Biomass Pyrolosis for Tar and Gas Production

David Domermuth, Ph.D.

Abstract – Wood tar, commonly called creosote, is as old as fire. The search for alternative energy has brought green research full circle back to this commodity. This paper describes the current research efforts at Appalachian State University with pyrolytic conversion of biomass to useful products. The current aspect of this project is the condensation of wood tar, green washed to be called biocrude. This process of biomass gasification has six potential revenue products and is the most likely candidate for economic viability; waste stream elimination, biochar production, biocrude production, heat, carbon sequestration, and fuel gas. The work is sponsored by an EPA, P3 student grant. The paper also reflects on student interaction and the merits of research based teaching.

Keywords: gasification, biocrude, Biovolitilization, producer gas, pyrolosis, renewable energy, biochar.

INTRODUCTION

Biomass has roughly one third the energy density of conventional liquid fuels; and the energy extraction can be very inefficient [1]. These two factors make biomass, alternative energy research very challenging. The ongoing research efforts reported in this paper are the culmination of four years of testing and improvements. All of the popular, pyrolitic conversion methods tested so far have not been economically viable, including conventional, downdraft gasification and a number of biochar production methods. A process has been developed that is not currently reported in the literature; so it was given the title, Biovolitilization or BV for short. This is by no means a new process, but the methods and purposes are combined to form a unique system. Initial tests of this process have been favorable and scaled up designs have been constructed and are being tested. The development of BV also produced a new concept of a biomass battery; a fuel tank that can batch process a load of biomass. The biomass batteries will have a known energy content and power duration that is stored in barrels. These two innovations, or rediscovered technologies, are designed for small scale use on farms, buildings, or small communities. The systems also have potential use wherever conventional fuels are scarce, biomass is available, and the products have a high economic value, particularly electricity. Potential venues include refugee camps, remote villages, and possibly research or remote operations.

The BV research is being performed in context with a companion project also sponsored by an EPA, P3 grant entitled “Affordable Bioshelter”. The intent is research and promotion of energy efficient greenhouses. The combined grant effort is creating an alternative energy complex called the Biotechnology Nexus. BV works symbiotically with the greenhouse as the recipient of heat for its combined heat and power, CHP function. The greenhouse also will benefit from the biochar production. Creosote might serve as a natural insecticide. So there are three potential symbioses. Plans for the Nexus include many additional technologies such as a composting toilet, biodigestion, bag gas, high density food production, education, a living area with a rocket stove heated couch, and perhaps a second still for graduate student motivation. The majority of this paper details the BV system but details on a greenhouse for testing CHP are also included. The six revenue streams are presented in the BV, system order, starting with waste disposal and carbon credits.

Waste Disposal and Carbon Credits

Green waste disposal fees are currently \$12/ton in Watauga county North Carolina to \$82/ton in King County Washington. The disposal cost is eliminated when the waste becomes an asset. The value of Carbon Credits is still being discussed by the international green community; set points of \$30/ton to \$50/ton have been proposed by Yale

University economics professor William Nordhaus [2]. These two components of the green waste stream can add revenue to the return on investment, ROI evaluation of the scenarios with the proposed GCI technology. Using renewable fuel is carbon neutral while sequestering biochar in the ground is carbon negative. The combined sum of the component values of wood waste stream conversion to electricity, CHP, char, etc. can be as much as $600/ton gross revenue [3]. A nice summary of biochar was compiled by a Finish Engineering student, Daniel Meyer, in 2009. ”The average Finn emitted 11 Mg CO2 in 2005 (UNSD 2008b). The molecular weight of CO2 (44.010), divided through the molecular weight of C (12.011), results in a mass conversion factor of approximately 3.664. Therefore, 11 Mg CO2 equals an amount of pure C of around 3 Mg. Assumed that the biochar had a fixed carbon rate of 80%, which is common for wood biochar, then 3.75 Mg biochar would be necessary to offset the emitted amount of CO2. Although biochar is the most recalcitrant organic carbon known, it is not invulnerable. Assumed that the chemical and or biological oxidation of biochar would reach 25% in several hundred years, and then the necessary amount would increase to 5 Mg [4]”.

