



Executive Summary
*Extended Operational Runs on Emery Hybrid
Gasifier to Accelerate Commercial Adoption*

Prepared for
University of Wyoming
Clean Coal Technologies Research Program

December 19th, 2012

Submitted by:

Emery Energy Company, LLC

159 Pierpont Avenue

Salt Lake City, Utah 84101

Phone: 801-364-8283

E-mail: bphillips@emeryenergy.com

Introduction

Emery Energy Company has successfully completed the extended testing of our proprietary *FlexFeed*[™] Gasification system. Through Emery Energy's 2009 Clean Coal Technologies Research Program award, along with monies from our 2008 award, we were able to complete construction and commissioning of the Gasification System. Emery also recently accrued additional operational hours on Wyoming coal that were not yet completed within the 2008 award.

Emery Energy was able to complete “proof of concept” and extended run-hour tests that were the critical next steps in the technology commercialization process. Emery's ability to develop predictability and reliability on the start-up, shut down and steady state conditions represents a significant milestone of the development and technical performance of the *FlexFeed*[™] Gasifier technology. This activity has helped reduce the risk of subsequent and ongoing development activities toward engineering scale up activities and will increase the appeal of the technology to potential licensees.

Objectives

Successful commercialization of a new gasification technology and its components requires that the system demonstrate long term operation without significant operational or maintenance issues or that those issues can be identified and mitigated. A minimum of 1,200 run hours was planned to enable data acquisition necessary to support scale up engineering and allow for potential users to establish a performance baseline and to evaluate system reliability. The objectives of this project included:

1. Demonstrate operational reliability of the technology

2. Obtain critical operational data necessary for subsequent engineering scale up.
3. Use operational data to begin ASPEN modeling efforts for various use scenarios of the technology for liquid fuels and chemicals production
4. To support ongoing commercialization and adoption of the technology by industry and merchant and project developers

Additionally, Emery was able to:

- 1) Demonstrate coal-to-syngas technical performance including:
 - Syngas composition
 - Hot gas efficiency
 - Coal feeding
 - Ash removal and handling
- 2) Demonstrate feedstock flexibility for biomass co-feeding in which co-feed blends by energy included: 5%, 10% and 15% by energy wood chips
- 3) Gain system and operator experience in the Wyoming climate

Results

Overall Run Description

The gasifier was run in both oxygen and air blown gasification modes. Coal was used as the primary feedstock along with wood chips and coal-wood blends (5%, 10% and 15% energy blends). There were 1367 hours of runtime accumulated. More than 80% of the gasification time was accrued in oxygen-blown mode with rest of the time in air-blown mode. Below is a summary.

Coal Run Duration Summary

Run #	Warming Bed	Feed		Running Hours		
	Start Date	Start Date	Stop Date	Run Duration	Feed Duration	Air Gasification
1	19-Mar	22-Mar	23-Mar	96.67	28.25	NA
2	27-Mar	27-Mar	29-Mar	55.23	50.4	NA
3	7-Apr	8-Apr	13-Apr	141.02	127.8	NA
4	5-Aug	6-Aug	8-Aug	59.82	52.8	76.8
5	15-Aug	16-Aug	16-Aug	22.45	14.95	13
6	17-Aug	18-Aug	22-Feb	99.62	89.53	29
7	27-Aug	28-Aug	1-Sep	110.13	84.08	17.3
8	6-Sep	7-Sep	14-Sep	197.67	187.65	23.5
9A	19-Sep	19-Sep	22-Sep	81.48	70.8	2.1
9B	24-Sep	24-Sep	27-Sep	59.22	58.6	11.4
10	2-Oct	2-Oct	5-Oct	56.28	48.28	3.1
11	11-Oct	12-Oct	25-Oct	333.8	321.75	26.27
12	27-Oct	28-Oct	29-Oct	53.8	42.5	9.5
Total				1367.19	1177.39	211.97

Facility Description

Gasifier

The gasifier is an ASTM Section 1 Division VIII code pressure vessel rated for 125 psig with a feed inlet on the top and the ash removal on the bottom. The syngas exit is located on the upper third of the vessel. The vessel is 17' tall and 5' in diameter. It's equipped with temperature readings in various locations, pressure readings on top and bottom and level indicators inside the top of the vessel. The gasifier walls are insulated with 6" of refractory and there's an internal hood.



