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Appendix: In-Stand Surface Application of Biochar in Forestlands

-Methodology Review-

External, R1 Review Round

Expert Peer Reviewers: Kelpie Wilson & Abby Colehour

Date Reviews Completed: 11.11.22

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CONTENT referenced by reviewer's comment *e.g. Section number + paste exact text*	**REVIEWER'S COMMENT** *Please paste the comment from the reviewer*	**AUTHOR'S RESPONSE** *Please describe how the comment was addressed and include new content in quotations*	**Reviewer's Conclusion** [PASSED/ REJECTED *WITH COMMENTS*]
Surface Application Considerations	Clarify the economics here. I believe this is based on selling the biochar: "As noted by Rocky Mountain Research Station Economist Dr. Dan McCollum, "[Place-based biochar production] can change the economics of forest treatments, such as thinning and fuel reduction treatments, and forest restoration projects. The result might be that more projects are economically feasible, and more projects get done".[1]"	This paragraph was removed	Passed

[1] Neukirch, *Biochar Basics,* 1.

Background and Reasoning - “local biochar expert, Kelpie Wilson”	Delete - local biochar expert, Kelpie Wilson	Replaced with “As highlighted by biochar consultant and Biochar in the Woods committee chair for the US Biochar Initiative, Kelpie Wilson, the best use of biochar would be to leave it in forest soils.”[2]	Passed
1.1: “apply water to the biochar immediately after application”	“apply water to the biochar immediately after application” with “ensure that biochar is adequately wetted during the production and application process”	Suggestions accepted	Passed
Section 2: “increase the economic viability”	needs clarification - are you hauling char off site and selling it? Or using it onsite for ecological benefits? How is that monetized? It is not clear how making biochar in the woods impacts economics of veg management projects.	Replaced with “provide new economic opportunities in the form of eco-credits and to improve ecological benefits of current forest management practices.”	Passed
Section 2: “from feedstock originating”	Add this text after “biochar” in first sentence to make it	Suggestions accepted	Passed

[2] WIlson, Biochar in the Woods, 5:58.

	clear that feedstock is not being brought into the site for production and application, but is being sourced directly from the site		
Section 2: “ecological benefits of current forest management practices”	This would be a good place to add additional context and nuance to appropriate uses of biochar. For example, “the creation of biochar alone is not an ecologically beneficial practice unless it is anchored within sustainable, regionally appropriate, regenerative land management systems that support overall ecosystem function, biodiversity, and sociocultural wellbeing.”	Suggestion accepted - added in “Importantly, the creation of biochar alone is not an ecologically beneficial practice unless it is anchored within sustainable, regionally appropriate, regenerative land management systems that support overall ecosystem function, biodiversity, and sociocultural wellbeing.”	Passed

Conservation Burns: "This is the simplest and most accessible way to produce biochar."	True in many contexts, but it requires water. There are simple and accessible ways to produce biochar without water, which might be more appropriate in some contexts.	Changed sentence to read: "Provided adequate water availability for quenching, this is the simplest and most accessible way to produce biochar."	Passed
Conservation Burns: "growth of invasive species and decrease carbon emissions"	Add: ", protect soil microbial life,"	Suggestion accepted	Passed
2.1: "eight"	Replace with "six"	Suggestions accepted	Passed
2.1: "These piles will be built in a cone shape, with the largest diameter material in the center of the piles, and the smaller material on the top and bottom"	Delete this text - One would construct a pile differently depending on the forest type, feedstock, climate and weather conditions, For example, in the Willamette Valley where conditions are wetter we place more small material on top because we need it to get the pile lit, and we sometimes lean larger logs against the outside of the pile to insulate the inner	Suggestions accepted - changed to "Optimal pile construction will vary according to the moisture content, size and species of the material."	Passed

	material and let the logs dry out and heat up To keep it more general you could instead say: -Piles will be constructed in a way that facilitates top-lighting and even burning of material (you could share the existing method as an example without being restrictive with it)		
2.1: “contain approximately 25% air space	Delete this text - left in largely free of dirt and rock as it was noted that this is crucial ad the most important point about pile construction	Suggestions accepted	Passed
2.1 - “approximately 25%	Replace: with “adequate”	This was changed to “The majority of the material must have a moisture content of 25% or less, as measured in the field.”	Passed
2.1: “All feedstock will be thoroughly dried”	Also a crucial point. I recommend no more than 25% moisture for the	This was left in and this text added: “The majority of the material must have a moisture content of 25% or less, as measured in the field.”	Passed

	majority of the material. Also important to describe how to take moisture measurements from the sides (past the bark layer) and not from the ends of logs.		
2.1: “prior to burning”	Delete this text	Suggestion accepted	Passed
2.1 ‘4-5”	Replace With “5-6”	This entire sentence was updated to read - “Optimal pile construction will vary according to the moisture content, size and species of the material. Piles will be widely distributed across the project area to decrease labor costs and emissions from transporting feedstock, and to retain forest nutrients in place. Project proponents must conduct appropriate background research to determine which construction methods are best suited to their local conditions.” ”	Passed
2.1: “The majority of the material must have a moisture content of 25% or less, as measured in the field.”	Add this text	Suggestions accepted	Passed

