Biomass Gasification and Char production

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Abstract – Biomass gasification is a well developed process of converting wood to fuel gas. The gas produced is currently not as economical or convenient as fossil fuel but has great promise as an alternative source. The process can also be used to convert waste streams of almost any organic material to power. The ongoing research presented in this paper is twofold; the production of biochar that can be used for soil augmentation and gasification for combined heat and power. Biochar enhances farming productivity by storing and slowly releasing nutrients to the soil that would otherwise be leached away. This paper also details how education is integrated with the research and presents opportunities for future developments and additional projects.

Keywords: gasification, wood gas, pyrolosis, renewable energy, biochar, EPA P3 grant.

INTRODUCTION

The green movement is a powerful draw for cash starved researchers. Stimulus money, tied to renewable energy is law hanging fruit and part of the motivation for the research described in this paper. Bio-energy, at best, has a slim profit margin. It is labor intensive and messy; like a puppy, you have to tend to it all the time. Wind and solar on the other hand, require little intervention but have been extensively developed. Hydroelectric has also been well developed, but is complicated by river, wetlands, and wildlife conservation; all of which are very important. That leaves nuclear, geothermal, and bio-fuels as energy sources besides fossil fuel. Nuclear died in the US with the Three Mile Island disaster. Geothermal is limited and has already disappointed the research efforts of this author. - The left over energy choice is bio fuels, and the myriad of avenues for realization; ethanol from corn, bio-diesel from sunflowers, and gasification from wood chips, to name a few. Gasification was passed over many years ago but is reinvestigated in this paper coupled with a derivative of the process, biochar. Biochar not only is a productive soil amendment but can yield carbon credits from carbon sequestration; Thank you global warming. Gasification is simply the heating or pyrolosis of bio-matter to produce fuel gasses. The process is described in detail later on. Bio-char is the result of pyrolosis prior to the biomass being reduced to ash. The historical background for this work follows along with observations contributing to the teaching versus research argument.

History at Appalachian

The study of gasification at Appalachian State University began in the fall of 2008 when a graduate student, Mike Uchal, approached Dr. David Domermuth to discuss the possibility of powering his motorcycle with wood chips. Months of discussion steered the conversation away from a mobile source to a stationary concept with the cogeneration use of heat for a greenhouse and eventually the trigeneration to include production of bio-char. Mike teamed up with additional graduate students to write an EPA, P3, phase I grant proposal for $9,999. The grant was awarded in the summer of 2009 at which point the author of this paper coined the acronym, DBFF, [Death by Federal Forms]. A number of additional people joined the team the following year to perform preliminary research and write the phase II proposal for $74,999. The expanded team competed with universities from across the nation on the DC mall during Earth Day for the grant. The winners, including ASU, were announced in a ceremony at the Academy of Science to close the event.

Students from the original team graduated and moved on. A new team of students has been formed along with an acronym for the work, Gas Char Initiative, GCI. The GCI is actively working on a number of projects described in detail in the next section.

Educational effects of research

A conscious aspect of this research project is an observation of how the effort involved affects teaching performance. The author is the subject and the evaluator, so objectivity could be questionable. One of the hypotheses being tested is the idea that an active research agenda helps the teacher to stay up to date and provide the students with a better educational experience. The antithetical argument supports that the time and energy balance is shifted away from student's education. This study has been in effect for two years with no noticeable difference. Teaching evaluations and student test scores have remained consistent. The dominant change has been a positive shift in the teacher's attitude. The environment at ASU has shifted over the last fifteen years from a predominantly educational focus to a hybrid half education half research emphasis. It is now an environment that favors and rewards grant winners.

The students involved with the research project are directly and positively influenced by the effort. This involvement is a far more effective teaching tool then traditional classroom education. The problem is how few students can benefit by comparison; for instance, five compared to a hundred. Grant money is an intoxicating drug that provides escape and freedom from the duties of conventional education but it is also addictive and can supplant our desire for teaching.

