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C
SYSTEMS

U.S. Forest activities produce over 80 million green tons of woody biomass residues each year, creating a renewable energy resource comparable in size to the annual production of oil from Alaska's North Slope, yet no technologies have emerged that can economically utillize this material

-- until now.

THE PROBLEM:
LETTING VALUABLE NATURAL RESOURCES GO TO WASTE

Forestry residues are comprised of branches, tree tops, and small diameter stems left over after normal operations. This material is typically concentrated into "slash piles" and burned, wasting a valuable resource and creating air quality and health problems linked to smoke production. Despite growing interests in tapping this domestic renewable energy resource, woody biomass presents several unique challenges for integration into the mainstream energy economy.

Woody Biomass have prohibitively high biomass transportation and production costs because of:

- **Low energy content per unit weight**
- **High water content (typically 20-50%)**
- **Material distributed over large spatial areas**
- **Natural resistance to chemical conversion.**

Previous Attempts:

Several attempts have been made to address different aspects of the transportation problem. Each approach faces serious problems that limit development and dissemination into the market.

1. Centralized Plants: Centralized plants allow for high conversion and low cost production efficiencies. However, existing centralized plants are struggling and few proposed plants are actually being financed for two reasons:

-- Large capital investment to risk ratio: Centralized plants typically require new, expensive, and complex technologies. These facilities typically require long start up/operational time before realizing profits.

-- High transportation costs & supply uncertainty: Large plants require high volumes of feedstock. Transporting feedstock is cost prohibitive (typically a radius of 30-50-miles is the maximum). This leads to supply uncertainty and the risk of overexploitation of forest resources.

2. Mobile Processors: Small-scale, portable technologies reduce transportation costs by bringing the conversion process to the forest. Mobile processor prototypes produce solid and liquid fuel products at high energy conversion rates. While this approach shows promise, several limitations exist:

-- High production costs: Portable units have low production rates relative to the capital equipment costs. These costs are further increased by feedstock pre-processing, long setup/takedown times, and intermediate transportation costs .

-- Unproven technology: Many processes can only handle narrow ranges of feedstock type, purity, and moisture content. Forestry operations require rugged, versatile equipment that can operate in a wide range of conditions. Numerous technical barriers remain to be solved before most current approaches can be considered viable.

THE SOLUTION: THE C6 BURN SYSTEM

C6 Systems has developed a novel slow-pyrolysis system that turns woody biomass into charcoal, or biochar, from woody biomass at the site of forestry operations. Slow-pyrolysis requires two essential items: heat to raise the temperature of woody material and the ability to restrict the flow of oxygen.

The C6 Systems technology (Fig 1) achieves both by covering slash piles with a heat resistant, semi-permeable engineered blanket. The pile is then ignited. The material acts as an insulating boundary layer, capturing and uniformly distributing heat released from partial combustion throughout the pile. The low permeability of the material limits the rate of oxygen transfer to the pile, thereby causing pyrolysis to occur. Steel aeration tubes inserted into the base of the pile provide further control over pyrolysis reaction. The C6 System design also promotes a more controlled burn environment resulting in improved emissions and less overall smoke. The result is a system that transforms slash piles into high value biochar, while minimizing emissions in a simple, cost effective manner. A prototype of our system has been built and field tested. Further modifications and system scale-up are currently in development. (Images on the right)

Implementation of the technology would require crews of 3-4 people to process a series of piles within a timber sale area. Crews would use conventional heavy machinery available on site to cover the piles with the blanket material and handle the char. A chipper/grinder would then process and load the char into chip vans or roll-on-container trucks. These would be used to transport the char to buyers.

