Portable in-woods pyrolysis: Using forest biomass to reduce forest fuels, increase soil productivity, and sequester carbon

Deborah Page-Dumroese[*]
1221 S. Main, Rocky Mountain Research Station, Moscow, ID 83843, Phone: 208.883.2339, FAX: 208.883.2318, ddumroese@fs.fed.us, [*]Conference presenter

Mark Coleman, College of Natural Resources, University of Idaho, Moscow, ID 83843 , mcoleman@uidaho.edu

Greg Jones, 800 E. Beckwith Av., Rocky Mountain Research Station, Missoula, MT 59801 jgjones@fs.fed.us

Tyron Venn, College of Forestry and Conservation, The University of Montana, Missoula, MT, 59812, tyron.venn@umontana.edu

R. Kasten Dumroese, 1221 S. Main, Rocky Mountain Research Station, Moscow, ID 83843, kdumroese@fs.fed.us

Nathanial Anderson, 800 E. Beckwith Av., Rocky Mountain Research Station, Missoula, MT 59812, nmanderson@fs.fed.us

Woodam Chung, College of Forestry and Conservation, The University of Montana, Missoula, MT 59812, woodam.chung@umontana.edu,

Dan Loeffler, College of Forestry and Conservation, The University of Montana, Missoula, MT 59812, drloeffler@fs.fed.us

Jim Archuleta, Umpqua National Forest, 2020 Toketee Ranger Station Road, Idleyld Park, OR 97447, jgarchuleta@fs.fed.us

Mark Kimsey, College of Natural Resources, University of Idaho, Moscow, ID 83843, mkimsey@uidaho.edu

Phil Badger, Renewable Oil International, LLC, P.O. BOX 26, Florence, AL 35630, pbadger@bioenergyupdate.com

Terry Shaw, College of Natural Resources, University of Idaho, Moscow, ID 83843, tshaw@uidaho.edu

Kristin McElligott, College of Natural Resources, University of Idaho, Moscow, ID 83843 Kristin.mcelligott@gmail.com

Citation: Portable in-woods pyrolysis: Using forest biomass to reduce forest fuels, increase soil productivity, and sequester carbon. Page-Dumroese, Deborah; Coleman, Mark; Jones, Greg; Venn, Tyron; Dumroese, R. Kasten; Anderson, Nathanial; Chung, Woodam; Loeffler, Dan; Archuleta, Jim; Kimsey, Mark; Badger, Phil; Shaw, Terry; McElligott, Kristin. 2009. Paper presented at the North American biochar conference; August 9-12; Boulder, CO. Center for Energy and Environmental Security. 13 p.

Portable in-woods pyrolysis: Using forest biomass to reduce forest fuels, increase soil productivity, and sequester carbon

Abstract

We describe the use of an in-woods portable pyrolysis unit that converts forest biomass to bio-oil and the application of the byproduct bio-char in a field trial. We also discuss how in-woods processing may reduce the need for long haul distances of low-value woody biomass and eliminate open, currently wasteful burning of forest biomass. If transportation costs can be reduced by in-woods processing, conversion of biomass to bio-oil may be feasible. Application of bio-char, a byproduct of bio-oil production, to forest soils may help retain soil moisture and nutrients. We also describe the feasibility of pelletizing bio-char, our experience at distributing bio-char in a forest ecosystem and the immediate changes in forest soil physical properties, and its utility as a substrate for production of native plants in nurseries.

Introduction

In the western US alone, approximately 73 million acres of national forest land have been identified as having unnatural, excessive amounts of woody biomass (USDA Forest Service 2000). Improper fire management during the past century has resulted in overstocked forests or too much coarse woody debris on the soil surface (Kauffman 1990). This makes the forests prone to catastrophic fire, rather than historic low-intensity, natural fires. In addition, more homeowners now live in the wildland-urban interface, and fire suppression costs have increased accordingly as federal and state agencies strive to protect those developments (USDA 2003). For instance, from 1995 to 1999, the cost of fire suppression increased five-fold within the Forest Service (Donovan and Rideout 2003). Therefore, fire hazard reduction has become an important topic for natural resource managers. The primary focus of fire hazard reduction is on thinning overstocked forests to generate forests with more natural conditions, which can be sustainably managed at lower risk of catastrophic wildfire (Nicholls et al. 2008).