RESEARCH SCOPE FOR THE GCI

Writing about a proprietary project is tenuous at best. The text needs to be fat enough to be captivating but thin enough to be secure. The basics of the GCI revolve around return on investment, ROI, just like any other project. The GCI also has to be sensitive to environmental concerns because it is based on biomass and once the trees are gone so is the project. This is the scenario Dr. Seuss described in his book “The Lorax”. This paper will concentrate on wood chips as a biomass model all though any organic material can be used. Wood chips have six potential value components; electrical energy conversion, heat, char, disposal fee, and carbon credits. Electricity and heat conversion can be viewed as common, from a scientific perspective, but are separated in this work as an end use. The current emphasis of this project is implementation of existing technology with an eye towards innovation.

Electricity

The analysis for this discussion is based on one ton of wood chips. A ton of chips has a volume of roughly three cubic yards or the large pile that one sees beside a roadway. This pile can be converted into on megawatt of electricity through complete gasification. Complete gasification converts the biomass to ash. The ash can then be used as a soil amendment or a component for light weight concrete. Electricity value is based on sell or purchase. Local power rates vary but the common purchase price in NC is $.07/kwh with a sell value of $.04/kwh. So it is much more profitable to produce power on a small scale for internal consumption. With that in mind, the one ton pile of chips, converted to electricity, is worth $70 when consumed internally, but only $40 if it is marketed on the grid. On the other hand, this renewable power can be sold at a green rate for power programs that have a green power purchase agreement. The green rate for North Carolina is potentially about $.11/kwh. The political wrangling for this agreement won't occur until this project reaches a mature enough state to supply a reliable supply of electricity. The mature state is a couple of years and a $200,000 grant in the future. Bio-char is another way to convert the pile of chips into revenue.

Bio-char

One ton of chips can yield between 300 and 500 pounds of char. This is an ongoing phase of investigation for the GCI so the reported yield values are based on other research findings [1]. Char can sell from $.3 to $1 based on varying market rates. The principle value of char is a soil amendment although a secondary market is charcoal for heat or back yard barbecue. The char is basically the carbonized skeleton of the vegetation. This thin porous structure has a large carbon surface area that attracts and retains soil nutrients; these essential elements very often leach away and enter the water system. Agricultural yields are improved as plants absorb the nutrients from the bio-char. The bio-char acts like batteries that collect, store, and release, the essential compounds for growth; so agricultural and water conservation is another phase of the GCI. Char production and specifics are addressed later in this paper.

Combined Heat and Power, [CHP]

The potential profit for the wood waste stream is marginal at best. It will probably be necessary to utilizing the heat produced in the conversion process of char or electricity for any 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 mission of this work is developing applications for developing countries. In that scenario the systems need to be created in country using simple manufacturing techniques and available materials. Then the applications of the systems are customized to meet the specific sociological customs such as communal cooking and marginal power availability.

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 illuminated when the waste becomes an asset. The value of Carbon Credits is still being discussed by the international green community; set points of $30 to $50 have been proposed by Yale University economics professor William Nordhaus [2]. These two components of the green waste stream can add revenue to the 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. Operating, maintenance, and capital costs would speculatively reduce the revenue by half, but the ROI is still less than two years as shown in the following proposal.

ROI for a typical green waste collection site

The GCI has a number of commercial sites interested in the technology. The most profitable current site is the Watauga waste processing facility in North Carolina. 5,000 tons of wood are collected annually. The waste can be converted into $350,000 of electricity, based on $70/ton of realized electricity. The estimated capital expanse to initialize the project is estimated at $500,000 with annual costs for one employee and expenses of $60,000; the ROI will be less than two years. This does not include bio-char production, carbon credits or combined heat and power [CHP] revenue. The potential gross yield for the combination at $500/ton of waste is $2.5 million. Realization of the higher value potential will require the development of a new type of reactor; a reactor that gasifies and chars, a flow through retort.