Combined Heat and Power

The potential profit for the wood waste stream is marginal. It will be necessary to utilize the heat produced in the production of char and electricity for the system to be profitable. The GCI is working with two different CHP scenarios, green house, and wood kiln heating. CHP can also be used for residential and commercial heat, hot water production, and cooking. The green house CHP uses the cooling water from an Internal Combustion, IC engine to warm the soil. The IC engine is operated with wood gas and is used to turn a generator. This represents a farm model where bio-mass is harvested on the property, used to produce power, heat the green house, and it produce char to improve the soil. The wood kiln scenario converts a saw mill’s waste wood stream to electricity for the mill and heat to dry the lumber. The CHP models are being developed and tested as funding allows. The processes require a significant amount of fuel processing and material handling development. The models will be evaluated on a total cost and energy use basis. Cost savings alone won’t be the sole impetus for evaluating the systems. It is possible that society will bestow some measure of value for products that are created by carbon neutral/negative procuresses. Another focus of this work is developing applications for developing countries. The systems need to be created on site using simple manufacturing techniques and available materials. Then the applications of the systems will be customized to meet the specific sociological customs such as communal cooking and marginal power availability. The reaction kiln/furnace will vary greatly depending on the country. Some countries have fire brick while others will have to use mud bricks or simple clay gob. Application of the technology for developing countries provides many exciting possibilities for grants and student projects.

Biochar

Biochar is similar to charcoal. The manufacturing process is usually the same except that biochar is heated to a higher temperature, 700 degrees Centigrade that alters the carbon cell structure. The simplest method of char production is achieved by heating a batch of biomass (wood chips), in an inverted container with an open bottom. This will sound similar to what you just read about gasification. That is why the two processes are studied together. Pyrolosis allows the chips to vaporize their water content and then liberate the volatile gases resulting in char. This only occurs because the inverted container protects the mass from air infiltration and oxidation. In the presence of air the chips would be converted to ash. “Biochar is a 2,000 year-old practice that converts agricultural waste into a soil enhancer that can hold carbon, boost food security and discourage deforestation. The process creates a fine-grained, highly porous charcoal that helps soils retain nutrients and water [5]. Using biochar can potentially create a very positive productivity cycle; example, char use increases food production and waste bio-mass, which can then be converted into more char, which improves fertility, which yields more food and more waste bio-mass to be converted to char. The principle work of the biochar community is educating and convincing the agricultural clients to invest in the amendment. The second principle value of char is carbon sequestration and green house gas control. “According to a new study, as much as 12 percent of the world’s human-caused greenhouse gas emissions could be sustainably offset by producing biochar, a charcoal-like substance made from plants and other organic materials. That’s more than would be offset if the same plants and materials were burned to generate bio-energy, says the study. Additionally, biochar could improve food production in the world’s poorest regions as it increases soil fertility" [6]. These quotes represent the world perspective; on a national scale focusing on soil amendment is a little easier.