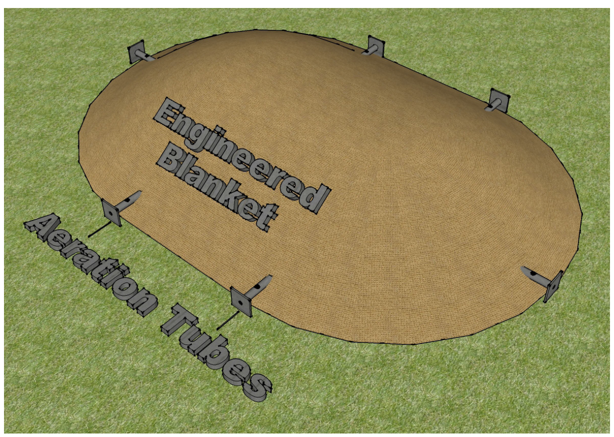
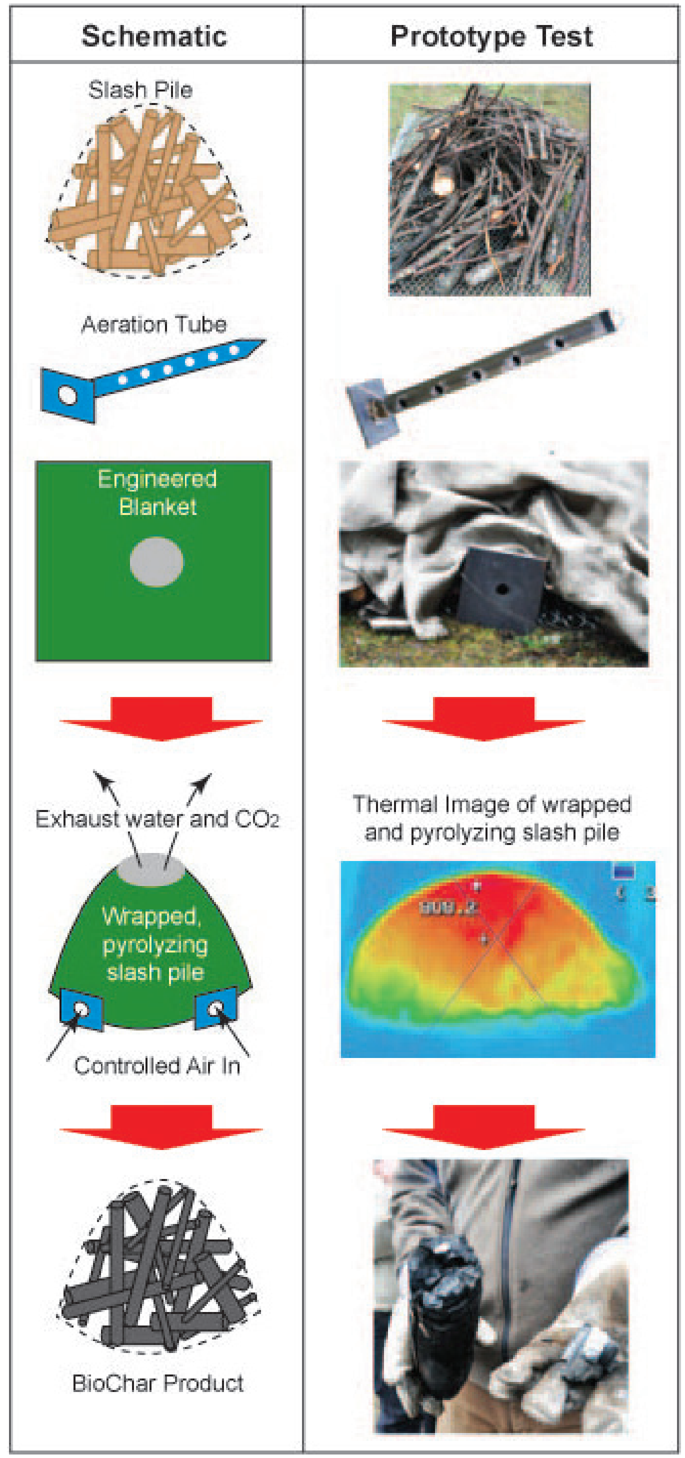
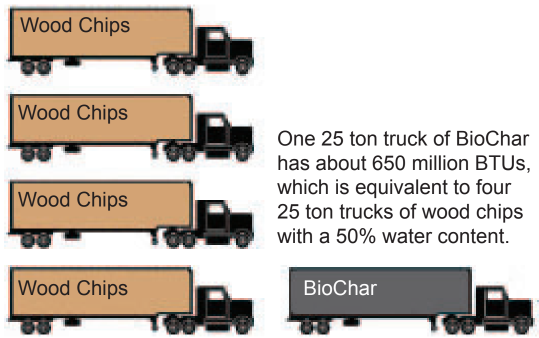


Fig. 1: Conceptual design of the C6 Burn System. The engineered blanket is a state of the art material that is heat resistant and semipermeable. Aeration tubes are placed into the slash pile. A simple valve allows for control of oxygen flow into the pile as it is burned.



The C6 Systems biochar process overcomes the major barriers identified to profitably utilize woody biomass:

1. Low transportation costs. Biochar has 4 times more energy content by weight than green biomass (50% moisture content); thus, profit margins of the C6 System are far less sensitive to transportation costs. The system can be profitable at distances greater than 150 miles from markets compared to the current value of 30-50 miles for centralized plants.



