BIOAg Project Report

Report Type: PROGRESS

Title: Impact of Process Emissions on Climate Offsets by Different Biochar Production Methods

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Abstract:

Agricultural use of biochar is generally considered a sustainable and climate-friendly way to increase farm productivity. These benefits, however, depend on how biochar is produced. I have performed some preliminary calculations for a range of biochar production technologies using published data for methane (CH_4) emission and biochar carbon efficiency that suggest that most biochar production approaches do not achieve carbon-neutrality until several decades to centuries after production. Given that carbon payback periods longer than a decade are considered unacceptable for climate-change mitigation technologies, it is clear that the biochar industry faces a significant challenge to clean up production emissions if biochar is to continue to claim to be climate friendly. I have assembled a team of biochar production experts who have agreed to work together to refine the model I have developed and to write a peer-reviewed publication that addresses the issue of methane, nitrous-oxide, and soot emissions during biochar production. This paper will introduce the problem, identify emission levels and production approaches that retain the climate benefits of biochar, and recommend biochar production research priorities to decrease emissions of climate-warming gases and aerosols. Further, we plan to make open-source versions of the algorithm (code and spreadsheet formats) freely available, and to publish the paper in an open-access format to ensure maximum impact. The proposed work resonates with several research goals of the BIOAg program and the WSU Grand Challenge in Sustaining Resources by addressing renewable, non-polluting, and environmentally sound approaches to production of food (as enhanced by biochar amendments to soils) and bioenergy. By sounding the alarm, we hope to spur the industry to address production emissions and ensure its economic future.

Project Description:

The work encompasses five tasks.

Task 1 completes development of the algorithm in spreadsheet form for calculation of the GHG footprint of biochar-production technologies and alternative biomass scenarios. Before the start of the BioAg project, the algorithm included inputs for biochar C efficiency, CH_4 emissions during production, water and C contents of biomass feedstock, fossil-C emissions reductions from bioenergy co-production (if any), biochar decomposition rate in soil, biomass decomposition rate on forest floor (for alternate scenario), estimated crop productivity enhancement from biochar amendments to soil, and annualized GWP values for CH_4 emissions (based on Refs 1 and 2). To this, we are adding N content of biomass and biochar, N_2O and soot emission factors during production, N_2O and soot GWP values (based on Refs 2 and 3), alternate biomass scenarios for intense wildfires and low-level wildfires that may include impacts of non-CH_4 volatile organics and other aerosols (which have climate-cooling effects opposite to those of CH_4 and N_2O), and factors to account for the impact of biochar amendments on soil organic matter levels in agronomic soils. The intent, however, is to produce a flexible algorithm suitable for localized estimates of the impact of biochar production methods on carbon-equivalent (C_{eq}) offsets, rather than a single all-encompassing global estimate (as was done in Ref 4), and to provide ranges of outcomes that reflect the different feedstock and production situations that may be encountered locally.

Task 2 focuses on the collection and normalization of published and other available input data for the full spectrum of biochar production methods (i.e., from traditional earth-covered pits to modern pyrolysis systems with co-production of bioenergy). Some datasets from private entities will likely need their sources to be kept confidential. A similar effort will be applied to attempt to cover the range in alternative biomass scenarios from slow decay of trees in forests, to rapid decay of herbaceous biomass in fields, to various wildfire scenarios. Choice of alternative scenario can have a critical impact on net GHG offsets calculated for biochar production methods.

Task 3 applies the algorithm to the analysis of the various combinations of biochar production methods and alternate biomass scenarios, compiles the results in terms of annualized C_{eq}-offset values and C-payback periods, and performs interpretive analysis of the relative impacts of various input parameters such as GHG emissions during production, biochar-C efficiency, and feedstock moisture content on overall C_{eq} offset values.

Task 4 involves writing and submitting a manuscript to a high-impact journal that describes the problem, outlines the algorithm, summarizes the results, provides limiting values of key production factors that ensure the production process is climate-friendly, and explores possible ways to improve emissions during biochar production such as simple changes in kiln designs.