Other Major System Components Include:

- Feed System - a maximum rate of 880 lb/hr (10.6tpd) for coal
- Plattco Valves – To remove ash from the gasifier
- Flare – Vents off gases
- Gas Analyzers – Gas analysis for H₂, CO, CO₂, O₂ CH₄

- Steam Generator - maximum capacity of steam generation is 1,380 lb/hr at sea level of steam at 125 psig.
- Industrial Gas Supply – Oxygen and nitrogen supply
- Natural Gas Burner – Heat the gasifier during startup
- Startup Air Blower – Supply air to the gasifier and burner in startup conditions
- Air Compressors – Operates many of the air actuated instruments
- PLC / HMI – Instrumentation Control System

Methods

Operational Methods

During steady state operations a target O₂ to steam-to-coal feed ratio was maintained. Temperatures in the bed and gas compositions from the syngas exit piping were continuously monitored. Hourly rounds were also done by an operator to monitor the various plant systems to make sure they are running safely and to identify and locate gaps (if any) between data entering the HMI vs. readings on the plant equipment.

Feedstock

The coal used was PRB Black Thunder coal provided by Arch Coal. It ranged from ¼” to 1 ½” in size. The moisture content was 20-25% and the average volatile matter was 33%. The wood used was Lodgepole Pine Phyllis ID 124 woodchips. It ranged from ¼” to 1 ½” in size. The moisture content was 11-15 % and the average volatile matter was 85%.

Emery was able to test up to 15% wood feedstock (on an energy input basis) which happened to equate to a 1:1 on a volume basis. Blending biomass is an important feature as it can have positive impacts on lowering the carbon footprint of resulting products, even before carbon capture and sequestration (CCS) are added.

Technical Information

Some data is provided for all runs however Runs 7, 8 and 11 were selected for more detailed analysis as they were the most consistent. These runs accrued 642 hours combined which is a good representation of how the system evolved with growing familiarity of operations.

Selected Run Analysis Summary - Dry Basis				
Parameter	Measurement	Run 7	Run 8	Run 11
H2	Mole Fractions	34%	40%	43%
CO	Mole Fractions	12%	19%	18%
CO2	Mole Fractions	32%	25%	30%
CH4	Mole Fractions	2%	16%	9%
Temperature	°F	1388	1593	1438
Coal Feed	lbs/hr	208	264	198
Oxygen Flow	lbs/hr	82	97.4	100
Steam flow	lbs/hr	160	231	166
O2/Coal	Ratio	0.39	0.37	0.51
Steam/Coal	Ratio	0.77	0.88	0.84

Summary of Run #7

The total runtime was 110 hours on gasification with 17 hours on air-blown gasification and balance were oxygen-steam blown. The average gas composition during the oxygen blown gasification on dry basis was 16.1 % CH₄, 19.4% CO, 24.5% CO₂, and 40% H₂. The run was 100% coal with a total of 11.2 tons fed to the reactor. The oxygen/coal ratio was 0.37 and the steam/coal ratio was 0.88 on weight basis. Average high bed temperature during gasification was 1593°F. The average heating value of the syngas on a dry basis was 373 BTU/scf.

The energy balance for the run resulted in a total of 237 MMBTUs supplied to the reactor using the heating value of the feedstock. The energy delivered by the gas was 230 MMBTU. This resulted in a gas thermal efficiency of 97% and rest of the energy was lost. The mass balance that was 94.4%

Summary Run #8

The total time accrued was 197 hours out of which 24 hours were on air-blown gasification and rest on oxygen-steam blown. The average gas composition during the oxygen-blown gasification on dry basis was 10.9 % CH₄, 16.4% CO, 29.6% CO₂, and 38.2% H₂. There was 15 tons of coal was fed with a small run utilizing 15% coal/wood blend. The oxygen/coal ratio was 0.51 and the steam/coal ratio was 1.3 on weight basis. Average high bed temperature during the gasification was 1388°F. The average heating value of the syngas on dry basis was calculated to be 302.8 BTU/scf.

