *(PI_G_01)* . **Operator 2** may need to adjust main syngas throttle valve or exhaust valve to stabilize gasifier pressure at ~0 psig.	
13	**Operator 2:** Slowly open the slag exhaust valve *(XV_N_03)* , allowing the slag vessel to equilibrium with the gasifier *(PI_G_01 & PI_G_02)*	
14	**Operator 2:** The level of CO must be checked at slag pot vent port *(XV_N_02)* before removing the lid to be sure they are within safety levels. Use a sensing instrument at the exhaust sample port on the slag pot to ensure safe conditions	CO Level ________

15	**Operator 2:** Shut off purge N2 on the slag pot *(XV_N_01)* when CO value is within safe limits. Open bleed valve *(XV_N_02)* to bring to atmospheric pressure.	
16	**Operators 2 & 3:** Unlatch the 20 clamps holding the slag vessel to the slag vessel lid and move it out of the way.	Heavy lifting (~70 lb) - use two people, pinch points.
17	**Operators 2 & 3:** Place the lid in a flat area where it cannot be damaged, taking care not to scratch or damage the lower flange surface.	Heavy lifting (~70 lb) - use two people
18	**Operators 2 & 3:** Move crane into place and attach four overhead crane lines to the 4 lifting eyes on the kettle, use special lifting chains	Mobile equipment use
19	**Operators 2 & 3:** Lift kettle 1/4" up. The kettle may need to be slid away from the slag pipe prior to lifting in order to prevent the kettle from catching the extended pipe inside the slag vessel.	Mobile equipment use
20	**Operators 2 & 3:** Carefully remove slag kettle and set it in safe area. The weight of the kettle is estimated to be approximately 320 pounds of slag plus the empty weight of the kettle	Mobile equipment use
21	**Operators 2 & 3:** Carefully place a new slag kettle into the slag vessel	
22	**Operators 2 & 3:** Slide the fresh kettle under the open end of the slag pipe.	
23	**Operators 2 & 3:** Verify that both the lid and the lip of the slag pot are clear of dirt and debris - any particles may cause insufficient seal of lid.	
24	**Operators 2 & 3:** Carefully place the slag vessel lid into place above the slag vessel being careful not to damage the silicone gasket on the vessel lid.	Heavy lifting (~70 lb) - use two people, pinch points.
25	**Operators 2 & 3:** Latch the vessel lid down by securing the 20 clamps in a criss-crossing pattern.	Pinch points
26	**Operator 2:** Begin controlled N2 pressurization of the slag vessel by closing exhaust and bleed valves *(XV_N_02/03)* and opening purge gas *(XV_N_01)* . **Operator 1:** Verify that a small pressure rise is occurring *(PI_G_02)* , thus indicating a sealed lid.	
27	**Operator 2:** Open the main syngas valve *(XV_S_01)* .	
28	**Operator 2:** Turn off the chamber venturi system by closing syngas exhaust valve *(XV_S_03)* and motive gas valve *(XV_N_05)* .	
29	**Operator 2:** Ensure nitrogen purge to flare for > 5 minutes. Restart the flare via *CA_SOP_09* .	Must remove all oxygen from gas line and flare.
30	Wait for pressure inside the slag vessel to stabilize <u>equal to</u> the gasifier chamber pressure (~3 psig).	
31	Refer to idle mode procedure *(CA_SOP_09)* to bring the gasifier out of idle mode.	
32	After resuming normal operations, test area around slag pot with handheld CO meter to ensure slag pot is not leaking.	Handheld CO meter
33	Dispose of waste slag kettle and stage an empty kettle near the system for the next kettle change out.	Heavy lifting, mobile equipment operation

Document Number: CA-SOP-007	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 2/5 - Minor Risks Could Exist	Frequency: 4/5 - Multiple Times Daily

Task Name: Normal Gasifier Operation

General Description:

When the gasifier is operating normally, very little changes are needed and very little risk is present. However, operators must be viligent to do walk-arounds and check for safe conditions. Also, operators must watch the labview screens to ensure that system continues to operate at steady-state

Step	Description	Hazards/Precautions
1	Pressure in the gasifier should be less than 5 psig. This is to check for blockage downstream	Gasifier Pressure _________
2	Pressure in the slag pot should be equal to the pressure in the gasifier. This is to ensure no slag is unintentionally transferred to slag pot.	Slag Pot Pressure _________
3	Temperature of the bottom melt is at least 1300 C This is to ensure liquid slag maintained and proper oxygen addition	Bottom S Thermocouple _________
4	Temperature of the syngas after the heat exchanger is < 200C This is to ensure proper cooling and protect downstream equipment	Post-HX Temperature _________
5	Flowrate of the syngas shold be around 200 lb/hr (or the sum of all the feeds going in) This is to check that the other flowmeters (including the auger) are still working within calibration/expectation	Syngas Flowrate ___________
6	Ensure the flare is not in alarm	Flare Operational ___YES ___NO
7	Ensure the feed hopper level probe is not in alarm	Feed Level OK ___YES ___NO
8	Ensure that rupture disk temperature is < 500 C	Rupture Disk Temperature _________
9	Verify oxygen, nitrogen, steam and feedstock are within expectations	Nitrogen _________ Oxygen _________
10	Verify that none of the temperature gauges have failed. Verify that the gasifier temperature profile looks normal	
11	Check that Data Historian is still active and check graphs to ensure that process is still steady-state.	
	Walk-Around (1x per hour):	
12	Check air conditions around slag pot and gasifier. Ensure that no syngas is leaking into the surrounding atmosphere	LEL ____________ CO _____________
13	Check that area around gasifier is clear of debris and muddy spots	Area Clear ___YES ___NO
14	Check gasifier for unexpected glowing red spots	Hot Spots ___YES ___NO
15	Ensure gas analyzer is consistently taking samples, that no error codes are lit, that helium tank is full and that filter is clear	Gas Analyzer OK ___YES ___NO
16	Ensure O2, N2 and Propane tanks are not low level. Monitor and record levels every 12 hrs	O2 Tank ________ N2 Tank __________ Propane

Document Number: CA-SOP-008	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 2/5 - Minor Risks Could Exist	Frequency: 5/5 - Multiple Times Hourly

Task Name: Gas Analyzer Operation

General Description:

The gas analyzer in use is a gas chromatograph that operates with a helium carrier gas. The analyzer takes about 15 minutes to run each sample and about 5 minutes to cool down and reset. The results are tranmitted from the gas analyzer via USB cable to the control room. Additional information on the unit can be found in separate documentation.