One 25 ton truck of BioChar has about 650 million BTUs, which is equivalent to four 25 ton trucks of wood chips with a 50% water content.

2. Low production costs: Production rates for the C6 Systems technology are higher than that for mobile processors (an estimated 10-18 tons per hour vs. 0.5-1 tons per hour). Our system is not prone to technological breakdowns/delays, can be easily transported, and is quick to setup. Also, the system requires minimal handling and processing steps which further reduces costs.

3. Employs known, low cost, low risk technology: Our novel process utilizes proven pyrolysis processes in a simple yet effective manner. The C6 Systems technology offers operational flexibility that is easily optimized to work synergistically with current forest practices and is not dependent on long-term supply at a fixed location. Our feasible, low-cost, highly scalable solution makes it ideal for rapid dissemination into both domestic and international markets.

Product Comparison:

Energy Source:	**Heating Value (MJ/kg)**	**Sulfur Content (Wt %)**
High Quality Coal*	27-30	0.4-0.7
Low Quality Coal+	15-19	0.7-4.0
Woody Biomass^	10	Negligible
BioChar	22	Negligible

(*Bituminous/anthracite, +Lignite/sub-bituminous, ^50% moisture content)

Below is an assessment of how our technology measures up against other technologies.

	C6 Systems	**Mobile Fuel Processors**	**Centralized Electricity & Heat Plants**	**Centralized Fuel Plants (Gasification/Fermentation**
Employs Proven Technology	✓	⊘	✓	⊘
Lower Capital Investment to Risk Ratio	✓	⊘	✓	⊘
Lower Transportation Costs	✓	✓	⊘	⊘
Low Production Costs	✓	⊘	✓	✓
High Value Products	✓	✓	⊘	✓
Energy Conversion Efficiency	⊘	✓	✓	✓
Flexible & Scalable to Local Needs	✓	✓	⊘	⊘
Rapidly Deployable	✓	⊘	⊘	⊘

MARKET OPPORTUNITIES

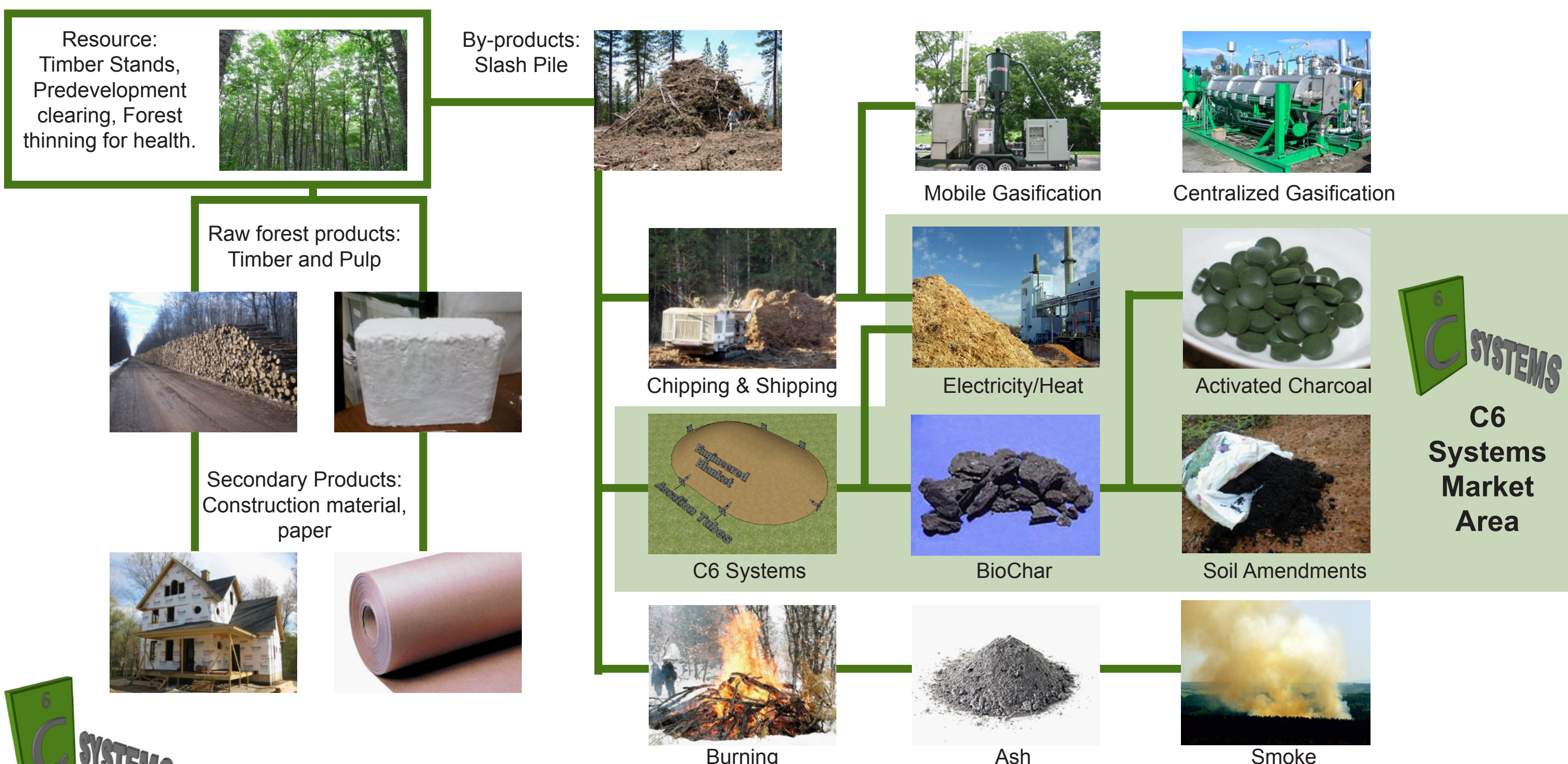
Biochar is an attractive product within several major industries for use as a solid fuel source for heating/electricity production, as a soil amendment, and as a raw material for chemicals production.