The energy balance for the run resulted in a total of 323.4 MMBTUs supplied to the reactor using the heating value of the feedstock adjusted to the moisture content. The energy delivered by the gas measured in scf was 307.5 MMBTU. This resulted into a gas thermal efficiency of 95.8% and rest of the energy was lost. The mass balance was 93.8%

Summary for Run #11

The total time accrued on the run #11 was 334 hours of which 26 hours were on air-blown gasification and rest were oxygen-steam blown. The average gas composition during the oxygen blown gasification on dry basis was 8.8 % CH₄, 17.9% CO, 29.7 % CO₂, and 42.6% H₂ as measured by the continuous gas analyzers. A total of 26.7 tons of coal was fed including a few hours of 10% wood blend. The oxygen/coal ratio was 0.44 and the steam/coal ratio was 1.12 on weight basis. Average high bed temperature during the gasification was 1438°F. The average heating value of the syngas on dry basis was 300.4 BTU/scf.

The energy balance for the run resulted in a total of 675 MMBTUs supplied to the reactor using the heating value of the feedstock adjusted to the moisture content. The energy delivered by the

gas measured in standard cubic feet was 495 MMBTU. This resulted in a gas thermal efficiency of 73.3 % and rest of the energy was lost. The mass balance analysis produced around 99% of mass balance based on feed supplied to the reactor.

Analysis

Quality of Syngas

Syngas composition can vary greatly due to the parameters of the gasifier such as the bed height and depth, as well as operational conditions such as bed temperature, steam/coal/oxygen ratio and feed rate.

The average oxygen-blown syngas composition was 10% Methane, 40% Hydrogen, 20% Carbon Monoxide, 30% Carbon Dioxide. When operating in air-blown mode, typical composition was 2% Methane, 15% Hydrogen, 20% Carbon Monoxide, 15% Carbon Dioxide and the balance Nitrogen. The syngas produced from all runs was very typical of a fixed bed dry bottom updraft gasifiers such as Lurgi, which at atmospheric pressure produce syngas compositions ranging from 4-16% CH₄, 11-22% CO, 24-35% CO₂, 34-43% H₂ in oxygen gasification mode.

During Run 11 multiple syngas samples were taken for outside analysis, which confirmed the plant's gas analysis measurements within an acceptable margin of error. The NOVA gas analyzer read slightly higher H₂ and methane and proportionally low CO. The CO₂ reading was equal in both analyses.

Energy and Mass Balances

The energy and mass balance analyses were completed using the coal/wood, steam, oxygen and air feed rates. The mass flow meter on the syngas line had several problems in giving correct readings due to tar deposition and particulate. Hence, the mass and energy balance was carried

out by balancing the carbon from the feed and the gas composition obtained from the gas analyzers.

Most of the mass balances were near equal for carbon as the carbon balance was forced and hydrogen and oxygen were off (by +/- 15%) due to unestimated carbon dioxide during the starting combustion stages. The energy balance was within a range of 70-99%.

Ash Analysis

- **TCLP**- Metal analysis for Chromium, Arsenic, Selenium, Silver Cadmium, Barium and Lead levels. The results showed that all samples were under the reporting limit.
- **Carbon Conversion** - Conducted using the standard ASTM D5373 method by Wyoming Analytical to analyze the carbon contained in the ash. This was used to calculate system efficiencies and energy and mass balances.
- **Proximate Analysis on Flare Char** – The results confirmed the presence of coal fines traveling down the piping to the flare.

High Altitude Performance

Emery wasn't able to directly quantify benefits of its system for high altitude. However, the Emery technology, with higher cold gas efficiency compared to entrained flow gasifiers, ultimately reduces the amount of oxygen required in coal gasification plants which has a direct benefit in by lowering electrical power and compressor demand.

Major Operation/Design Challenges

The average feed rate for the gasifier was 221 lbs/hr with a maximum feed rate of 5.3 TPD. The following issues have been identified as bottlenecks in reaching the 10 TPD rate.