Step	Description	Hazards/Precautions
	Setting up the Gas Analyzer	
1	Chain helium tank to the supports. Attach pressure regulator and supply tubing to the GC	Proper securing of pressurized tank important for overall safety
2	Turn on gas analyzer and ensure accompanying software is operational on local PC	See other documentation on hazards and procedure for GC operation
3	Connect cylinder of calibration gas to the inlet of the GC. Run tubing from outlet to a safe location	Hazardous gas will be exiting at outlet, ensure discharge is well-vented
4	Open calibration gas cylinder and start sampling sequence on the GC. Refer to other documentation on starting up GC for the first time.	
5	Shut off calibration gas cylinder and wait for sample analysis	
6	If sample analysis does not match calibration gas composition, refer to other documentation to adjust the GC and re-run calibration test; otherwise proceed.	
7	Disconnect calibration gas. Connect gas sample tubing from syngas stream to the inlet of the GC. Connect outlet of the GC to exhaust tubing (discharging back into syngas line).	
	Normal Operation of the Gas Analyzer	
8	Gas analyzer will be pre-programmed to sample as frequently as is possible with a sampling cycle that includes purge and cool-down.	
9	Results will be visible at a local display on the analyzer as well as transmitted to the control room for the data historian and viewing on LabView.	
10	There is a filter *(F_S_01)* in line at the inlet of the GC. If filter gets dirty, it may be necessary to change it out. Close isolation valves *(XV_S_04 & XV_S_05)* and change out filter.	Line will have a small amount of syngas in it, so use caution when opening
11	Gas analyzer has possible error codes that will appear on the local display and may need troubleshooting. Refer to other documentation to correct and error codes	
12	The helium tank will eventually run out if the run goes on long enough, although not expected in this run. Refer to other documentation to shut down, purge unit and change out this gas cylinder	Proper handling and securing of pressurized tank is important for overall safety

Document Number: CA-SOP-009	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 4/5 - Major Risks Exist	Frequency: 2/5 - Once Only

Task Name: Flare Operation

General Description:

Proper installation and start-up of the flare must be achieved in order to handle the syngas produced from the OmniGas unit. Failure of the flare will lead to shutdown of operations. Explosion risk is present and certain purge rates must be met to safely operate the flare. This procedure details start up and shut down procedures.

Step	Description	Hazards/Precautions
1	Inspection guidelines are found in separate documentation and should be followed upon installation	Read flare documentation
2	It is required to introduce at least ten (10) system volumes of gas to provide sufficient volume to drop the 02 level to less than 8%. This will be completed during the nitrogen purge and instrumentation test *(CA_SOP_001)*	
3	To prevent air from entering the system from the flare tip during normal operation, a continuous system purge is required. Purge rate is 189 scfh. For pure nitrogen this is equivalent to 14.7 lb/hr.	All flare systems are susceptible to flashback and explosion if not properly purged to keep 02 (air) from entering the system
4	Turn "Panel Power" selector switch (HS-100) to the "ON" position. "Panel Power ON" indicator (XL-100) will illuminate.	
5	Ensure the local ESD push-button (if any) and remote "ESD" push-buttons (if any) are in the normal position	
6	Place the “System OFF/ RUN” selector switch (HS-101) to the “OFF” position	
7	Ensure that Propane is supplied to the Fuel Gas Rack. Open the manual main gas block valve.	
8	The system is configured to operate automatically when the operator selects the “RUN” position. If during the start-up sequence, the operator wishes to terminate operation. Pushing any of the remote or local “ESD” pushbuttons (if any) or by placing the “System OFF/RUN” selector switch (HS-101) in the “OFF” position will stop the flare only if all manual assist and waste gas valves are closed	
9	**To Shutdown the Flare, either:**	
9a)	ESD Pushbutton Depressed	
9b)	Manual fuel gas valves closed	
10	**During Flare Start-up Sequence “Auto”, the Unit will Execute the Following Steps:**	
10a)	Place the “System OFF/ RUN” selector switch (HS-100) in “RUN”	
10b)	Place HET-101 in the on position	
10c)	Place HS-101 in manual position	
10d)	Open manual pilot gas block valve, proceed to energize the ignition transformers HET-101 for 10 seconds by pushing HS=100. Pilot proven indication TAL-101 will extinguish within 60 seconds. Repeat if necessary. This system utilizes a continuous pilot monitor and TAL=101 will illuminate if pilot fails	

10e)	Place HS-101 in the auto position. This system utilizes a continuous pilot C1 monitor and TAL=101 will illuminate if pilot fails	
10f)	The operator may now proceed with introduction of waste gas to the flare	
10g)	"Alarm Light" signal is initiated by contact closure on relay CR-50	
11	**Basic Troubleshooting:**	
11a)	If flare goes into alarm (indicating it has shut down or pilot has failed), check panel for any additional indicator lights. Refer to Flare Troubleshooting guide. If conditions are safe, Attempt to restart flare. **Note:** take handheld CO monitor with you to evaluate a failed flare.	Ensure syngas gas or purge gas is flowing to flare at all times. If flare is non-operational, CO will be emitted to the area. Alert all personnel in the area.
11b)	If flare cannot be restarted after 10 minutes of attemps, put gasifier into idle mode via *CA_SOP_010* until problem can be rectified	

Document Number: CA-SOP-010	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 4/5 - Major Risks Exist	Frequency: 3/5 - Potentially Once Daily

Task Name: Temporary Feed Shutdown (Idle Mode)

General Description:

This procedure will take the gasifier into an "idle mode" where no gas feeds are entering the unit, except for a nitrogen purge. Reaction in the gasifier will stop and temperature will start to drop. If the temperature drops too much from being in idle mode too long, the slag will freeze and the test will be over. Also, re-energizing the gasifier out of idle mode has risks and must be done gradually to avoid shocking the system

Step	Description	Hazards/Precautions
	NOTE: In many cases, the unit has been purged and flare is shut down prior to this idle mode. If the flare is to be shut down, it is ideal to purge the gasifier first. However, it it critical, upon restarting the flare to purge the entire unit with nitrogen for 10-15 mintues at 40 lb/hr.	
1	In the control room, record the flowrates of feed *(HI_B_02)* , oxygen *(FI_O_01)* , steam *(FI_W_01)* and nitrogen *(HI_N_01)* . This will be the target values upon restarting.	Feed __________ Oxygen ____________ Steam __________ Nitrogen
2	In the field, turn off the feed auger motor by turning control knob to lowest/off position *(VFD)* .	Elevated work
3	In the control room, open the nitrogen bypass valve *(FXV_N_02)* . Close the oxygen and steam actuated shut off valves *(FXV_O_01, FXV_W_01)*	
4	In the field, shut and lock-out the oxygen and steam flow control valves *(FCV_O_01, FCV_W_01).*	Steam valve may be hot, use gloves. Use lock-out tagout procedures to ensure no accidental entry of oxygen to reactor
5	In the field, adjust nitrogen flow control down to 30 lb/hr *(FCV_N_01)* .	
6	In the field, ensure nitrogen is going to both parts of the lance by ensuring manual valve at N2 bypass *(FCV_N_03)* is open and by examining local flow indicator *(FI_N_02).*	Insufficient N2 flow to both parts of the lance will allow slag into lance and will plug the lance
7	In the field, reduce water quench to 8 lb/hr by opening quench discharge valve *XV_W_05* . Adjust heat exchanger operation to 15% of normal/full operation via supply valve *XV_W_03* . Refer to Cooling Coordination Spreadsheet for additional detail.	Use quench supply and discharge flow indicators *(FI_W_04/05)* to calculate quench flow to reactor.
8	Ensure that pressure in the gasifier is stable and above 1 psig *(PI_G_01).*	
9	Ensure that gasifier temperature is not dropping too rapidly. In order to keep the slag from freezing, the bottom temperature probe *(TI_S_01)* must stay above 1250C. If temperature is dropping too rapidly, notify supervision and then: reduce nitrogen flow to 20 lb/hr, reduce quench water to zero, check nitrogen bypass flowrate and reduce if possible	
10	Lower nitrogen flow if possible (*FCV_N_01)* , keeping gasifier pressure positive, but must be kept above 20 lb/hr at all times while flare is in operation.	
	When desired, bring gasifier out of idle mode:	