Two markets with significant potential are:

1. Soil Amendments: As a soil amendment, Biochar improves soil water holding capacity, crop yields, disease management and pest management. It is also considered a major carbon sequestration strategy . The soil amendment market encompasses gardeners, nurseries and farmers. Two companies have expressed interest in large quantities of biochar for use within this geographic region.

Our research indicates that current wholesale prices for raw biochar range from $100-300 per ton. Although still developing, these markets are showing major growth throughout the U.S. and within the Pacific Northwest.

2. Energy markets: Rising biomass transportation costs make burning local Biochar for electricity and heat potentially more appealing than burning hog fuel. Markets for densified biochar in Washington include Avista Utilities, Kettle Falls, WA and Boise Cascade, Wallula, WA. Avista Utilities consumed approximately 500k tons of hog fuel from forest operations in 2010 with marginal financial benefits due to transportation costs. A large biomass electricity plant is currently proposed for the Shelton area. Based on current hog fuel prices and relative energy content, price estimates for biochar range from $50-65 per ton.



Competition for C6 Systems biochar product is limited due to capital investment requirements and technological challenges. Currently, there are six companies outlined in the following table, that could potentially be in direct competition for converting forestry biomass to biochar.

Company	Location	Facility	Technology
New Earth Renewable Energy, Inc	Seattle, WA	Mobile, Centralized	Torrefaction
Ambient Energy, LLC	Olympia, WA	Consulting	Gasification
Dynamotive	Vancouver, BC	Centralized	Gasification
Agri-Therm	London, On	Mobile	Pyrolysis
HM3 Energy	Gresham, OR	Centralized	Torrefaction
Biochar Engineering	Golden, CO	Mobile	Gasification

(Source: http://www.biochar-us.org)

PROFIT

Net Revenues:
Annual profits of $525,000 are estimated for one 3-4 person crew processing 15,000 tons of biochar.

Supply of biomass from forestry activities is not a limiting factor in the foreseeable future. In Washington and Oregon, there is an estimated 8 million green tons of piled, road accessible residue produced each year with double that amount produced as a result of thinning operations. Other potential sources include woody debris generated during land clearing, agricultural waste products, and municipal solid wastes.

Based on an analysis of machinery costs, labor needs, financing costs, and production flows, we have estimated that one 3-4 person crew could process 60,000 - 100,000 green tons of biomass into 10,000-20,000 tons of char per year. Production costs are estimated to be $40-70 per ton of biochar.

Assuming mid range price/cost scenarios, the profit potential is considerable. Selling 15,000 tons of biochar per year at an average price of $100 ton at a production cost of $65/ton would result in an annual profit of $525k.

Growth Potential

The future of the C6 System could have world wide applications. Processing one third of the potential biomass supply from logging residues in Oregon and Washington would require over 30 crews. To reach broader markets we envision eventually providing two service models.