Task 5 takes the spreadsheet algorithm, adapts it to a coded version (programming language yet to be determined, although it may likely be Python due to its open-source nature), verifies that identical results are obtained by both versions, and then posts them both on publicly available websites such as those maintained by CSANR and the Ithaka Institute.

Work in these five tasks is being performed by a team consisting of myself and six collaborators (with their own funding) selected on the basis of their experience and knowledge of the subject matter. I am leading the effort, and focusing my technical efforts on algorithm development, alternate scenario development, interpretive analysis, and writing the first draft of the manuscript. The Ithaka Institute has offered to take on development of the coded version of the algorithm.

Outputs

- Overview of Work Completed and in Progress:

  Task 1—We have added GWP calculations for N_2O and soot to the algorithm. Seven alternative biomass scenarios are envisioned. Of these, three have been completed (combustion for bioenergy, biomass decay, wildfire), and four are in various stages of completion (conventional slash burning, conservation slash burning (top-lit), landfill disposal, and aerobic composting). We expect to complete this task by 10 January 2021.

  Task 2—We have compiled emissions and production data for 23 different biochar production methods, and hopefully will have data for a few more before we write the manuscript. We expect to complete this task by 10 January 2021.

  Task 3—Application of the algorithm is easily done, but we await completion of Tasks 1 and 2 before generating final values suitable for interpretation and publication.

  Task 4—We accepted an invitation to submit our manuscript as part of a special article collection on the research topic "Carbon Sink Accounting, Certification and Trade" to be published in the open-access journal *Frontiers in Environmental Science*. The full manuscript is due on 15 January 2021. If the deadline for the special issue is not met, we will still submit the manuscript to the same journal.

  Task 5—Work on this task has not started.

- Methods, Results, and Discussion (discussion for final reports only):

  An overview of the methods used is provided in the project description (above). Some details of the GWP calculations and development of the wildfire alternative biomass scenario are given here, followed by an example showing the relative impacts of the three alternative biomass scenarios on the Ceq offsets of a modern slow pyrolysis biochar production method.

  The GWP calculations for CO_2, CH_4, and N_2O are based on the methods given by Refs 1 and 2. First, annual values for the absolute GWP [AGWP(t)] per unit mass are calculated for a single pulse of each gas of interest. The AGWP depends on the radiative efficiency of the gas/aerosol as an absorber/emitter, the lifetime of the gas/aerosol in the atmosphere, and, in the instance of CH_4 and N_2O, interactions between gases that affect their atmospheric lifetimes. For CH_4 and N_2O, a simple first-order decay rate is assumed for lifetime, whereas for CO_2 a combination of three first-order decay processes is used. Second, the GWP values for each year [GWP(t)] are calculated as the ratio of the AGWP values of the gas of interest and CO_2 [i.e., $GWP(t) = AGWP_x(t)/AGWP_{CO2}(t)$]. Finally, the GWP values assuming continuous production (as distinguished from a single year's worth of production) are calculated by summing the single-pulse GWP values for the current (i.e., t_x) and all previous (i.e., t_1, t_2, t_3, . . ., t_{x-1}) years and dividing this sum by the number of years of production (t_x). For soot, the GWP values were estimated by fitting a power law relationship to the data of Ref 3 for black carbon aerosols, after correcting the AGWP values for CO_2 to match those used by Refs 1 and 2. Plots of the GWP values for the three variant GHGs (GWP for CO_2 = 1) are shown in Fig. 1 for the single-pulse and continuous-production situations.