11	In the field, increase quench flow to 30 lb/hr by closing back quench discharge valve XV_W_05. Increase heat exchanger operation to 60% of full operation via supply valve XV_W_03. Refer to Cooling Coordination Spreadsheet for additional detail.	Use quench supply and discharge flow indicators *(FI_W_04/05)* to calculate quench flow to reactor.
12	In the field, increase nitrogen flow to previous rates (as recorded) via *FCV_N_01.* Monitor nitrogen flowrate, gasifier pressure and downstream syngas flowmeter *(FI_N_01, PI_G_01, FI_S_01)*	
13	In the control room, open the steam and oxygen actuated valves *(FXV_O_01, FXV_W_01)*	
14	In the field, unlock and slowly increase steam and oxygen flow control valves *(FCV_O_01, FCV_W_01)* to 50% of normal. This must be done in conjuction with operator in the control room. Monitor flowrates, gasifier pressure and temperature when doing this. *(FI_O_01, FI_W_01, FI_S_01, PI_G_01, TI_S_01).* **Note:** there may be some condensation in the steam line, therefore open the steam supply valve <u>very</u> slowly and carefully to prevent steam explosion and pressure spike in gasifier	Steam valve may be hot, use gloves. Lock-out tag-out procedures. Monitor gasifier pressure and temperature when
15	In the control room, close the nitrogen bypass control valve *(FXV_N_02)*	
16	In the field, increase feed auger motor to 50% of normal *(VFD, HI_B_02)*	Elevated work
17	In the field, increase quench to ~50 lb/hr and HX to 100%. Again refer to Cooling Coordination and operator associated valves.	
18	In the field, increase feed to 100%. Increase O2 and steam to 100% of normal operations. Operator in control room at all times monitoring various flowrates, temperatures and pressures	Elevated work, hot valves

Document Number: CA-SOP-011	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 3/5 - Minor Risks Exist	Frequency: 2/5 - Once Only

Task Name: Final Gasifier Shutdown

General Description:

Final shutdown of the gasifier will be done once, at the end of the testing run, and generally involves other procedures that are done at points during normal operation (idle mode, slag tap) but importantly includes the unique "Final Slag Tap" procedure that has it's own procedure. Generally, all that remains is shutting down the auxiliary units and closing valves.

Step	Description	Hazards/Precautions
1	When the last silo of feed is empty (indicated by level probe *LALL_B_01*), switch on clamshell heater on slag tap line - this gives roughly 30 minutes of operation time for the line to heat up to desired temperature	
2	Continue normal operations until the feed hopper is empty. This will be indicated by a sudden drop in syngas flowrate *(FI_S_01)* .	
3	Proceed to the normal slag tap sequence procedure. *CA_SOP_005,* but do not restart the flare at the end. Shut down flare if not done.	
4	When the slag tap is complete, nitrogen purge should still be flowing through the lance *(FI_N_01/02)* .	
5	**Operators 1 & 2:** Load and stage a silo of 50% coal and 50% magnetite. The goal of adding this material is to get the slag mix as iron-rich and hot as possible before the final/salamander slag tap. See *CA_SOP_004*	
6	**Operator 1**: Ensure nitrogen supply and bypass actuated valves are open *(FXV_N_01/02)* . Adjust bulk density input for feeder to ~48 lb/ft3. **Operator 2:** Increase nitrogen flow to eductor to 60 lb/hr *(FCV_N_01)* . Start feeder at 5 lb/hr addition *(HI_B_02)* .	Elevated work to adjust feed rate.
7	Immediately after starting feeder: **Operator 2**: Check flow control valve *(FCV_O_01)* is closed. **Operator 1**: Open actuated oxygen supply valve *(FXV_O_01.)* **Operator 2**: Unlock and gradually open oxygen flow control valve *(FCV_O_01).* Increase flowrate in the field to 3x the coal mass rate (flow rate will be visible in control room by Operator 1)	No steam addition and no gasification reactions desired since flare is off.
8	**Operator 1**: Monitor temperatures across gasifier. Combustion will be proved by lower temperature probe. Ensure temperature continues to a maximum of 1375 C *(TI_S_01)* . **Operator 2**: Adjust coal and oxygen flowrate as needed.	
9	When this feeder is empty (again indicated by drop in syngas flowrate), put the gasifier into idle mode with a 20 lb/hr nitrogen purge through the lance *(FCV_N_01)* .	
10	In the field, turn on syngas eductor/venturi (via *XV_S_03* and *XV_N_05)* to drop gasifier pressure to 1 psig *(PI_G_01)* .	
11	Ensure manual (hand) supply valves for oxygen and steam *(SV_O_01, SV_W_01)* are closed and locked	Unanticipated flow of oxygen or steam during final slag tap is highly dangerous

12	Proceed to final slag tap procedure: *CA_SOP_012* . This will be done under slight nitrogen purge to ensure that the lance is kept clear of slag.	
13	Shut off gas analyzer.	
14	Turn off all cooling water to the syngas heat exchangers *(XV_W_03, XV_W_04)*	
15	When slag pot has cooled sufficiently, refer to slag kettle removal procedure *CA_SOP_006* .	
16	Let gasifier cool normally to ambient temperatures. This may take 1-2 days.	
17	When temperature probes show that all gasifier temperatures are <100C, proceed to disassmbly.	
18	Loosen bolts in a star-like pattern on the lance and lid. Remove with crane for inspection and photos.	Elevated work and crane operation.
19	Samples of final slag materials should be sent out for analysis.	
20	Remainder of slag material should be disposed of per prior arrangements	
21	Send out samples of any "dust" captured in the vent piping and heat exchanger	
22	Examine lance, gasifier shell and vent piping for oxidation, pitting, flaking, wall thinning	
23	Gasifier may then be crated and arranged for shipment	

Document Number: CA-SOP-012	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 5/5 - Catastrophic Risks Exist	Frequency: 2/5 - Once Only

Task Name: Final Slag Tap

General Description:

The final slag tap of the gasifier is highly dangerous since it involves drilling out very hot refractory and then allowing for the molten slag to pass through the hole to the outer atmosphere and launder. Personnel must be specifically trained for operating the hammer drill. Tape/barriers must be set up to keep others at a safe distance. Proper PPE must be worn.

Step	Description	Hazards/Precautions
	When gasifier is cold, pre-drill 1" into the refractory at the tapping port to get the drill started for the hot tap	
	Secondary containment will have already been established around the gasifier and around the launder/tapping area	In event of spill or catastrophe, need contaiment for hot slag
	Unsafe levels of H2 and CO are removed via continuous nitrogen purge. Check CO level at syngas sample port before proceeding.	CO___________
	Wear proper high temperature safety clothing, face shield, and gloves.	PPE in place
	Nitrogen purge will remain on throught this procedure. This is to help push the slag out during tapping and to ensure the lance stays clear. However, but pressure will be kept low through use of the venturi	
1	Remove bottom 3" ANSI flange. Nuts will be welded on for ease and safety of bolt removal.	
2	Remove ceramic packing inside the flange/pipe. This can be done with a simple hook to pull on the wire loop connected to the packing.	Proper tools
3	Prepare the overhead crane and 4 lifting lines.	Mobile equipment use, training
4	Install launder on hooks on the gasifier. Lauder will also collect/hold the ~8000 cubic inches of slag that is tapped	
5	Place safety barriers as required around the slag tap equipment. Inspect secondary containment.	
6	Using proper high temperature, long reach hammer drilling equipment, drill through the hot face refractory. Adjust pressure in gasifier via the eductor/venturi if slag is flowing too slowly	
7	Allow molten slag to drain onto the launder. As the slag level reaches the bottom, nitrogen will start to exit the port, causing spitter/spatter of slag. Keep clear of direct line of the port.	
8	Turn off nitrogen flow to the gasifier at manual valve *(SV_N_01)* and control panel (FXV_N_01). Lock out the manual valve.	
9	Wait for any remaining slag to leave gasifier.	
10	Wait for gasifier and launder to cool. This may take 1-2 days.	
11	Attach crane to launder hooks. Carefully move the slag to a safe distance.	