Background & Reasoning: “reduce costs for forest managers”	Cost of what?	This sentence was deleted	Passed
2.2: “and reduces emissions by ensuring that most of the smoke is burned”	Replace with “Some larger or wetter logs will remain incompletely charred. These will be extinguished and set as”	Replaced as suggested	Passed
2.2: “ lit from the top to create an oxygen limiting environment”	Replace: “lit from the top and managed to create an oxygen limiting environment” with “ignited in such a way that a strong flame is developed, forming a cap on the top of the pile.”	Suggestions accepted	Passed
2.2: “As the flames move downward, they consume the oxygen that would otherwise reduce charcoal to ash.”	Replace: “As the flames move downward, they consume the oxygen that would otherwise reduce charcoal to ash.” with “The flame burns smoke emissions, reducing particulates. Piles will be tended to ensure the flame cap…”	Suggestions accepted	Passed

2.2: “reduces emissions by ensuring that most of the smoke is burne”.	Quenching has nothing to do with burning smoke. The flame cap is what burns the smoke.	This was omitted and this content was added “Piles will be tended to ensure the flame cap is maintained. As long as a strong flame is maintained, biochar production temperatures will range from 1100 to 1400 degrees F.”	Passed
2.2: “Optimal pile construction will vary according to the moisture content, size and species of the material.”	Add this content in	Suggestions accepted	Passed
2.2: This leaves a low-oxygen environment on top where biomass is converted to charcoal. A temperature of 700-750° F will be maintained throughout to reduce emissions from pyrolysis. Pyrolysis will take approximately 20 minutes per pile, at which point the pile will be quenched with pressurized water.	Again, too restrictive. Not sure where you got 20 minutes from. It will take longer, and be variable depending on the pile characteristics. Remove the numerical details on temperature and pyrolysis time, as this varies depending on site-specific factors. The point is, in order to maximize charcoal formation and carbon sequestered,	Changed to: “As long as a strong flame is maintained, biochar production temperatures will range from 1100 to 1400 degrees F. Once the pile is reduced to mostly glowing coals and strong flaming has stopped, the coals will be quenched with water and raked to a thin layer to lose heat. “	Passed

	-Light from the top (as already mentioned) -Flame should be present consistently throughout the burn with minimal smoke or smoldering until all woody material has ignited and gone to coal, at which point the pile will be quenched Delete: “This leaves a low-oxygen environment on top where biomass is converted to charcoal.		
2.3: “10-15%”	You need to define terms here. What is carbon conversion efficiency? C in biomass to C in biochar? Or biomass to biochar? By dry weight or by volume?	This section was removed	Passed
2.3: “700-750° F using coniferous feedstock will produce a stable char with estimated pH levels in the range of 8-9.”	Temperatures in a burn pile in the flame will be hotter than this. pH of this char will be more like 9-10, depending on ash content	The was removed	Passed

	Also noted for this section: Water doesn't need to be pressurized, it just needs to put out the coals. It is also possible to quench by suffocation (cut off air supply, using no water). See note about other biochar production methods in the general comments section. Indeed we don't collectively have all of the field trials to confirm efficiency for conservation burns. I myself am not an expert in this matter. However, given the wide range of variables inherent in making biochar in the woods, it is near impossible to assure a consistent temperature or burn efficiency, regardless of how much research is done about it. Rather than attempt to control these variables, I think a more useful way to standardize		

	this method is to measure the volume of coal produced. After quenching: -Remove unburned or partially burned biomass -Scoop charcoal into a bucket with known volume -Filter charcoal through a screen (i.e. 1/4” wire mesh) to reduce ash and soil volume -As buckets are filled, disperse the char evenly through the same area from which the feedstock originated. Keep track of the number of buckets as you go. This is the lowest tech way to disperse charcoal and requires human power, quite literally a bucket brigade. -Consult Kelpie Wilson for sources referencing this strategy		