This abundant woody biomass has potential for biofuel development. It is estimated that in the 15 Western States, more than 28 million acres of forestlands could benefit from hazardous fuel reduction treatments, yielding approximately 345 million oven dry tons from accessible areas (Rummer et al. 2003). Although this plentiful supply of forest biomass is available, finding an economical way to convert this biomass to energy and to add value to byproducts created during conversion has been difficult. Currently, non-merchantable residue remaining from thinning adds to the large volume of biomass found at landings within logging operations where whole-tree harvesting is practiced (Perlack et al. 2005). This biomass is usually burned in place to further reduce wildfire. Unfortunately, the energy, carbon, and nutrients are thereby wasted. Therefore, developing a way to efficiently convert this excessive, waste biomass into beneficial bioenergy has merit. Fast pyrolysis may be such a method.

What is fast pyrolysis?

Wood pyrolysis has been used for centuries to create charcoal or tar used to caulk boats, embalm the deceased, and improve soil productivity (Mohan et al. 2006; Winsley 2007). Using a “slash and char” practice, approximately 50% of the initial carbon in the biomass is sequestered and contrasts to only 3% carbon sequestration from “slash and burn” forest practices (Lehman et al. 2006). “Fast” pyrolysis gets its name because it uses a faster heating rate as compared to conventional pyrolysis methods (Mohan et al. 2006). Either method (fast or conventional) involves the process of heating a biomass feedstock in the absence of oxygen (Huber et al. 2006) and condensing the resultant vapors. Fast pyrolysis produces high yields (up to 80% of the dry weight) of bio-oils suitable for transportation fuels or for refinement for other uses (Huber et al. 2006). Fast pyrolysis requires that uniform-sized biomass is used as feedstock to ensure even heating. The specific characteristics of these products are dependent on the species or tree component used and pyrolysis temperatures (Mohan et al. 2006).

In-woods processing using fast pyrolysis (Badger and Fransham 2006) is one approach to converting biomass to bioenergy that may be profitable for the reactor operator and offer long-term forest sustainability. Both profit and sustainability are critical during the financial analysis of this alternative energy source. A mobile pyrolysis unit can cover the cost of biomass removal through the production of bio-oil and the byproduct bio-char (which can be sold or kept on-site as a soil amendment). The key advantages include a method for reducing accumulated forest biomass while simultaneously reducing wildfire risk, and production of bio-char. In addition, the in-woods fast-pyrolysis unit is compact and does not require a carrier gas to sustain the pyrolysis reaction.

Economics of fast pyrolysis

An aspatial financial model of a 50 bone dry ton per day (BDTPD) mobile in-woods pyrolysis unit has been developed in a spreadsheet software package using pyrolysis system cost and production estimates from ROI (Renewable Oil International, LCC), a firm that has developed mobile pyrolysis technology. Quotes have been obtained to estimate financing and insurance costs, and Oregon State and federal income tax scales have been applied to estimate after tax profit. The unit has an expected life of 10 years, costs $3.46 million and includes a loader, drier and storage drums for bio-oil and bio-char. Three employees are required on-site to operate the unit.

The fast pyrolysis unit is assumed to be located near a recently harvested or thinned forest site. Chipped forest residues are delivered to the unit at 30% moisture content. To reduce feedstock haul distance and cost, the unit is assumed to move twice during a 12 month period. The unit will be operated for 12-hour workdays, 329 days per year. Accounting for typical downtime, the pyrolysis unit will consume the equivalent of 21.9 BDTPD (7127 BDT per year); however, the technology is designed to utilize forest residues at 10% moisture content. As a proportion of input weight, outputs are 57.5%

(55%-60%) bio-oil, 27.5% (25%-30%) bio-char, 1% tar, and the remainder is syngas, which provides the majority of the energy required to run the mobile fast pyrolysis unit.