12	Dispose of cooled slag and launder properly.	
	The following steps are done to prepare the gasifier for re-use and may be done on site, or later after gasifier has been shipped/relocated:	
13	Using appropriate ramming equipment and techniques, force a chrome based ramming mix (Rescoram 10CR or similar) into the drilled out hole.	
14	Replace ceramic packing inside the 2 1/2"” pipe.	
15	Clean any slag from the 3” flange face and install a new gasket.	
16	Install the 3” ANSI flange.	
17	Torque the four 5/8” flange bolts to a final torque of 90 ft-lbs each using the appropriate criss-cross pattern.	

Document Number: CA-SOP-013	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 5/5 - Catastrophic Risks Exist	Frequency: 1/5 - Improbable

Task Name: Emergency Shutdown - E-Stop

General Description:

In the event of a major problem or failure, it may be necessary to shut down the gasifier and all components immediately. An "Emerency Stop" button (E-Stop) has been installed to automatically put the gasifier into a safe state when depressed by any operator. However, it is the operators' duty to ensure valves have closed per design and that manual valves are also shut.

Step	**Description**	**Hazards/Precautions**
	Reasons why to press E-Stop: 1) Temperature of the gasifier exceeds 1400 C 2) Pressure of the gasifier exceeds 15 psig and/or burst disk pops 3) Flare failure > 5 min 4) Fire or any evacuation	
	E-Stop button is pressed:	
1	Oxygen supply valve (FXV_O_01) closes	
2	Nitrogen supply valve (FXV_N_01) stays open	
3	Nitrogen bypass valve (FXV_N_02) opens	
4	Steam supply valve (FXV_W_01) closes	
5	Cooling water valve (FXV_W_02) stays open	
6	Fuel gas (propane) valve (FXV_F_01) stays open	
7	Feed auger motor (HS_B_01) shuts down	
8	Power to flare (HS_X_01) should be maintained	
9	Power to clamshell heater shuts down	
	Manually check:	
11	Flowrate on oxygen and steam should drop to zero *(FI_O_01, FI_W_01)*	
12	Feed auger should show 0 rpm (0 lb/hr) *(HI_B_02)*	
13	If possible, close oxygen and steam supply valves in the field *(SV_O_01, SV_W_01)* . Turn auger motor control to 0% *(VFD knob)*	Field conditions must be safe to be turning manual controls near gasifier
14	If gasifier is to remain shut down, wait 5 minutes of nitrogen purge and then test CO with handheld meter at bleed valve by flare.	

	Final Shutdown after E-Stop:	
15	If conditions are safe, management may decide proceed with a slag tap sequence before final shutdown (similar to normal gasifier final shutdown, *CA_SOP_011*)	
16	If conditions are unsafe, management may decide to let the gasifier cool completely under nitrogen purge	
17	Or management may choose simply to shut down nitrogen flow completely, along with flare, propane supply and cooling water	
	Return to Normal Operations	
18	If all conditions are safe and returned to normal, operators may proceed with managmenet approval to re-start the gasifier.	
19	If not yet done, close oxygen and steam supply valves in the field *(FCV_O_01, FCV_W_01)* . Turn auger motor control to 0% *(VFD knob)*	Don't want to start up under full-flow conditions, but do so gradually from zero
20	Return E-Stop button to normal (unpressed) position. Return any flipped breakers to their normal position.	
21	In the field, increase feed auger motor to 25% of normal *(VFD, HI_B_02)*	
22	In the control room, open the steam and oxygen actuated valves *(FXV_O_01, FXV_W_01)*	
23	In the field, slowly increase steam and oxygen supply valves *(SV_O_01, SV_W_01)* and flow control valves *(FCV_O_01, FCV_W_01)* to 50% of normal. This must be done in conjuction with operator in the control room. Monitor flowrates, gasifier pressure and temperature when doing this. *(FI_O_01, FI_W_01, FI_S_01, PI_G_01, TI_S_01).* **Note:** there may be some condensation in the steam line, therefore open the steam supply valve <u>very</u> slowly and carefully to prevent steam explosion and pressure spike in gasifier	
24	In the control room, close the nitrogen bypass control valve *(FXV_N_02)*	
25	In the field, increase feed auger motor to 50% of normal *(VFD, HI_B_02)*	
26	In the field, ensure quench to ~50 lb/hr and HX to 100%. Refer to Cooling Coordination and operator associated valves.	
27	In the field, increase feed to 100%. Increase O2 and steam to 100% of normal operations. Operator in control room at all times monitoring various flowrates, temperatures and pressures	

Document Number: CA-SOP-014	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 5/5 - Catastrophic Risks Exist	Frequency: 1/5 - Improbable

Task Name: Emergency Shutdown - Full Stop

General Description:

There are select conditions when a full stop to the gasifier is required (i.e. no purge with nitrogen attempted). In these cases, the risk of leaving combustible gas in the reactor is outweighed by other risks. These scenarios are VERY rare and a full stop should be seen as a last alternative.

Step	Description	Hazards/Precautions
	Some scenarios for a full stop: 1) Slag starts to come down tap pipe while kettle removal is in progress 2) Gasifier pressure exceeds 30 psig (due to blockage of the vent port) 3) Explosion or fire at the flare	
1	Press the E-Stop button via control room and immediately also close: 1) Nitrogen shutoff 2) Propane supply valve	
2	Depending on the situation, if it is safe to do so, close the manual shutoff valves (in the field) for all nitrogen, steam, oxygen, natural gas	
3	Call management to notify of emergency and direction on how to proceed.	

Document Number: CA-SOP-015	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 4/5 - Major Risks Exist	Frequency: 1/5 - Improbable

Task Name: Power Failure

General Description:

In the event of a power outage, a number of things will happen very quickly, but this is basically a E-Stop sequence. The main risk is for the power to come back on and the system to try and start up all at once.