2.4 - Additional considerations	Again, this is very regionally limited. Consider making this more general: -Burn within appropriate seasonal burn windows considering local fire safety conditions and air quality regulations/recommendations (practitioner could be asked to document/reference their knowledge and alignment with these) -Safe burning conditions should factor in atmospheric and soil moisture, fuel moisture, wind speed and direction, slope and aspect, time of day, pile size, proximity of piles to surrounding vegetation… -Piles should not be located within wetlands or floodplains in order to reduce flood loss. There may be exceptions to this if local conditions or	No change made - noted	Passed

	management practices allow sufficient no-till incorporation of biochar into the soil in a way that prevents loss by flooding (again, practitioner could be asked to document/demonstrate this)		
2.5: “Between 2-10 tons of biochar will be applied per acre, or about 16-18 cubic”	Kelpie: dry bulk density of this kind of biochar is about 250 pounds per cubic yard. Thus, 2-10 tons would equal 16 - 80 cubic yards. You are much more likely to produce the lower end than the higher end. Each pile will yield at most a half a cubic yard in my estimate. Probably more like a quarter of a yard - about 5 cf or 7-8 five gallon buckets per pile. Producing 16 cubic yards (2 tons) of biochar	Replaced with “Application rates will vary depending on how much excess fuel needs to be removed to achieve forest management objectives. A common threshold is between 1-3 tons of biochar per acre, or about 8-24 cubic yards/acre. More importantly, biochar should be dispersed back out onto the same acreage that the feedstock originated.”	Passed

	would require about 64 piles per acre. Abby: Too specific. Appropriate application rate depends entirely on how much excess fuel needs to be removed to achieve forest management objectives. If you instead use the metric of volume of biochar produced, and reimbursements/credits can be based on volume produced, regardless of per acre densities, this would allow the appropriate flexibility for widely varying local conditions. It is important, however, that biochar gets dispersed back out onto the same acreage that the feedstock originated.		

2.6: “spread with rakes”	Or buckets or other hand tools	Changed to: “Other hand tools and buckets may be appropriate as well.”	
2.6: “While still under development, researchers at The Missoula Technology and Development Center have partnered with the Rocky Mountain Research Station to design and test a high-capacity biochar spreader. This spreader can be mounted on a log forwarder and used on skid trails and log landings to distribute biochar. This type of technology will be critical to scaling place-based biochar production and application efforts for future projects.”	I do not see this spreader as having any utility for spreading biochar from a conservation burn. It is really for spreading large amounts of biochar created off-site.	Changed to “Other hand tools and buckets may be appropriate as well.”	Passed
Section 3: “Benefits of In-Stand Surface Application of Biochar”	This section would be another good place to emphasize that “forest	Added text: “Forest health varies widely depending on location and forest type, and it is thus critical that land managers and practitioners of this	Passed

	health" varies widely depending on the region and forest type, and that it is critical that land managers and practitioners of this methodology demonstrate a knowledge of the local forest type, management objectives, and how biochar fits into that.	methodology demonstrate a knowledge of the local forest type and management objectives first, before producing biochar. Though biochar will be integrated into these strategies differently depending on location,"	
Section 3: "hectare"	Add in Per annum	Suggestion accepted and additional text added	Passed
Section 3: "ground"	Surface application also mimics the way that wildfire would add biochar as charred material falls from burned trees onto the soil surface.	No edit required - noted	Passed
3.1.b "Although there is some evidence that biochar can deplete soil carbon stocks in the short	There is a better way to describe this. I will work on it.	Replaced with "Although application of biochar may temporarily increase microbial respiration in soils, increasing CO2 emissions, cumulatively biochar has	Passed

term, biochar applied without additional organic materials appears to dampen this impact."		been shown to increase soil carbon stocks in forests by as much as 41%."[3]	
3.1.b: "Soil carbon is the single best indicator of soil health"	I'm not a soil expert, but this seems questionable	Changed to: " Just as pyrolysis of biomass releases some carbon into the air in the process of fixing the remaining carbon, so biochar application to soil often promotes increased microbial respiration. This is called priming and can occur from the addition of nutrients, pH changes, and the contribution of biochar stable carbon to the support of microbial life.[4] However, after biochar has aged in soil it begins to increase and protect soil carbon stocks through the formation of humus that adheres to biochar surfaces.[5] In addition, soil carbon emissions of CO2 and other GHG may start to decrease due to the increased metabolic efficiency of the microbial community as a whole in the presence of biochar.[6] This is called negative priming. In addition to carbon, biochar also	

[3] Sarauer, J. L., Page-Dumroese, D. S., & Coleman, M. D. (2019). Soil greenhouse gas, carbon content, and tree growth response to biochar amendment in western United States forests. *GCB Bioenergy*, *11*(5), 660–671. https://doi.org/10.1111/gcbb.12595

[4] Kuzyakova, Y., Friedelb, J. K., & Stahra, K. (2000). Review of mechanisms and quantification of priming effects. *Soil Biology & Biochemistry 32 (2000) 1485-1498.* https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.709.6588&rep=rep1&type=pdf