Dynamotive, a Canadian firm that has developed and utilized fixed-site pyrolysis technology, sells bio-oil (energy content 0.08 MMBTU/gal) at a price per unit of energy that is equivalent to number 2 fuel oil (energy content 0.14 MMBTU/gal, less 10% (Bouchard 2009). In the financial analysis, $1.38/gal has been adopted as the delivered market price for bio-oil, which is based on a number 2 fuel oil price of $2.67/gal[1]. On the recommendation of Dynamotive, a heating value equivalent delivered price for bio-char of $150/ton has been adopted (Bouchard 2009). Note, that if alternative markets, including horticultural applications, are developed, bio-char could be a much more valuable product. Bio-oil is assumed to be sold into a large market five hours by road from the mobile plant, while char is assumed to be sold into regional markets two hours by road from the unit.

A discounted cash flow analysis for a 10-year investment period revealed the mobile pyrolysis unit generates an after tax internal rate of return of 5.4%, an after tax net present value of -$138,000 (using a 7% net of inflation discount rate) and has a pay-back period of 9 years. The average annual revenue and after tax profit, was estimated at $1.45 million and $101,000, respectively. The findings from this preliminary economic analysis are encouraging. The model facilitates sensitivity analyses for all assumptions, and given uncertainty about the marketability of bio-char, it is interesting to note that at a delivered price of only $135/ton, the pyrolysis operation is not financially viable. The financial

---

[1] This was the average number 2 fuel oil price from January 2008 to June 2009. Current number 2 fuel oil prices are lower; however they are likely to rise.

model does not yet account for using or disposing the 70 tons of tar that the operation will produce annually.

On-going economic research on fast pyrolysis will continue to improve the financial model, and compare the financial performance of mobile and fixed-site pyrolyzers for a case study area in the Umpqua National Forest, Oregon. An economic model will also be developed to estimate and compare the fossil fuel consumption, and carbon and particulate matter emissions arising from production and consumption of bio-oil and bio-char from forest residues, relative to disposal of forest residues via in-woods burning and using fossil fuels to generate the equivalent amount of usable energy.

Advantages of bio-char

Bio-char produced through mobile fast pyrolysis is similar to charcoal manufactured through traditional or modern pyrolysis methods. Bio-char is similar to black carbon found naturally in fire-ecosystems and highly resistant to decomposition. Conifer wood is generally considered to contain about 50% carbon and 0.3% nitrogen, while conifer wood charcoal is about 80% carbon and from less than 0.1% (Forbes et al. 2006; Tyron 1948) to about 1.5% nitrogen (Gaskin et al. 2008). The porous nature of bio-char has several other soil benefits. Bio-char can increase the water holding capacity and reduce soil bulk density (Gundale and DeLuca 2006; Lehmann et al. 2006). It can also provide a source of cation exchange sites (DeLuca and Aplet 2008). Bio-char has the potential to promote plant growth and could be stored in the soil to sequester carbon (Warnock et al. 2007). Bio-char may also serve as a source of reduced carbon compounds that may directly or indirectly benefit soil microbial populations (Pietikäinen et al. 2000)

Combined, the properties of bio-char suggest it may be a long-term method of carbon sequestration on forest sites and perhaps lead to an overall gain in productivity for many forest sites – particularly those with little organic matter within the mineral soil, depending on the nutrients found in the original forest biomass (Gaskin et al. 2008). Nitrogen and sulfur may be retained in significant amounts within bio-char. This means that site productivity can be improved if bio-char is returned to the harvest site after energy extraction.

Returning bio-char to the mineral soil can increase soil organic matter content. Bio-char not mixed into the mineral soil may be vulnerable to water or wind erosion or to loss in subsequent fires (Zackrission et al. 1996). Methods to retain bio-char within a forest site could include pelleting the bio-char, mixing it into the mineral soil, or allowing wildfires to convert forest biomass and coarse wood into charcoal and wood ash (DeLuca and Aplet 2008). Bio-char represents an opportunity to return removed in the biomass from project locations and the reapplication to project sites may outweigh other potential uses. Our work on reapplication of bio-char to a forest site on the Umpqua National Forest has just started, but we are evaluating reapplication rates based on total biomass removed and changes in soil physical, chemical, and biological properties. We are also evaluating tree growth and nutrient status on these plots.