Step	Description	Hazards/Precautions
	Upon power outage, the actuated valves should fail into their safe position (the same as the E-Stop positions)	
	Upon power outage, no temperatures, flowrates or pressure will be able to be monitored via the control room.	
1	Lighting in the control room and on the pad will remain on, powered by battery and generator	
2	Immediately shut off oxygen pipe at manual valve *(SV_O_01)*	
3	Turn auger motor control knob *(VFD)* to zero	Elevated work
4	Turn nitrogen flow down at manual valve *(FCV_N_01)* to a purge (exact flowrate will not be known, but need to ensure some purge flow is maintanted)	
5	Close manual steam supply valve *(SV_W_01)*	Hot piping, use gloves
6	Verify that flare has automatically shut down and natural gas supply has stopped to flare	
7	Decrease quench supply and HX water supply to a minimum via *XV_W_03/04* . See Cooling Coordination for detail.	
	When power is restored, verify that no material or energy is being added to the gasifier (besides nitrogen purge). <u>If</u> the team decides to try and re-start the reactor, and conditions are safe, do so according to the below modified start-up procedure:	
8	If not yet done, close oxygen and steam supply valves in the field *(FCV_O_01, FCV_W_01)* . Turn auger motor control to 0% *(VFD knob)*	Don't want to start up under full-flow conditions, but do so gradually from zero
9	In the field, increase quench flow to 30 lb/hr by closing back quench discharge valve XV_W_05. Increase heat exchanger operation to 60% of full operation via supply valve XV_W_03. Refer to Cooling Coordination Spreadsheet for additional detail.	
10	In the field, increase nitrogen flow to previous rates (as recorded) via *FCV_N_01*. Monitor nitrogen flowrate, gasifier pressure and downstream syngas flowmeter *(FI_N_01, PI_G_01, FI_S_01)*	
11	In the control room, open the steam and oxygen actuated valves *(FXV_O_01, FXV_W_01)*.	

12	In the field, slowly increase steam and oxygen supply valves *(SV_O_01, SV_W_01)* and flow control valves *(FCV_O_01, FCV_W_01)* to 50% of normal. This must be done in conjuction with operator in the control room. Monitor flowrates, gasifier pressure and temperature when doing this. *(FI_O_01, FI_W_01, FI_S_01, PI_G_01, TI_S_01).* **Note:** there may be some condensation in the steam line, therefore open the steam supply valve very slowly and carefully to prevent steam explosion and pressure spike in gasifier.	
13	In the control room, close the nitrogen bypass control valve *(FXV_N_02)*	
14	In the field, increase feed auger motor to 50% of normal *(VFD, HI_B_02)*	
15	In the field, increase quench to ~50 lb/hr and HX to 100%. Again refer to Cooling Coordination and operator associated valves.	
16	In the field, increase feed to 100%. Increase O2 and steam to 100% of normal operations. Operator in control room at all times monitoring	

Document Number: CA-SOP-016	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 3/5 - Minor Hazards Exist	Frequency: 1/5 - Improbable

Task Name: Compressed Air Failure

General Description:

In the event of a compressed air failure, a number of things will happen very quickly, but this is basically an accelerated idle-mode sequence.

Step	Description	Hazards/Precautions
1	Upon compressed air outage, the actuated valves should fail into their safe position (the same as the E-Stop positions) -Oxygen supply closed -Nitrogen supply open -Nitrogen bypass open -Steam supply closed -Natural gas remains closed -Cooling water remains open	
2	There is no alarm for compressed air failure, but it will be evident via Low Flow Alarm on Oxygen and Steam *(FI_O_01, FI_W_01)*	
3	The feed system must be turned off, either via LabView or the manual control in the field *(HS_B_01)*	
4	Close oxygen and steam manual flow valves in the field *(FCV_O_01, FCV_W_01)*.	
5	If the air compressor(s) can be restored to normal operation fairly quickly (~10 minutes), keep nitrogen at full flow rate *(FCV_N_01)*	
6	If downtime will be > 10 minutes, proceed to throttle nitrogen flow to a minimum purge and adjust quench water to a minimum (open *XV_W_05* all the way)	
7	Upon restoration of compressed air supply, the valves will need to be returned to normal operating positions manually. Proceed to idle-mode start-up sequence.	
8	If not yet done, close oxygen and steam supply valves in the field *(FCV_O_01, FCV_W_01)* . Turn auger motor control to 0% *(VFD knob)*	Don't want to start up under full-flow conditions, but do so gradually from zero
9	In the field, adjust quench flow to 30 lb/hr by closing back quench discharge valve XV_W_05. Adjust heat exchanger operation to 60% of full operation via supply valve XV_W_03. Refer to Cooling Coordination Spreadsheet for additional detail.	
10	In the field, increase nitrogen flow to previous rates (as recorded) via *FCV_N_01.* Monitor nitrogen flowrate, gasifier pressure and downstream syngas flowmeter *(FI_N_01, PI_G_01, FI_S_01)*	
11	In the control room, open the steam and oxygen actuated valves *(FXV_O_01, FXV_W_01)*.	

12	In the field, slowly increase steam and oxygen supply valves *(SV_O_01, SV_W_01)* and flow control valves *(FCV_O_01, FCV_W_01)* to 50% of normal. This must be done in conjuction with operator in the control room. Monitor flowrates, gasifier pressure and temperature when doing this. *(FI_O_01, FI_W_01, FI_S_01, PI_G_01, TI_S_01)*. **Note:** there may be some condensation in the steam line, therefore open the steam supply valve very slowly and carefully to prevent steam explosion and pressure spike in gasifier	
13	In the control room, close the nitrogen bypass control valve *(FXV_N_02)*	
14	In the field, increase feed auger motor to 50% of normal *(VFD, HI_B_02)*	
15	In the field, increase quench to ~50 lb/hr and HX to 100%. Again refer to Cooling Coordination and operator associated valves.	
16	In the field, increase feed to 100%. Increase O2 and steam to 100% of normal operations. Operator in control room at all times monitoring various flowrates, temperatures and pressures	

Document Number: CA-SOP-017	Revision Number: #0
Creation Date: 3/8/13	Revision Date: NIL
Severity: 3/5 - Minor Hazards Exist	Frequency: 2/5 - Unlikely

Task Name: Instrumentation Failure(s)

General Description:

Instrument failures could come in different forms: failure of a single sensor, failure of the signal transmission, failure of computer hardware or software. In any case, it impairs the ability for the operators to understand or control what is going on in the field, but without actually affecting or changing gasifier performance.

Step	Description	Hazards/Precautions
1	These types of instrument failures will be monitored on a case-by-case basis and no comprehensive procedure will be developed at this time.	
2	However, in most cases, the gasifier will continue to run normally, thus giving some time to rectify to failure, and no emergency action is needed. Management should be notified.	
3	In the worst-case scenario, where control of the actuated shut-offs (FXVs) are inhibited, and where even the E-Stop for some reason is inhibited (failure at the control box), proceed immediately to shut off manual supply valves of oxygen and steam *(SV_O_01, SV_W_01)*	
4		

Document Number: CA-SOP-018	Revision Number: #1
Creation Date: 3/8/13	Revision Date: 4/3/13
Severity: 5/5 - Catastrophic Risks Exist	Frequency: 1/5 - Improbable

Task Name: Fire Procedure

General Description:

In case of fire at the gasifier, flare, control room, feed pile or anywhere else at the site, a basic procedure has been developed. In all cases, basic fire safety and fire fighting training apply.

Step	Description	Hazards/Precautions
	All Personnel Should Be Trained on the following: -Know where Fire extinguishers are located through-out. -Fire Extinguisher training. -Provide 3' around all electrical equipment, fire protection devices, heating equipment including kitchen appliances. -Keep 44" clearances in all aisles to all exits at all times. -Know the Areas of Refuge and purpose. -Know secondary exit routes	
	In Event of a Fire:	
1	Remove anyone from immediate danger	
2	Push the emergency stop button, activate building fire alarm and sound airhorn	
3	Call fire response team (or 911) if fire is sufficiently large	
4	Call site and project management	
5	Evacuate the testing pad and control room and reconvene at designated assembly area. Ensure that all personnel are accounted for.	
6	Extinguish the fire, if it can be done safely	

Document Number: CA-SOP-019	Revision Number: #0
Creation Date: 3/8/13	Revision Date: NIL
Severity: 5/5 - Catastrophic Risks Exist	Frequency: 1/5 - Improbable

Task Name: Evacuation Procedure

General Description:

Evacuation procedure for all other types of emergencies.