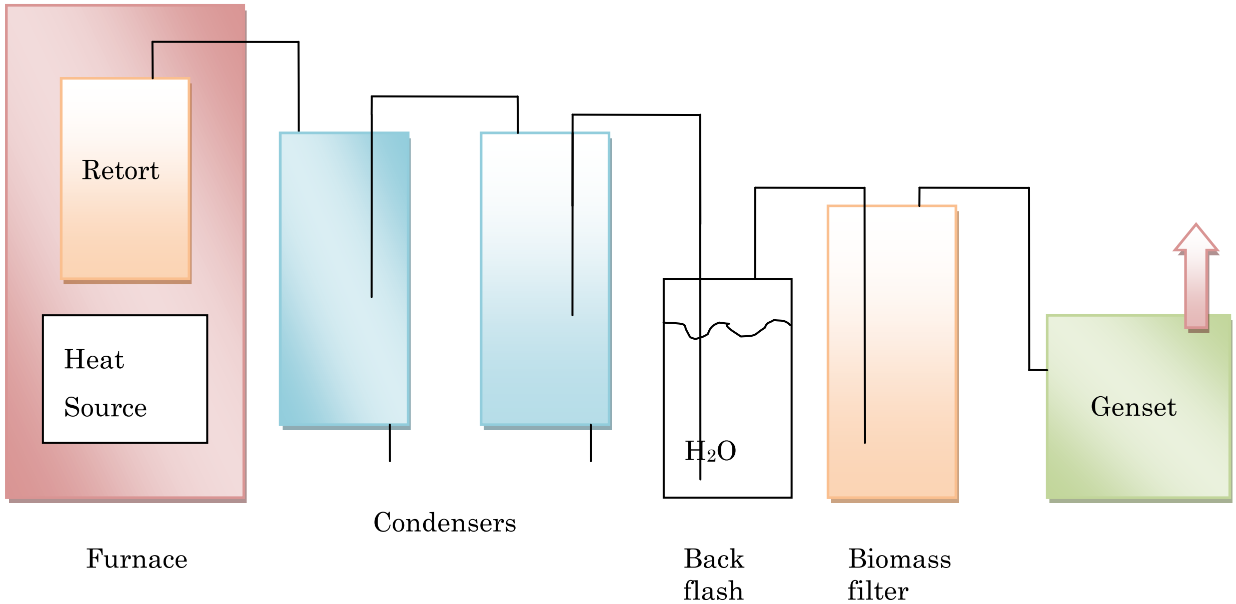
Biocrude

Biocrude, usually called creosote, bio-oil, pyrolosis oil, and simple pyoil, is produced by condensing smoke. Traditionally it has been a byproduct of coal gasification, called coal tar; this research is concentrating on renewable energy and oil condensed from biomass smoke. The specification is covered under ASTM D7544: "Standard Specification for Pyrolysis Liquid Biofuel". Research with applications of pyoil is being conducted by a number of companies such as BTG Biomass Technology Group in The Netherlands. "Bio-oil can be used as a substitute for fossil fuels to generate heat, power and / or chemicals. Short-term applications are boilers and furnaces (including power stations), whereas turbines and diesel engines may become available on the somewhat longer term. Upgrading of the bio-oil to a transportation fuel is technically feasible, but needs further development. Transportation fuels such as methanol and fuels created with the Fischer-Tropsch process, can be derived from bio-oil. Furthermore, there is a wide range of chemicals that can be extracted or derived from the bio-oil." [7] Generating the fuel on a small scale with the BV system is a little presumptuous, but hopefully will find a market when the commercial research is successful. In the meantime is has other uses such as pesticide. The BV system is also designed to allow for fractional cracking of the smoke. The high temperature crude is black, while the low temperature condensate is almost clear.

BIOVOLITILIZATION

Biovolitilization, (BV) was the name given to the "new system". The name aptly describes what the system does; it volatilizes bio mass into smoke and gas leaving behind the biochar. The basics of BV are not new concepts but they are not described in current literature and have not been configured or used as described in this paper. The system was devised after years of experimenting with traditional and well documented gasification, and biochar production systems. The evolutionary development is long and tedious but has resulted in a simple system with high potential revenue. BV combines gasification and biochar production into one system with the six potential revenues: waste elimination, heat, biochar, biocrude, carbon credits, and power. The system operates off of its own pressure in contrast to a downdraft gasifier that requires a startup vacuum; thus it is self powered. BV is designed for small scale implementation such as small farms, single dwellings, or small communities. The operational details follow.