Adding value to bio-char: Growing native plants for restoration

As noted above, although bio-char is mainly carbon, it may contain high levels of phosphorus, potassium, calcium, nitrogen, and sulfur which are important plant nutrients. Because of this, bio-char may have utility in nurseries.

In the United States, about 350 million seedlings are grown annually in containers for wildland restoration; most are produced in the western (250 million) or southeastern (100 million) United States near forested land where conversion of woody biomass to bio-energy would occur. Generally, the production substrate is a mixture of peat moss and inorganic materials. Vermiculite is the most commonly used inorganic material because it has low bulk density (100 kg m^{-3}), neutral pH, and relatively high cation ion exchange capacity (82 mmol kg^{-3}) (Landis et al. 1990). Use of vermiculite has, however, become more difficult because of rapidly increasing costs. Between 2004 and 2008 the cost increased from \$65 to \$98 m^{-3} (Landis and Morgan 2009).

Compared to vermiculite, bio-char has twice the bulk density, similar pH, and nearly 2 times the cation exchange capacity (140 mmol kg^{-3}). Unfortunately, bio-char from fast pyrolysis is a fine ashy-dust difficult to handle and therefore difficult to evenly incorporate into a substrate for container seedlings. Our pilot efforts suggest that bio-char can be pelleted through extrusion using a mixture of sawdust, starch, and polylactic acid. Pelleted bio-char would be easier to handle, and the larger size of pellets may improve total porosity and aeration porosity in containers, highly desired attributes. Having an inorganic material capable of holding additional applied nutrients would mean less nutrient loss through leaching during irrigation, thereby mitigating potential environmental contamination of ground and surface water.

Using bio-char pellets to replace vermiculite as part of a soilless medium has one other important value-added property. Because bio-char is retained in the root plug of outplanted seedlings, the carbon is subsequently sequestered below ground without additional cost. Assuming (1) an average, modest-size container with 105 cm^3 volume, (2) using up to 25% biochar to replace the customary 50% vermiculite, and (3) 350 million seedlings produced per year, this technique has potential to sequester nearly 1600 metric tons of carbon annually.

We plan two nursery experiments. In the first experiment, with collaboration from the Finnish Forest Research Institute, we will analyze various mixtures of peat and pellets (including the sawdust, starch, and polylactic acid) for total and available nutrients, cation exchange capacity, carbon-to-nitrogen ratio, and pH after incubation. In addition, we will measure physical properties of the mixtures, including bulk density, shrinkage, and porosity, as well as develop moisture retention curves. Based on the results, we plan to grow a crop of native plants at the University of Idaho as part of experiment two. During the growing season we will monitor nutrient leaching and seedling allometry. At the end of the growing season seedlings will undergo standard tests of morphological and physiological quality.

Forest Management Implications

A portable fast pyrolysis system offers a solution to biomass accumulation in forested ecosystems. By using abundant and renewable forest biomass that is annually produced through forest harvest residues or hazard fuel reduction it is possible to generate a liquid fuel (bio-oil) that will reduce dependence on foreign or non-renewable energy sources. In-woods biomass conversion can also improve the economic and environmental impact of biomass utilization for energy production. In addition, the bio-char byproduct can be redistributed onto the forest site or used in nursery media to improve nutrient exchange capacity, water holding capacity, and sequester carbon. The current situation of burning forest residues as waste can be altered using in-woods processing to create a renewable bio-oil and bio-char.

References

Badger, P.C., Fransham, P. 2006. Use of mobile fast pyrolysis plants to densify biomass and reduce biomass handling costs – a preliminary assessment. Biomass and Bioenergy. 30: 321-325.

Bouchard, T. Chief Operating Officer, Dynamotive Energy Systems Corporation, Personal Communication, March 26, 2009.

DeLuca, T.H., Aplet, G.H. 2008. Charcoal and carbon storage in forest soils of the Rocky Mountain West. Front. Ecol. Environ. 6: 18-24.

Donovan, G.H., Rideout, D.B. 2003. A reformulation of the cost plus net value change (C+NVC) model of wildfire economics. For. Sci. 49: 318-323.