Flow through retort

The flow through retort is the optimum method to maximize the yield for processing bio-mass with pyrolosis. A flow through retort converts a continuous flow of bio-mass into bio-char without the use of external energy. Systems have been developed that use electricity or natural gas to perform the pyrolosis but the added energy negates much of the profit potential. One large scale system has been developed by Tucker Inc. in Conover, NC that can process a ton of waste per hour with the potential of generating 1.5 megawatts of power [3]. The system was designed to convert environmentally harmful landfills into fixed carbon. The system is not what the GCI is seeking. It was not designed to convert a wood waste stream into char while producing power with the liberated gas, but it should be possible to convert it to this end. This type of device has the potential to liberate %80 of the bio-mass energy while producing char. The development and implementation of this "Holy Grail" of gasification is the "end game" intent of the GCI. It just might provide the means for the author to recover the retirement losses created by the dot com collapse and the oversold real-estate fiasco. The principle difficulty with this process is dirty gas.

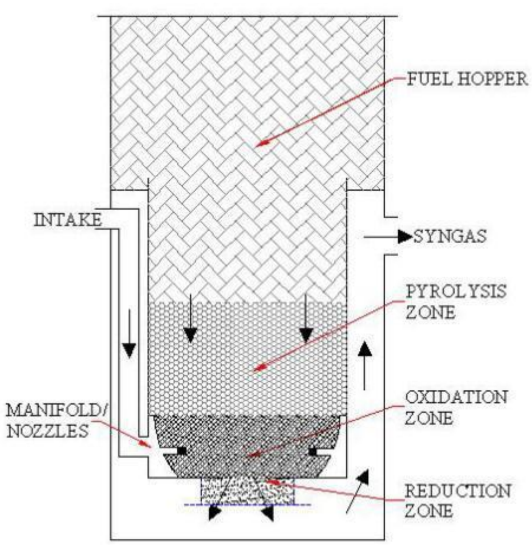
Pyrolosis is not very different from a camp file; lots of smoke and fly ash. The fly ash can be centrifugally separated and filtered but the smoke is a sticky/grimy problem to clean. Smoke is composed of tiny tar droplets. Ideally the tar is cracked in the reaction process into useful gases for combustion in the engine. The remaining dirty products are either condensed if water based or filtered out if particulate. Wood chips can be used as a course filter. The chips then become fuel and the tar gets a second chance at gasification.

GASIFICATION

There are a number of methods for changing bio-mass into gas. This description is the hot process called pyrolysis. Technically, "**Pyrolysis** is a thermochemical decomposition of organic material at elevated temperatures in the absence of oxygen" [4]. The simplest, poor version of pyrolysis is a camp fire. Simple combustion is producing the heat which is breaking down or converting the bio-mass into gases, coals, and ash; the gases then burn as dancing flames. Occasionally the gases lift with the smoke and ignite in the air. The next version of pyrolysis is a method for making bio-char; a sealed chamber is heated with the steam and gases escaping through a vent pipe. The sequence of escaping gases begin with steam, then smoky volatiles, and eventually clean burning fuel gases. This is a dirty process because the smoke is composed of fine tar particles which gum up whatever they condense on and create a creosote layer. The popular process referred to as gasification is slightly more complicated, but very simple to explain with a little chemistry.

The device consists of a closed top cylinder filled with bio-mass in the top and charcoal in the bottom, figure one. Bio-mass fuel, typically wood chips, is heated in the closed container by the charcoal. Air tubes supply oxygen to oxidize the charcoal and produce CO_2. Steam is produced by the heated wood and both gases are drawn down through the hot charcoal. The hot charcoal tears oxygen atoms off of the two gases as shown in the following equations; the coals also break down smoky tars into their constituent gases.

$C + C0_2 + 164.9\ \text{kJ/mol} = 2C0$
$C + H_20 + 122.6\ \text{kJ/mol} = CO + H_2$



Figure, one

These basic reduction reactions create the primary two fuel gases H_2 and 2CO. These hot gases are cooled and cleaned before they can be used to power and engine. The gases have about half the energy density of conventional fuels like gasoline vapor, so a 10 horsepower engine will only produce 5 horsepower. The fuel gas commonly referred to as wood gas is also limited by the nitrogen that is carried through the process when air is used as the oxygen supply. The fuel is called syngas, in the absence of nitrogen, and has a higher energy density. Wood gas clean up is a little bit complicated and requires about have of the apparatus of a gasifier.