The following diagram shows the five basic vessels that are piped together to make the BV system. The first vessel, the one on the left, contains the biomass in a retort that is surrounded by a furnace, and heated with a stove. The gas travels under its own pressure to the second vessel which is one of two centrifugal separators/heat exchanger/condensers. The condensers are located within the greenhouse to provide heat while they fractionate the smoke into heavy black creosote and lighter creosote. The fourth vessel is partially filled with water and functions as a flash back arrestor. During startup there is the potential for an explosive mixture of air and gas to ignite within the vessels. The flash back arrestor is the primary safety mechanism but the vessels are also equipped with aluminum foil membranes that can burst and allow a potential explosion to release out the top of the connecting piping. The flash back arrestor is connected to a flare, not shown, and a filter before the gas enters the generator. The gas flow is controlled with a series of selector/diversion valves. The initial gas is flared off until a steady flame is achieved, then the gas is piped through a series of filters and into the generator. The first, biomass filter is filled with wood chips to collect any residual creosote. The chips are eventually used as fuel. The second fiber filter (air filter) is used to remove fine particulates. Combustion air is also filtered prior to mixing with the BV gas and fueling the generator.



HISTORY OF PRODUCER GAS

Producer gas is an allusive technology to track down. The gas has many names including, syngas, town gas, coal gas, illumination gas, wood gas, and manufactured gas. Volatilizing coal has been the primary production process for these gases. The first commercial manufactured gas plant was in England in 1805; with as many as 20,000 sites worldwide before natural gas became the mainstay [8]. The Fakenham Museum of Gas and Local History is the only surviving town gasworks in England and Wales and is typical of early gas work . The gas was made by volatilizing coal in a closed container, retort. An example of current gas works is the SilvaGas® process. “The basic process of gasification involves converting a biomass solid into a gas. The gasification process does not involve combustion; rather, it converts biomass to synthetic natural gas in an oxygen free, superheated environment. Most existing biomass gasification processes utilize partial combustion, or air blown gasification; which generates a low Btu gas that cannot be substituted for natural gas. The SilvaGas® process is highly competitive with renewable power alternatives (i.e. wind, solar natural gas) because the SilvaGas® process can be dispatched to match load demands and is not resource or site specific. The product gas can be used as a direct substitute for any fossil fuel used in the production of energy. At the completion of the gasification process, the material is reduced to about 1% of its original mass; dramatically prolonging the useful life of landfills and eliminating hazards associated with waste disposal. The system produces reduced emissions of greenhouse gases, which are 98% below conventional fossil fuel plant, and 40% below conventional biomass plants. SilvaGas® represents a clean affordable and environmentally sound alternative to fossil fuels, a solution to the world’s waste management issues and an opportunity to improve land use.” [9] The BV system is similar to the SilvaGas® process, but on a very small scale, with biochar as a chief product.

EFFICIENCY AND ANALYSIS

Analysis of BV efficiency has begun as follows. A 30 gallon barrel contains about 4 cubic feet of woody biomass. The biomass weighs about 30 pounds per cubic feet or 120 pounds for the barrel with an energy density of 1.9 KWH/lb or 228 KWH for the barrel. If the burn cycle lasts 6 hours then the output will be 38 KW, roughly 51 horsepower. The reality will be much less. The target for the BV system is enough gas to operate a 5kw genset using a 10 horsepower motor. This is probably too optimistic since it will require an efficiency of 20 %. It might be achievable with a 55 gallon system. This is not an actual energy balance just a potential output power calculation.

The energy balance has to include the heat source, the CHP derived, and the product energies of biochar and biocrude produced. Commercial efficiencies are in this range as follows; “The combined heat and power generation via biomass gasification techniques connected to gas-fired engines or gas turbines can achieve significantly higher electrical efficiencies (22 % to 37 %) compared to biomass combustion technologies with steam generation and standard turbine technology (15 % to 18 %). Using the produced gas in fuel cells for power generation can achieve an even higher overall electrical efficiency in the range of 25 % to 50 %, even in small scale biomass pyrolysis plants and during partial load operation”. [10]