Design Modification

The gasifier had to be modified due to damage during initial shakedown runs. The gasifier has a concentric cylindrical steel vessel (“hood”) attached internally which was 7-1/2’ in length but it was trimmed to 3-1/2’. After, the syngas started blowing a lot of fines in the exit line. When the temperatures in the exit piping dropped ($>180^{\circ}\text{F}$), the outgoing tars were deposited on the walls of the exit piping. The fines mixed with the tars and stuck to the piping reducing the diameter.

Steam Boiler

For a 10 TPD coal feed rate the required steam feed would be 951 lb/hr. The actual steam output of this unit was limited to 662 lb/hr. This output was due to altitude of 7,200 ft. above sea level and some general mechanical issues.

Flare

The flare design caused many operational challenges and delays. The original design of the flare tip flame arrestor had a 1/32” honeycomb which plugged as soon as it saw significant particulate or tar loading. Redesigned burner tips helped improved the systems ability to reduce clogging.

Fine Carry Over

The fines entered the gasifier through the coal delivered and fines were also created during the feed delivery process. Fines settled in the walls of the piping, particularly in the bends of the piping creating build up. The fines also stuck to the tar buildup in the piping.

Ash Removal

The first challenge was the location of the discharge leg which when emptied; the coal bed would fill in the discharge leg with the bed directly above it causing an uneven bed. Also, when discharge was too fast there’d be dried coal and hot embers repositioned atop of the

discharge plate creating a possible dangerous situation. When ash removal was too slow, the bed continued to rise higher which potentially could have allowed feed to travel downstream.

Eventually sustainable rates were achieved.

Start Up Burner and Blower

The startup blower has limited capacity and can only provide up to 500 scfm air which is divided into 300 scfm for the startup burner and the rest for the gasification startup.

Future Product Outcome Scenarios

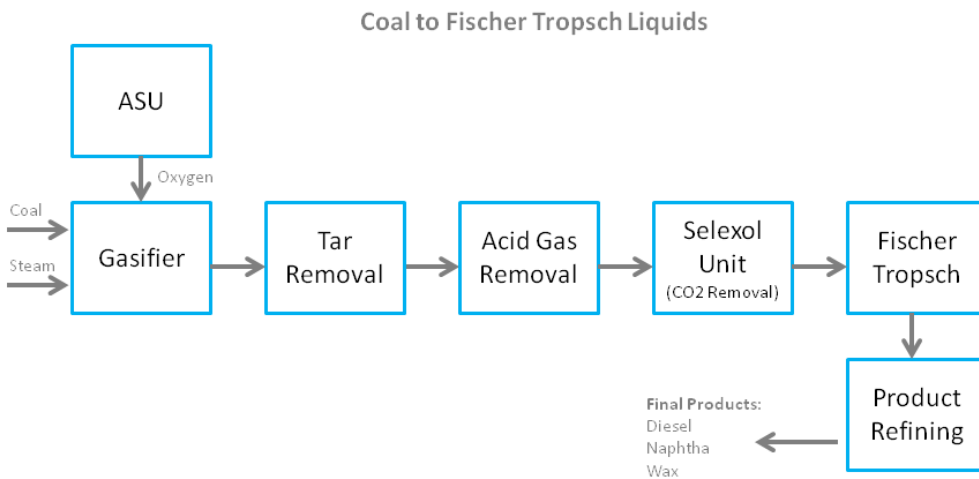
In addition to Fuels and Chemical product schemes for commercial scale plants, Emery Energy originally considered (and proposed) evaluating the production of electrical power and substitute natural gas (SNG) as potential pathways for commercial projects. However, since the beginning of this project, the market conditions have changed significantly (due to new discoveries of shale gas), that has resulted in very low prices for both natural gas and electrical power. As such, it did not make sense to evaluate commercial applications that related to power or SNG. Rather, our analysis has focused on two product areas including: Fischer Tropsch Diesel fuel production and Gasoline production. Both of these products streams have maintained much higher values (on an energy basis) than power or SNG.