[5] Zimmerman, A. R., Gao, B., & Ahn, M.-Y. (2011). Positive and negative carbon mineralization priming effects among a variety of biochar-amended soils. *Soil Biology and Biochemistry*, *43*(6), 1169–1179. https://doi.org/10.1016/j.soilbio.2011.02.005

[6] Ameloot, N., Graber, E. R., Verheijen, F. G. A., & De Neve, S. (2013). Interactions between biochar stability and soil organisms: Review and research needs. *European Journal of Soil Science*, *64*(4), 379–390. https://doi.org/10.1111/ejss.12064

		increases nutrient availability, including soil phosphorus, potassium, and nitrogen, and decreases nutrient loss from leaching."[7,8]	
3.2: "resulted in a 41% mean increase in woody biomass"	I think this was nursery trees, not forest trees	This was researched and determined to be accurate	Passed
3.2: "Additionally, conservation burns avoid the scarring and subsequent growth of invasive species common after wildfires or slash pile burns."[9]	This is huge and should be emphasized. Will look for some more references for you.	No action required	Passed
3.2: "health"	There is a whole other line of evidence to bring in here regarding depletion of wildfire char in forest soil horizons due to fire suppression. See my paper Biochar for Forest Restoration in the Western	Do you think this is adequately covered in the following section: Wildfire Mitigation and Recovery?	Passed - agreed that it is covered in the Wildfire Mitigation and

[7] Borchard et al. (2019). Biochar, soil and land-use interactions that reduce nitrate leaching and N2O emissions: A meta-analysis. *Science of The Total Environment*, *651*, 2354–2364. https://doi.org/10.1016/j.scitotenv.2018.10.060

[8] Jindo et al. (2020). Role of biochar in promoting circular economy in the agriculture sector. Part 1: A review of the biochar roles in soil N, P and K cycles. *Chemical and Biological Technologies in Agriculture*, *7*(1), 15. https://doi.org/10.1186/s40538-020-00182-8

[9] Amonette, *Biomass to Biochar,* 63.

	United States (2015) for quotes and references: https://img1.wsimg.com/blobby/go/55a2e356-17ba-48af-b8c3-a76d3f66be29/downloads/Biochar_for_Forest_Restoration_WBA_rev.pdf?ver=1663358352628		Recovery section.
Maximizing Net Carbon Capture "emissions"	Note: See the LCA comparison between flame cap kilns and a mobile gasifier for detailed documentation for why this is true. Report here: https://img1.wsimg.com/blobby/go/55a2e356-17ba-48af-b8c3-a76d3f66be29/downloads/w2w-biochar-lca-final-report.pdf?ver=1663358352629	No edit required	Passed
Wildfire Mitigation and Recovery: "Revitalizing these practices through place-based biochar production"	No. Revitalizing these practices through the return of Indigenous stewardship of the land is the best tool and should be	Changed to: "Short of revitalizing these practices through the return of Indigenous stewardship of the land, place-based biochar production can support the restoration of forests to a condition where prescribed and cultural burning is once again	Passed

	prioritized above all else. Place-based biochar production is a temporary intervention and harm-reduction tool as we recover from fire suppression. Biochar production can support the restoration of forests to a condition where prescribed and cultural burning is once again possible.	possible. Place-based biochar production is a temporary intervention and harm-reduction tool as we recover from decades of fire suppression. “	
4.1: “In forestlands”	…in forestlands in which the removal and conversion of biomass is consistent with the best management practices appropriate to the forest type. Land should never be converted from other uses or managed explicitly for biochar production. Biochar production can help close the loop in forest management systems that require removal of excess woody debris.	Added in: “in which the removal and conversion of biomass is consistent with the best management practices appropriate to the forest type.”	Passed

4.3.b: “Additional water should be added to thoroughly wet biochar immediately after application to the soil surface.”	Kelpie: details? Is this necessary? if you are already using water to quench? Do you need more? Abby: ? I have not heard of this. What is the purpose? This poses an additional barrier that may not be necessary	Verra's main concern with surface application is that biochar could be lost to wind or water transport. This stipulation is in response to their concern about wind transport if biochar is dry and small. Response: Good point. I'll make it a little more broad - added “if, needed”	Passed

Additional Notes:

Note from an initial meeting requested on October 11, 2022 to address: “*The main section..to discuss…the conservation burn methodology. I think it needs more work. For one thing, there is not just one way to do this. There are important considerations that will change how piles are built depending on feedstock moisture, species and size of the logs. There are also several places where I have questions about definitions and assumptions. You can see the preliminary comments I have added to the draft that you shared with me.*”