Forbes, M.S., Raison, R.J., Skjemstad, J.O. 2006. Formation, transformation and transport of black carbon (charcoal) in terrestrial and aquatic ecosystems . Sci. Total Environ. 370: 190-206.

Gaskin, J.W., Speir, A., Morris, L.M., Ogden, L., Harris, K., Lee, D., Das, K.C. 2007. Potential for pyrolysis char to affect soil moisture and nutrient status of a loamy sand soil. In: Proceedings of the Georgia Water Resources Conference. 27-29 March 2007. University of Georgia, Athens, GA.

Gaskin, J.W., Steiner, C., Harris, K., Das, K.C., Biben, B. 2008. Effect of low-temperature pyrolysis conditions on biochar for agricultural use. Transactions of the ASABE. 51: 2061-2069.

Gundale, M.J., DeLuca, T.H. 2006. Temperature and source material influence ecological attributes of Ponderosa pine and Douglas-fir charcoal. For. Ecol. Manage. 231: 86-93.

Huber, G.W., Iborra, S., Corma, A. 2006. Sythesis of transportation fuels from biomass: chemistry, catalysts, and engineering. Chem. Rev. 106: 4044-4098.

Kauffman, J. B. 1990. Ecological relationships of vegetation and fire in the Pacific Northwest, In: Walsted, J.D; Radosevich, S.R., Sandberg, D.B, (tech coord). Natural and prescribed fire in Pacific Northwest forests. Corvallis, OR: Oregon State Univ. Press; 39-52.

Landis, T.D., Morgan, N. 2009. Growing media alternatives for forest and native plant nurseries. In: Dumroese, R.K., Riley, L.E., (tech coords). National proceedings: forest and conservation nursery associations—2008. Fort Collins, CO: USDA Forest Service Rocky Mountain Research Station. Proceedings RMRS-P-58: 26-31.

Landis, T.D., Tinus, R.W., McDonald, S.E., Barnett, J.P. 1990. Containers and growing media, Volume 2, The Container Tree Nursery Manual. Washington, DC: USDA Forest Service Agriculture Handbook 674. 88 p.

Lehman, J., Gaunt, J. Rondon, M. 2006. Biochar sequestration in terrestrial ecosystems – a review. Mitig. Adapt. Strat. Global Change 11: 403-427.

Mohan, D., Pittman, C.U., Jr., Steele, P.H. 2006. Pyrolysis of wood/biomass for bio-oil: A critical review. Energy and Fuels 20: 848-889.

Nicholls, D. L., Monserud, R.A., Dykstra, D.P. 2008. A synthesis of biomass utilization for bioenergy production in the western United States. USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-753. 48 p.

Perlack, R.D., Wright, L.L., Turhollow, A.F., Graham, R.L., Stockes, B.J., Erbach, D.C. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 59 p.

Pietikäinen, J. Kiikkilä, O., Fritze, H. 2000. Charcoal as a habitat for microbes and its effect on the microbial community of the underlying humus. Oikos 89: 231-242.

Rummer, B., Prestemon, J., May, D., Miles, P., Vissage, J., McRoberts, R., Liknes, G., Sheppard, W., Ferguson, D., Elliot, W., Miller, S., Reutebuch, S. Barbour, J., Fried, J., Stokes, B., Bilek, E., Skog, K. 2003. A strategic assessment of forest biomass and fuel reduction treatments in Western States. Washington, DC: USDA Forest Service. 18 p.

Tyron, E.H. 1948. Effect of charcoal on certain physical, chemical, and biological properties of forest soils. Ecol. Monogr. 18: 82-115.

USDA Forest Service 2003. Large fire cost reduction action plan. Washington D.C., USDA Forest Service. 24 p.

Warnock, D.D., Lehmann, J., Kuyper, T.W., Rillig, M.C. 2007. Mycorrhizal responses to biochar in soil – concepts and mechanisms. Plant Soil 300: 9-20.

Winsley, P. 2007. Biochar and bioenergy production for climate change mitigation. New Zealand Sci. Rev. 64: 5-10.

Zackrisson, O., Nilsson, M-C., Wardle, D.A. 1996. Key ecological function of charcoal from wildfire in the boreal forest. Oikos 77: 10-19.