Block Diagrams

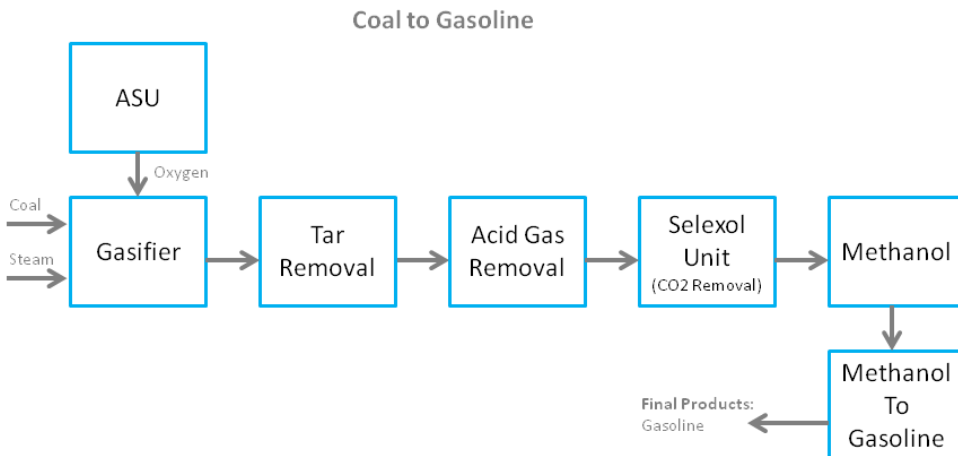
Coal to Fischer Tropsch Liquids

The block diagrams below represent the basic sequence of the major ‘process islands’ required to produce the final product. In both cases, note that ‘tar removal’ is included. This is based on the system demonstrated in Laramie, that didn’t include the entrained flow sections, which may eliminate the need for this island, further reducing costs and complexity of the plant. Also, there

isn't a 'water-gas shift' section in either of the plants, as the data from the Emery gasifier already produces a minimum of 2:1 H₂:CO. In the Coal-to-Fischer Tropsch Liquids case, we don't try to define final product mix, as there are many variables when selecting technology providers for the islands, including catalyst type and resulting product mix (i.e. ratio's of diesel, naphtha, wax, tail gas, etc.). Hence the final product is simplified as 'diesel.' Selexol also removes H₂S.



In the case of Coal-to-Gasoline, it's assumed to be the ExxonMobil MTG™ process, and hence the product is only gasoline and doesn't have the variables/options that Fischer Tropsch does.



Aspen Modeling

Emery conducted capital cost estimating for a 1,000 ton/day commercial demonstration plant for the gas cleaning and conditioning island based on actual average syngas characteristics from the test runs. The results totaled approximately \$41 Million. However, this is just one component of an overall capital cost model which still needs to be further developed in subsequent design and engineering scale up activities in order to confirm whether it is high or low and how it relates to overall balance of plant costs.

The ASPEN modeling conducted by Emery targeted a 1,000 ton/day coal gasification facility. This size was selected as the likely minimum size to make economic sense, while limiting the Emery technology 'scale-up' to a commercial scale demonstration. Hence it is important to note that one cannot compare 'apples-to-apples' of Emery's technology to others, due to the scale difference. Furthermore, it was not practical, based on the limited amount of monies and data collected during the recent operations, to extrapolate Emery's technology to large-scale commercial plants that are based on much larger scale entrained flow gasifiers. This activity needs to come as a result of future scale up engineering work in order to more firmly quantify the specific costs and benefits of the Emery technology compared to other technologies. As such, the Emery ASPEN modeling was limited to the gas processing from the outlet of the Emery gasifier to the production of methanol. Doing this focused the modeling efforts and system requirements to be based on actual syngas characteristics resulting from the Laramie facility. This is referred to as inside battery limits or ISBL. Outside the battery limits (OSBL) for the sake of overall capital costs estimates, Emery used figures derived from the Idaho National Laboratory Technical Evaluation Reports and simply used 'scale factoring' in order to match the

size of the modeled Emery plant. Below is a narrative describing the approach and unit operations actually modeled.