CONCLUSIONS AND FUTURE PLANS

Analysis of the BV system is a classical, applied chemical engineering application/problem; calculating the energy and mass balance to determine the operating efficiency. Two systems have been built and tested. BV1, for one gallon reactor, worked fine and proved that such a system was possible. The second system, BV30 (guess what size it is) was modeled after BV1 and performed adequately. BV30 included a furnace and barrels for condenser/heat exchangers. The output gas was almost smoke free. The first barrel warmed up but still condensed most all of the creosote while the second barrel remained cool. The flash back arrestor did its job, no explosions. Less gas was produced then expected but analysis of the reacted wood showed a lack of heat. The system was operated for one hour during which time it charred three pounds of wood, much less than expected. The next version will use more heat and an insulated furnace. This should produce the gas flow required to operate an internal combustion engine. The goal is production of sufficient gas to operate a genset. The input was about 50,000 BTU with about 8,000 BTU of gas produced and a pound of creosote. The next step is to redesign and run a measured test of mass change, temperatures, and gas output. A simple model will be used to create an equation around the parameters of, temperatures, inputs and outputs, to determine the energy and mass changes. This will lead to economic feasibility studies, return on investment calculations and hopefully implementation plans. All of this work is being conducted by a team of graduate and undergraduate students. It is a fantastic teaching through research environment. An additional goal is grant writing to fund continued research.

Teaching through research

This is the fourth year of biomass gasification research. To date, approximately 45 students have been directly involved. The first group of students built the original greenhouse and two gasifiers. The current group of students is building a commercial, twenty by thirty foot greenhouse and the BV gasifiers. Three groups have created experiments to measure agriculture improvements though soil amended with biochar. One very excited group, used biochar to amend the lightweight soil for green roof systems. The results were encouraging. Currently students are also investigating biochar as a water filter media. The author and PI of the grants has been able to take an advisory role and happily watch students lead the project. Work on these projects usually becomes the capstone educational experience for the participants. One of the PI’s jobs is to serve as a protective screen between the giant hair ball of the university bureaucracy and the creative spirit of the untainted students. One result of this screening was the shredding of his university credit card, but alas, such is the life of academics.

REFERENCES

[1] Gaunt, John, *Low-temperature slow pyrolysis offers an energetically efficient strategy for bioenergy production*, http://biocharfarms.org/biochar_production_energy/, 2010, NJ

[2] Nordhaus, William , *A Question of Balance - Weighing the Options on Global Warming Policies*, Yale University Press, 2008, CT

[3] Domermuth, David, *Biomass Gasification and Char production*, ASEE-SE, Conference proceedings, 2011

[4] Meyer, Meyer, *Biochar a Survey*, http://www.lupus78.de/projekte/uni/Biochar.pdf, Tampere University of Technology, Finland, 2009

[5] THE SOCIETY OF BIOCHAR INITIATIVES, http://www.biocharsoc.org, 2010

[6] Reynolds, Joseph , *Renewable Energy Without Greenhouse Gases*, http://www.suite101.com, 2010

[7] http://www.btgworld.com/index.php?id=23&rid=8&r=rd, BTG Biomass Technology Group, 7500 AV Enschede, The Netherlands, 2011

[8] Hatheway, Allen, Doyle, Briget, *Technical history of the town gas plants of the British Isles*, http://www.hatheway.net/Downloads/2006_IAEG_UK_FMGP_technicial_history.pdf, 2011

[9] http://www.biggreenenergy.com/Default.aspx?tabid=2887, Biomass Gas & Electric, LLC, Norcross, Ga., 2011

[10] *Pyrolosis of Biomass*, http://www.habmigern2003.info/biogas/Pyrolysis.htm, madur.com, 2011

Biographical Information

David Domermuth is an associate professor at Appalachian State University. He has been teaching for 26 years. His career began in metals manufacturing, shifted to furniture, and now Industrial Design. David teaches the engineering aspects of product design. He has three degrees in Mechanical Engineering and has lived abroad for five years. David's current research is concentrated on gasification of biomass as a renewable energy source and using biochar for soil augmentation. He is a follower of Jesus Christ and a deacon at Alliance Bible Fellowship. His primary hobby is road biking with 37 years of riding in the Appalachian Mountains.