1. **Direct Service:** Using the technology to process and sell biochar in the western US.
2. **Indirect Services:** Through licensing, manufacturing, and selling the technology.

Capital Costs for 1 Crew	
C6 Systems Fabric & Tubes for 15 sets	$75k
Heavy machinery (material handling & grinding)	$335k
Support trucks and other equipment	$175k
Total Capital Requirements	**$585k**
Annual Capital Repayment (Amortized at 7% over 7 years)	**$106k**

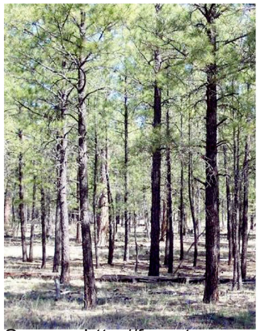
Operating Costs (per year)	
Employee Salary and Benefits	$220k
Fuel & Lube	$95k
Equipment Repair, Parts & Maintenance	$104k
Administration, Legal & Insurance	$95k
Additional 10% buffer	$51k
Total Operating Costs (per year)	**$565k**

ENVIRONMENTAL BENEFITS

Clearly there are many environmental benefits for developing technologies and processes that allow for access to these under-utilized resources. We have identified 4 primary areas where the C6 System will be most beneficial.

Environmental Benefits:
- **Promoting healthy forests**
- **Reduced smoke emissions**
- **Carbon sequestration**
- **Soil amendment.**

1. Promoting healthy forests can be expensive; therefore, it is necessary to expedite a cost-effective plan to remove woody biomass from the forest. Forest health is supported by our plan because it reduces the cost to remove biomass, and it provides a service with lower start up costs. Also, there is potential to pay a small amount of money per/ton to landowners for their biomass which can encourage treatments that facilitate forest health.




Two images of a similar forest. The forest on the left is over crowded and less healthy than the forest on the right.

Source: http://forestenergysystems.com/healthy-forest.php

2. Smoke emissions are a major societal concern from an air quality and human health perspective. Currently, our team is researching the likelihood that the innovative technology C6 system can address our current smoke emission problems.

3. Carbon sequestration naturally occurs through biological, physical, and chemical processes removing and storing carbon into carbon sinks for instance into soils and forests. During the pyrolysis process a small amount of carbon is released into atmosphere but the rest is sequestered as biochar, since the atmospheric carbon is captured from the air to make biochar the net process is calculated to be carbon negative.

4. Soil amendment research shows biochar improves the chemical and physical properties of soil, and fertility for crop establishment. Also, biochar increases biomass productivity, water holding capacity, pH levels, electrical conductivity and cation exchange capacity. Finally, it Increases population of phosphate solubilizing and nitrogen-fixing bacteria and increases percentage of 1-2 mm water stable aggregates all these combined can support plant vigor perhaps enabling plant resistance to insects and diseases. Using biochar as soil amendment is a simple way to promote environmentally sound methods to produce healthy and sustainable yields of agricultural crops. On a positive note biochar as soil amendment would decrease the release of harmful pesticides or chemical fertilizers into the soil and water resources. Those two benefits by cleaning up the soil and water would be large societal and environmental achievement.


Classic image of “Terra preta” which was historically amended soil in the Amazon drainage basin.
Photo: Bruno Glaser, Author: Rsukiennik

TEAM BIOS

Derek Churchill is a PhD student at the University of Washington focusing on biomass and large scale fuels reduction treatments. He started and currently runs his own forestry consulting business where his experience includes writing large scale landscape restoration and management plans, developing an FSC monitoring template, designing and managing over 35 harvest operations on more than 3500 acres, and overseeing a 35,000 acre forest inventory project.

Nate Doran is currently a Foster MBA 2013 Candidate at the University of Washington, with a focus on Finance and a passion for starting a cleantech business. He previously consulted with a manufacturing company to improve sales operations and marketing.

Everett Isaac is a PhD student at the University of Washington studying the fire ecology of the east Cascades and biomass utilization. He has worked for Yakama Nation/ Bureau of Indian Affairs for twelve years within the forestry field actively involved in the protection, enhancement, and development of the resources within the 600,000 forested acres.

Gregory Newbloom is student a PhD Candidate in the department of Chemical Engineering at the University of Washington, with a research focus on developing stable organic solar cells. He was a research intern with the National Aeronautics and Space Administration developing composite materials to lower energy consumption for space travel, as well as a process engineering intern for Boise Cascades Inc. and initiated several projects to reduce energy consumption throughout the facility.