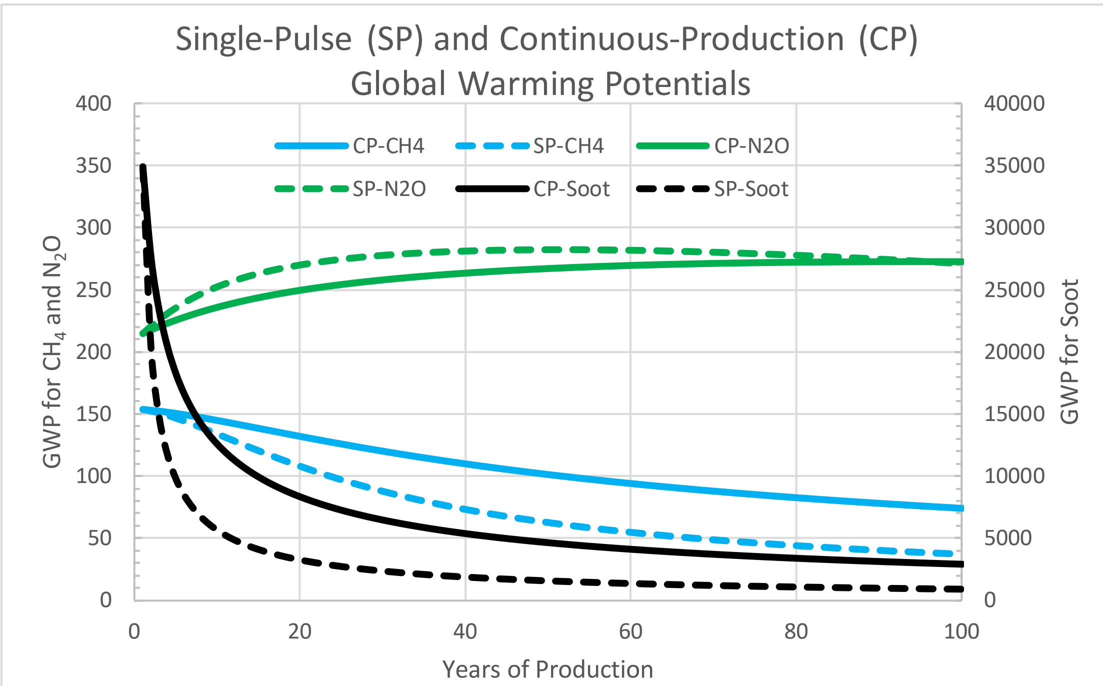

Figure 1. Evolution of single-pulse and continuous-production GWP values for CH_4, N_2O and soot, assuming a constant CO_2 atmospheric concentration of 408 ppmv.

The wildfire alternative biomass scenario required estimation of the fractions of the biomass converted to biochar and to necromass (dead biomass not consumed by the fire), with the remainder assumed to have been combusted. The following typical parameters were adopted, based on existing literature (Refs 5 through 8). Values of 3.6%, 64.9%, and 27% were assumed for biochar, necromass, and combustion C efficiency (i.e., the fraction of biomass C converted to each form). The half-life of the necromass was assumed to be the same as for the original biomass. Carbon content of the biochar was assumed to be 60%, somewhat less than for commercial biochar due to the lower mean production temperature. A methane emission factor of 2.5 g CH_4/kg dry biomass was used.

An example of the difference made by the choice of alternative biomass scenario for one of the best biochar production methods is given in Figure 2. Here the net C_{eq} emissions over time of biochar production by a modern slow pyrolysis kiln method are plotted for three alternative scenarios: 1) natural decay of the biomass, 2) modern combustion of the biomass to generate energy, and 3) wildfire (using the parameters described in the previous paragraph). If natural decay is the alternative fate of the biomass, a full 40 years is required before the production of biochar generates a net C_{eq} benefit (i.e., the C-payback period). This period is well beyond the generally accepted maximum limit of 10 years for C payback. However, for each of the other two scenarios, modern bioenergy and wildfire, the production of biochar by the modern slow pyrolysis method yields an immediate and lasting C_{eq} benefit on the order of -250 g C_{eq}/kg biomass C. The result in the wildfire scenario continues to improve in value over the course of 100 years to -400 g C_{eq}/kg biomass C. This result is especially encouraging, given the need for wildfire fuel reduction in forests of the western states in the U.S.