The Emery syngas to methanol process was simulated using Aspen plus. The syngas from the Emery gasifier enters the system at 15 psia. It is then compressed to 660 psia before entering the Selexol unit. In the Selexol unit the H₂S and a portion of the carbon dioxide are adsorbed in a diethanolamine solvent. The syngas is then compressed to 951 psia. The syngas then enters a heat exchanger to preheat the gas before entering the methanol reactor. The gas then enters a zinc oxide guard bed to reduce the H₂S concentration to around 2 parts per billion. The gas exiting the methanol reactor is used to preheat the methanol feed gas. In the methanol reactor carbon monoxide reacts with hydrogen to form methanol. There are almost no other compounds formed in the methanol reactor. Unreacted syn gas and methanol leave the system through a pressure reducing valve. The methanol yield from syn gas is around 11%. By recycling the gas exiting the methanol reactor the yield can be increased to 40-50%. Emery has modeled the reactor based on the Air Products liquid phase methanol process. The reaction of CO and H₂ to produce methanol is highly exothermic. The Air Products process uses an ebulated bed to improve the heat transfer from the system. This enables them to achieve a 40% conversion per pass compared to other processes which gives a 20% conversion.

The Aspen Process Economic Analyzer was used to estimate the plant costs. This involves loading the process flowsheet information including temperatures, pressures and flows along with unit operations information into the program. Based on this information the program designs the equipment and estimates the cost of each equipment item. The total equipment

estimate is \$14.9 million. The program then estimates the total installed plant cost which is \$48.6 million. This includes piping, instrumentation, foundations etc. Emery has scaled down an estimate prepared by INL in 2011 and obtained a value for the methanol synthesis plant of \$42 million.

Conclusions and Recommendations

Equipment Recommendations:

In order to continue to improve operations and reliability at the Laramie facility, we recommend the following:

- Increase steam generator capacity by replacing existing system with a new plant with a minimum of 1,200 – 1,500 lbs/hour of steam capacity (vs. the ~600 lbs currently).
- Add second set of gas analyzers to capture live syngas data at 2 points in the syngas exit.
- Redesign the flare to have larger orifice plate and install knock out drum.

Emery Technology

The Laramie pilot facility is a partial embodiment of the full Emery technology. Due to total limited monies available to Emery for the development and operations of this project, Emery still has remaining technology objectives that relate to potential future testing at the Laramie facility and/or things that can be implemented at larger scale commercial demonstrations. Below we define these technology components in the context of the Laramie facility:

- 1) Demonstrate the entrained-flow component of the Emery technology by either:
 - a. Building an adjacent dedicated reactor that discharges its hot syngas into the existing flanged ports of the current gasifier (size, configuration TBD)

- b. As an alternate to the above, use a natural gas partial oxidation reactor to product hot syngas to discharge into the existing flanged ports
- 2) Replace dry-bottom ash removal with a 'slagging' bottom by designing an alternative bottom to the gasifier (the plant is already flanged to enable this future modification)
- 3) Determine tar destruction benefit of the above approaches, to reduce gas cleaning

Conclusion

Emery achieved significant progress during extended operational testing at the Laramie facility. Over a course of 12 runs, Emery was able to achieve over 1367 hours of operation using PRB coal and producing a syngas suitable for conversion to fuels and chemicals. The challenges experienced included the following: 1) limited ability to monitor exact location of gasifier bed (coal) depth due to nonfunctional technology choice on the probes; 2) inability to produce enough steam which in turned limited our overall throughput capacity to 6 tons/day of coal; 3) intermittent challenges with the flare operation, for which most were overcome in the end.

Key objectives were met including: 1) proof of concept (i.e. fixed-bed gasification technology demonstration on PRB coal); 2) regular and reliable coal lump coal feeding; 3) mostly reliable ash/solids discharge from the bottom of the gasifier; 4) the ability to run on oxygen as well as air; 5) the ability to collect operating data (temperatures, pressures, gas analyses, etc.) using our automated PLC and HMI interfaces; 6) the ability to gain 'operator experience'.