Jeffrey Richards is a PhD student at the University of Washington in the chemical engineering program. He has previously worked as a research scientist at the University of Kentucky and Purdue University on energy related projects, and the Naval Research Laboratory as a student researcher. He was most recently employed by the United States Naval Research Laboratory developing tools for marine environment assessment

Azra Vajzovic is a PhD candidate at the University of Washington, School of Forest Resources, focusing on bioethanol and xylitol production by naturally occurring yeast in Populus trees. Currently, she is a part of the Bioenergy Department at the University of Washington, working on large- scale fermentation processes using renewable resources to not only produce fuels, but also a variety of bioproducts which can further offset our use of fossil fuels.

Jenny Knoth is a PhD candidate at the University of Washington, School of Forest Resources, focusing on growth enhancement of bioenergy crops on non-agricultural land. She has professional experience in forest resources, pulp and paper mill operations, as well as, a co-founder of non-profit science education program.

Elliot Schmitt is a PhD candidate at the University of Washington, School of Forest Resources, researching the optimization and control of bioprocessing of lignocellulosic feedstocks to higher-value biofuels and biochemicals. He has worked for private industries, government, and NGO research facilities, specializing in simulation and modeling.

Jonathan Tallman is a PhD student at the University of Washington, School of Forest Resources, conducting a comparative analysis of fire severity within forest stands on Yakama Reservation, US Forest Service and Washington State DNR lands. He has worked 15 years within the logging industry and the last 2 years as a Tribal Forester and wildland firefighter.

Maura Shelton is a PhD student at the University of Washington, School of Forest Resources, researching culturally significant species as an indicator to determine the appropriateness of biomass removal for biofuel production. She has worked financial analysts, refugee camp aid, and an instructor.

Mike Tulee is a PhD student at the University of Washington, School of Forest Resources, researching woody biomass energy extraction and methanol production. His work experience includes policy analyst at the Center for Native Education; Project Manager and Education Program Specialist for a variety of Native American educational programs in Washington state and Washington DC

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Mike Noon is a PhD student at the University of Washington, Civil and Environmental Engineering researching the role of algal species in dictating the form and performance of algae-to-fuel life cycles. His work experience includes Intern with Ohio Environmental Protection Agency.

John David Tovey III is a PhD student at the University of Washington, College of Built Environments in the Urban Design and Planning program. His work experience includes Owner/Consultant of Red Elk Design Collaborative, Senior Designer and Project Manager, Landscape Designer.

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Perlack, R.D. et al. 2005. Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. DOE/GO-102005-2135. Oak Ridge National Laboratory,Oak Ridge, TN. 60 pp. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf

Mason, C.L.; Gustafson, R.; Calhoun, J.; Lippke, B.R.; Raffaeli, N. Wood to Energy in Washington: Imperatives, Opportunities, and Obstacles to Progress. *School of Forest Resources, University of Washington*, Seattle WA. 2009.

Coleman et al. 2010. Can Portable Pyrolysis Units Make Biomass Utilization Affordable While Using Bio-Char to Enhance Soil Productivity and Sequester Carbon?. USDA Forest Service, Rocky Mountain Research Station. RMRS-P-61.

Steiner, C.; McLaughlin, H.; Harley, A.; Flora, G.; Reed, A. U.S. Focused Biochar Report: Assessment of Biochar's Benefits for the United States of America. *Center for Energy and Environmental Security.* United States Biochar Initiative. 2010.

Voosen, P. 2010. Once-Lowly Charcoal Emerges as 'Major Tool' for Curbing Carbon. New York Times

Skog, Kenneth E.; Patton-Mallory, Marcia; Rummer, Robert R.; Barbour, R. James. 2008. Strategic Assessment of Bioenergy Development in the West- Biomass Resource Assessment and Supply Analysis for the WGA Region. Western Governors Association (and Antares Group Inc. 38pp.

Debano, L., F., 1990. THE EFFECTS OF FIRE ON SOIL PROPERTIES. Forestry Sciences Laboratory, Arizona State University Campus, Tempe AZ, 1990.

Gaunt, J., L., and J. Lehmann, 2008. Energy Balance and Emissions Associated with Biochar Sequestration and Pyrolysis Bioenergy Production. Environmental Science & Technology200842 (11), 4152-4158, 2008.

Kelli R., G., et. al. 2009. Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change. Potential Environmental Science & Technology201044 (2), 827-833, 2009.