Step	Description	Hazards/Precautions
1	Hit E-Stop Button	
2	Refer to existing Wyle evacuation procedure	
3		

APPENDIX D:
Several Gas Composition Data Results

SENECACH203 - Calibration Data

661.chr – Start-Up Burner Exhaust

688.chr – Auto-Ignition with Excess Oxygen

742.chr – Sawdust Gasification

746.chr – Sawdust Gasification

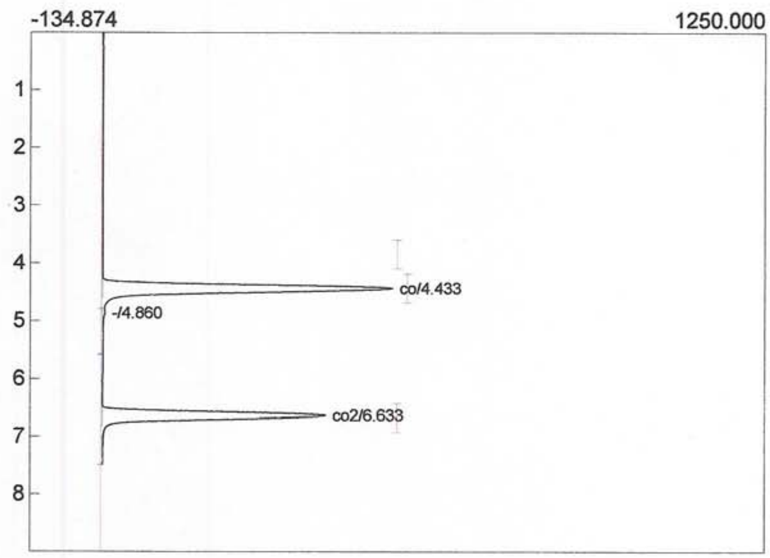
Lab name:
Client: DIVERSIFIED
Client ID: n9283
Collected:
Analysis date: 04/15/2013 15:21:35
Method: VALVE
Description: fid
Column: HAYSEPD MOLE SEIVE
Carrier: he at 22 psi
Data file: SENECACH203. ()
Sample: gases

Temperature program:

Init temp	Hold	Ramp	Final temp
40.00	2.000	20.000	200.00
200.00	10.000	0.000	200.00

Events:

Time	Event
0.100	G ON (ValveRotate)
2.000	A ON (StopFlow)
6.000	G OFF (ValveRotate)
6.000	A OFF (StopFlow)



Component	Retention	Area
co	4.433	4804.8729
co2	6.633	3637.7196
		8442.5925

7% CO

15% CO_2

Lab name:
Client: DIVERSIFIED
Client ID: n9283
Collected:
Analysis date: 04/15/2013 15:21:35
Method: VALVE
Description: tcd
Column: HAYSEPD MOLE SEIVE
Carrier: n2 at 22 psi
Data file: ()
Sample: gases

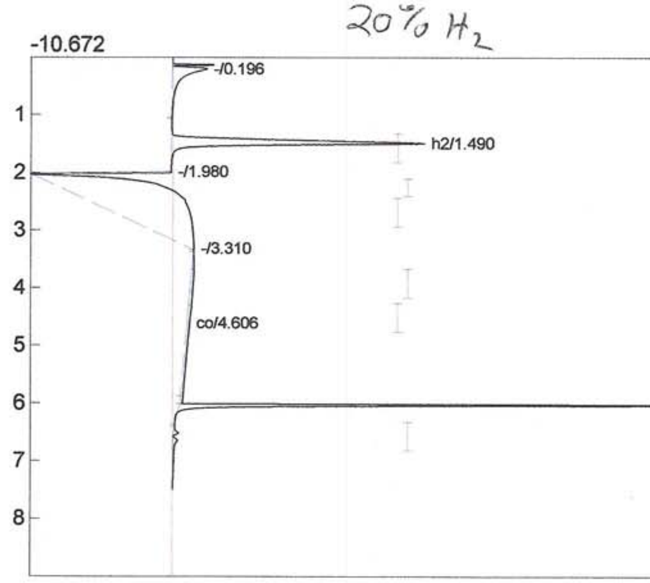
Temperature program:

Init temp	Hold	Ramp	Final temp

Events:

Time	Event
0.000	ZERO

20% H_2



Component	Retention	Area
h2	1.490	102.3364
co	4.606	12.3664
		114.7028

Lab name: SRI Instruments
Client: Valued Customer
Analysis date: 04/27/2013 19:16:01
Method: Syringe Injection
Description: FID-CHANNEL 1
Column: RESTEK 15METER MXT-1
Carrier: HELIUM AT 5 PSI
Data file: 661.CHR (C:\data\DEC GC data)
Sample: RUN1
Comments: TYPE YOUR COMMENTS HERE

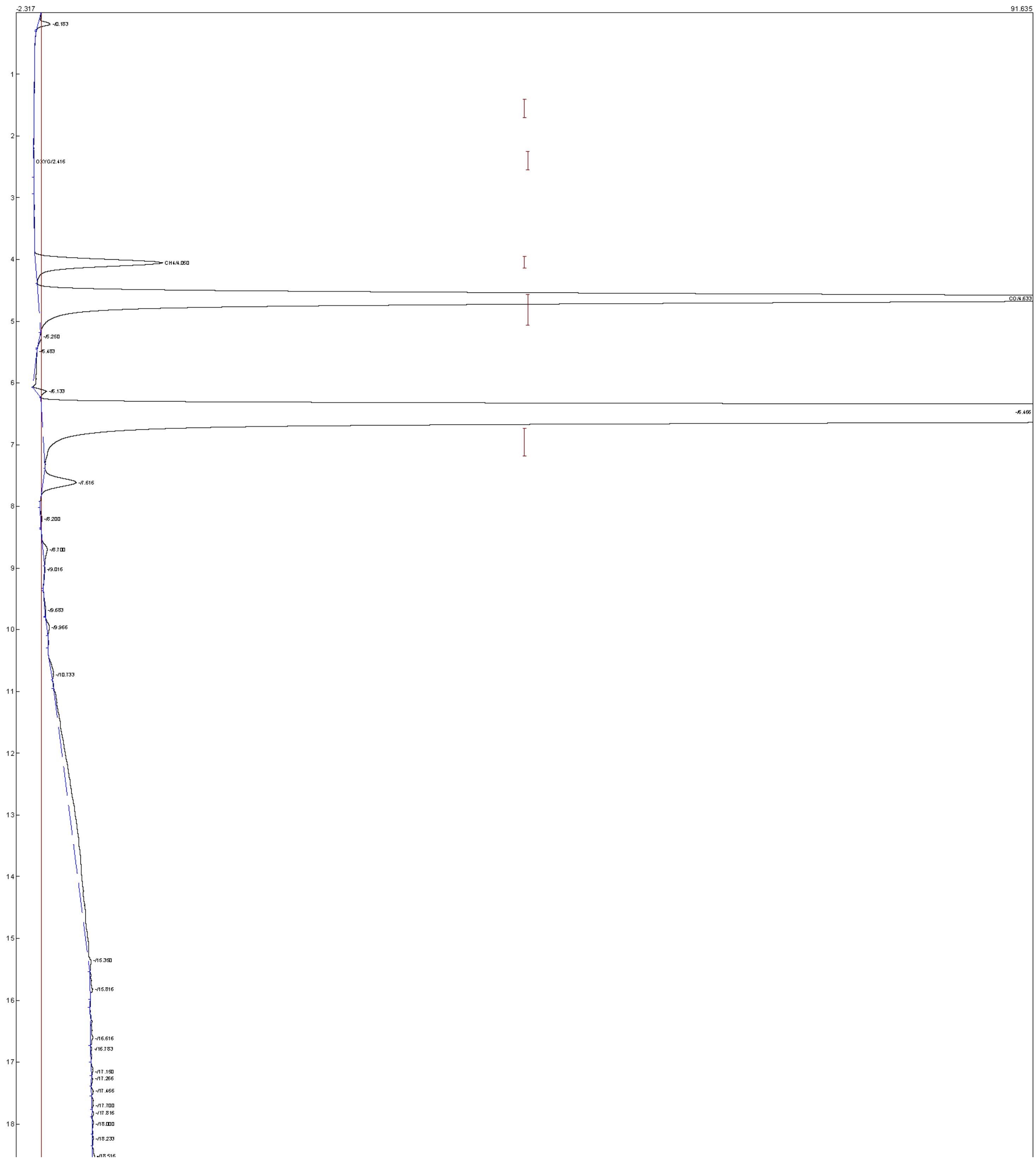
Temperature program:

Init temp	Hold	Ramp	Final temp
40.00	2.000	20.000	200.00
200.00	10.000	0.000	220.00

Events:

Time	Event
0.000	ZERO
0.100	G ON (Valve Rotate)
2.000	A ON (Stop Flow)
6.000	G OFF (Valve Rotate)
6.000	A OFF (Stop Flow)

Component	Retention	Area	Height	External	Norm area % Units	Area %
H2	0.000	0.0000	0.000	0.0000	0.0000	0.0000
OXYG	2.416	0.5060	0.045	0.0000	N/D	0.0065
CH4	4.050	99.6945	11.750	0.0000	N/D	1.2746
CO	4.633	1249.6420	122.210	0.0000	N/D	15.9766
CO2	0.000	0.0000	0.000	0.0000	0.0000	0.0000
		1349.8425		0.0000	100.0000	100.0000



-2.317
91.635
0.183
OXYG/2.416
CH4/4.050
CO/4.633
5.250
5.483
6.133
6.466
7.616
8.200
8.700
9.016
9.683
9.966
10.733
15.350
15.816
16.616
16.783
17.150
17.266
17.466
17.700
17.816
18.000
18.233
18.516

Lab name: SRI Instruments
Client: Valued Customer
Analysis date: 04/28/2013 06:31:03
Method: Syringe Injection
Description: FID-CHANNEL 1
Column: RESTEK 15METER MXT-1
Carrier: HELIUM AT 5 PSI
Data file: 688.CHR (C:\data\DEC GC data)
Sample: RUN1
Comments: TYPE YOUR COMMENTS HERE

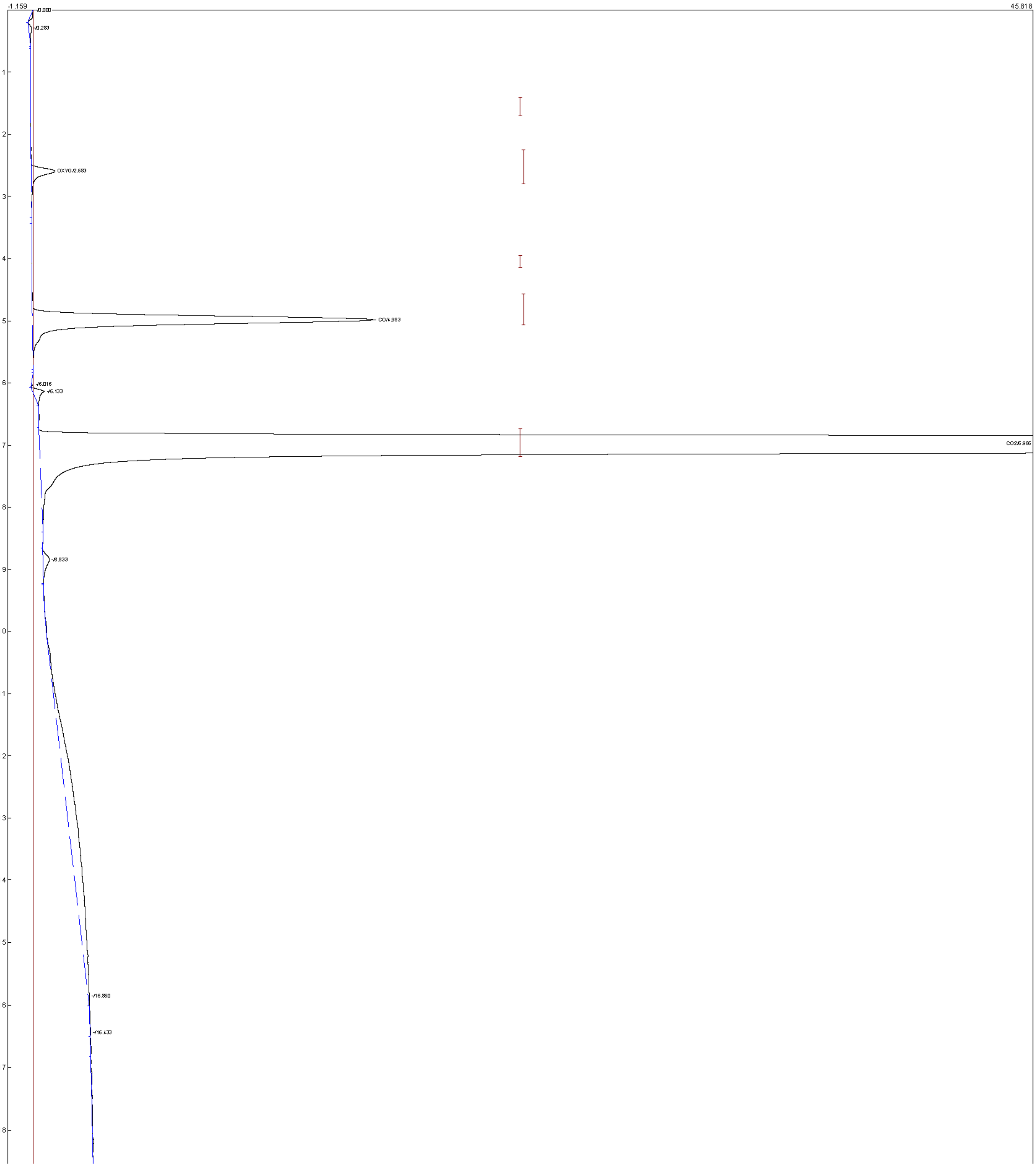
Temperature program:

Init temp	Hold	Ramp	Final temp
40.00	2.000	20.000	200.00
200.00	10.000	0.000	220.00

Events:

Time	Event
0.000	ZERO
0.100	G ON (Valve Rotate)
2.000	A ON (Stop Flow)
6.000	G OFF (Valve Rotate)
6.000	A OFF (Stop Flow)

Component	Retention	Area	Height	External	Norm area % Units	Area %
H2	0.000	0.0000	0.000	0.0000	0.0000	0.0000
OXYG	2.583	9.6400	1.097	0.0000	N/D	0.2104
CH4	0.000	0.0000	0.000	0.0000	0.0000	0.0000
CO	4.983	145.1970	15.756	0.0000	N/D	3.1688
CO2	6.966	4330.2390	397.119	0.0000	N/D	94.5027
		4485.0760		0.0000	100.0000	100.0000


-1.159
45.818
0.000
0.283
OXYG/2.583
CO/4.983
6.016
6.133
CO2/6.966
8.833
15.850
16.433
1
2
3
4
5
6
7
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Lab name: SRI Instruments
Client: Valued Customer
Analysis date: 04/30/2013 19:25:59
Method: Syringe Injection
Description: FID-CHANNEL 1
Column: RESTEK 15METER MXT-1
Carrier: HELIUM AT 5 PSI
Data file: 742.CHR (C:\data\DEC GC data)
Sample: RUN1
Comments: TYPE YOUR COMMENTS HERE

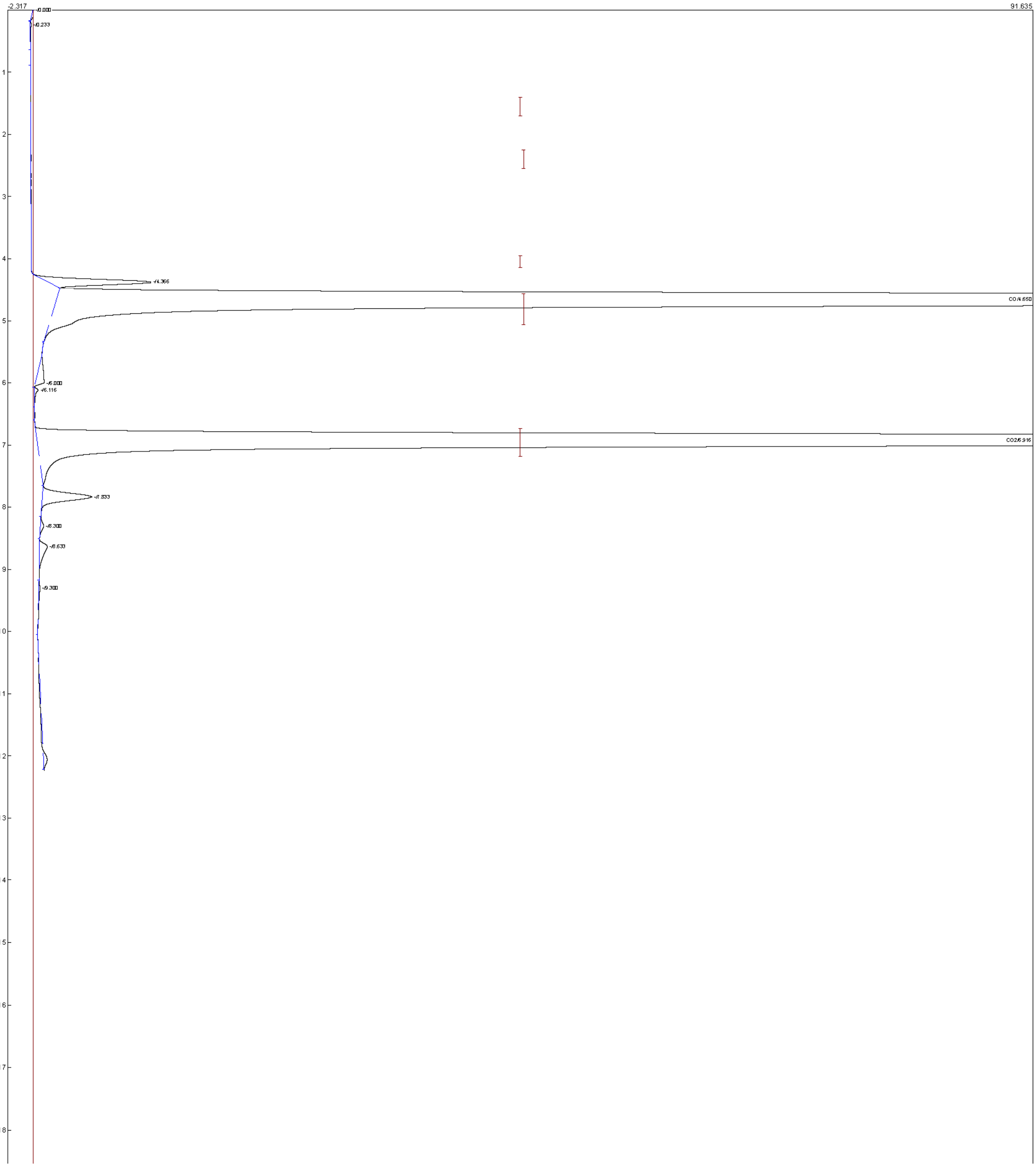
Temperature program:

Init temp	Hold	Ramp	Final temp
40.00	2.000	20.000	200.00
200.00	10.000	0.000	220.00

Events:

Time	Event
0.000	ZERO
0.100	G ON (Valve Rotate)
2.000	A ON (Stop Flow)
6.000	G OFF (Valve Rotate)
6.000	A OFF (Stop Flow)

Component	Retention	Area	Height	External	Norm area % Units	Area %
H2	0.000	0.0000	0.000	0.0000	0.0000	0.0000
OXYG	0.000	0.0000	0.000	0.0000	0.0000	0.0000
CH4	0.000	0.0000	0.000	0.0000	0.0000	0.0000
CO	4.650	3176.7750	326.705	0.0000	N/D	54.3175
CO2	6.916	2549.0735	257.578	0.0000	N/D	43.5849
		5725.8485		0.0000	100.0000	100.0000


-2.317
91.635
CO/4.650
CO2/6.916

Lab name:	SRI Instruments
Client:	Valued Customer
Analysis date:	04/30/2013 21:16:32
Method:	Syringe Injection
Description:	FID-CHANNEL 1
Column:	RESTEK 15METER MXT-1
Carrier:	HELIUM AT 5 PSI
Data file:	746.CHR (C:\data\DEC GC data)
Sample:	RUN1
Comments:	TYPE YOUR COMMENTS HERE

Temperature program:

Init temp	Hold	Ramp	Final temp
40.00	2.000	20.000	200.00
200.00	10.000	0.000	220.00

Events:

Time	Event
0.000	ZERO
0.100	G ON (Valve Rotate)
2.000	A ON (Stop Flow)
6.000	G OFF (Valve Rotate)
6.000	A OFF (Stop Flow)

Component	Retention	Area	Height	External	Norm area % Units	Area %
H2	0.000	0.0000	0.000	0.0000	0.0000	0.0000
OXYG	0.000	0.0000	0.000	0.0000	0.0000	0.0000
CH4	0.000	0.0000	0.000	0.0000	0.0000	0.0000
CO	4.733	1594.6850	174.370	0.0000	N/D	49.2550
CO2	6.950	1496.5525	164.180	0.0000	N/D	46.2240
		3091.2375		0.0000	100.0000	100.0000