A centrifugal separator spins out the heavy ash particles. Then the gas is cooled to condense residual water vapor and to increase its energy density. Fine dust that remains can be filtered with bio mass and with a conventional engine air filter. Start up is very smoky and moist so a vacuum pump or compressed air fed venturi is used to create the fuel gas draw. The initial gas is flared off until it is clean, usually about five minutes. A typical machine like the PSG 20kwh, made by Planet Green Solutions can operate for up to 24 hours at a time.

BIOCHAR PRODUCTION AND USE

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 will 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 stimulates a productivity cycle; char use increases food production [bio-mass], which can then be converted into more char, which improves fertility and so forth. 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.

CONCLUSIONS

Three years of investigation have convinced the GCI members that this is a viable field for continued research with the potential for profitability. The group has developed a number of realistic scenarios for CHP. One group developed a combination gasifier, biochar reactor that is still being tested and a couple of biochar reactors have been built and used for testing different char stock. Five grant proposals have been written and submitted, a series of talks and lectures have been presented, and countless contacts have been established with interested individuals and organizations.

Student comments

“This project has allowed me to take an active role in the fabrication and development of the GEK at Appalachian State University. I have gained valuable experience in the science behind gasification as well as a new appreciation for a technology that I knew nothing about before attending ASU. The idea behind CHP and greenhouse heat generation is exciting to explore and we hope to have some conclusive results by the end of the year.” (Sebastian Brundage, graduate student)

"Working on the EPA P3 Gasification process broadened my knowledge in many ways. I expanded my research skill set by helping to complete the review of literature for the writing of the grant proposal. I learned metal fabrication skills that have benefited me many times since the project. I also learned a work ethic that I did not posses before. It was extremely common (5 days a week) to finish a full school day and then spend another 6-8 hours on building the gasifier. Working for 18-20hrs a day became my norm. This skill set has helped me achieve goals and has set me on a path post graduate school, to being in the job I want to be, not the job I settle for. Presenting at the national mall to Lisa Jackson, head of the EPA was a highlight in my graduate school career and winning the second round funding was a life highlight. I would not trade that experience for anything." (Landon Williams, graduate student)

Findings

The potential for gasification is limited by cheap fossil fuel. Abundant coal and oil keep electricity costs down to $.04/kwh and make grid tied gasifiers unprofitable. Off grid gasification is as competitive as wind power, six times cheaper then solar, and equal to hydro. The advantage is on demand power that is independent of good wind and hydro sites. The disadvantage is reliance on a biomass supply and the responsibility of tending the machine twice a day. Biochar production is the most promising area of the research to date. Biochar production is currently a viable business, so the research has shifted to CHP with biochar. The ROI looks promising for this venture but the basic applied research still needs to be done.

Progress and future plans

A Research Center has been constructed at Resource Wood Inc., in Church Hollow, Foscoe, NC. The center occupies a corner of the RWI sawmill/woodlot surrounded by biomass. The center currently consists of a small green house, storage building, and trailer garage; the green house is a test plot for combined heat and power and the trailer is a mobile platform for testing and demonstrating gasification. A new project has been started for application of biochar for agricultural augmentation and water conservation. Four undergraduate students are participating in an independent study course to learn about Green Roof Systems, (GRS). They will be conducting research sponsored by three grants and an assistantship. The work will evaluate the effectiveness of biochar for GRS soil. This study is unprecedented in the literature. The GRS, gasification, and biochar production projects are focusing on participation in the 14th Annual Celebration of Student Research and Creative Endeavors, held on Thursday, April 14, 2011 at Appalachian State University.

A manufacturer of gasification equipment from Indonesia has recently been found that is cheaper and more reliable than used so far for return on investment calculations. Several new proposals will be developed for funding proposals based on the Indonesian machine. The biochar research will continue in three phases; phase one will be basic production of char using a simple inverted vessel, phase two will also be a batch production but with a retort system that is self heated, the third phase is the design and development of a flow through retort. The design concept has been completed and could lead to two patents.

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Biographical Information

David Domermuth is an associate professor at Appalachian State University. He has been teaching for 24 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 36 years of riding in the Appalachian Mountains.