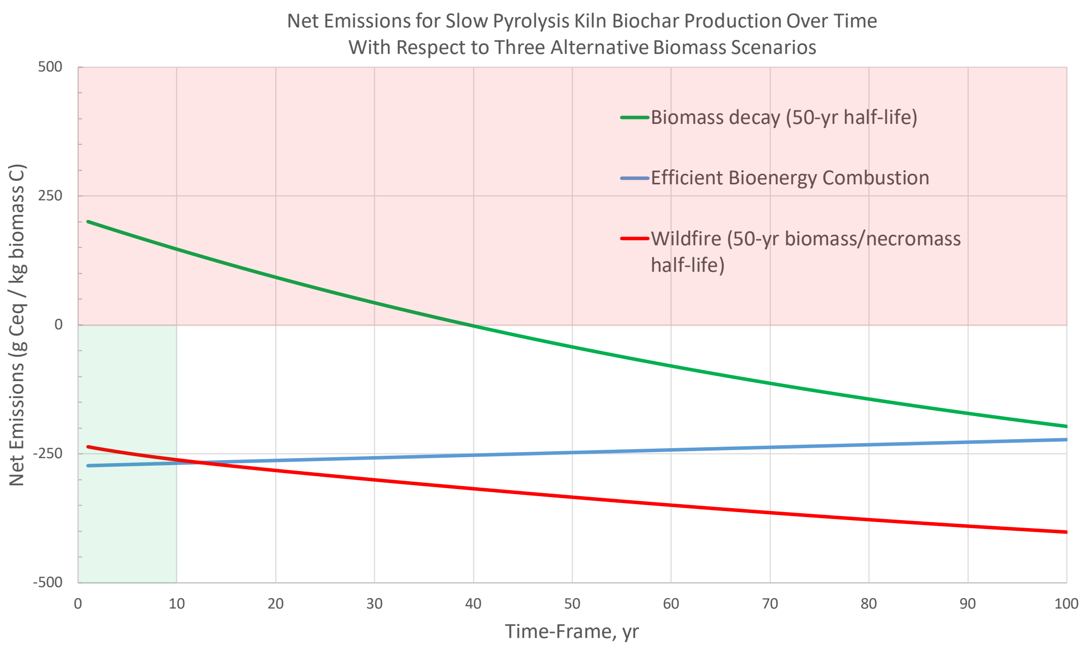

Figure 2. Net emissions for continuous biochar production by a slow pyrolysis kiln method with respect to three alternative biomass scenarios: 1) natural biomass decay with a 50-year half-life, 2) modern efficient bioenergy combustion, and 3) wildfire assuming a 50-year half-life for necromass. Net emissions by biochar production are beneficial when less than zero.

- Publications, Handouts, Other Text & Web Products:
  None.

- Outreach & Education Activities:
  The subject of this project is an integral part of any discussion I have with prospective biochar practitioners and funding clients. It has been woven into several proposals (e.g., 2019 USFS Wood Innovation Grant, BLM and a pending proposal as subcontractor to CalFire) and was a prime topic for discussion during the Biomass to Biochar: Maximizing the Carbon Value workshop held in April 2020 by CSANR.

Impacts

- **Short-Term**: Datasets that quantify, in an easily understood number, the relative climate impacts of different biochar production technologies.
- **Intermediate-Term**: Raise awareness in the biochar community of the importance of production emissions to the overall climate-friendliness of the technology (1-3 years); Give strong impetus to research efforts to further improve the emissions of low-capital-intensive approaches to biochar production (1-3 years); Reporting of emissions along with biochar yields and chemical properties as key factors to consider when purchasing or producing biochar (3-5 years); Dealing with emissions during biochar production will also inevitably lead to comparisons of emissions by other biomass conversion technologies, such as composting (3-5 years).
- **Long-Term**: Successfully raising awareness and changing research priorities should help the biochar industry avoid falling into a trap of blissful ignorance that, if exposed in the wrong way, could lead to the public perception that biochar cannot be climate-friendly (5-10 years); Avoiding this trap and tackling the problem head-on could be the very thing that saves the industry and also allows it to make a much stronger contribution to mitigation of climate change as envisioned by Ref 4 (10-100 years).

Additional funding applied for/secured: This concept has been used in three unsuccessful proposals (2019 and 2020 USFS Wood Innovation Grant, and BLM), and one currently pending proposal (CalFire).

Graduate students funded: None.

Recommendations for future research:

Clearly, more actual measurements of GHG emission factors for biochar production and alternative biomass scenarios are needed.

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