Biochar's Role in Climate Mitigation

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The biochar industry is at a pivotal point in its existence due to the role allocated to it in the 2018 IPCC climate change report[1] as a carbon sequestration strategy. Biochar is a very stable form of carbon which makes it valuable for sequestration purposes. However, a significant factor limiting biochar's more widespread usage is its value proposition perception: cost of the product versus the benefit(s) it provides. While the purely economic benefits are being developed with more and more end uses, there is a lack of clarity about biochar's carbon sequestration capability to further bolster its larger (long-term global) value and policy change is needed.

Background

The Intergovernmental Panel on Climate Change (IPCC, 2018) identified seven carbon capture strategies (See Appendix A), of which biochar was one. A pair of follow-up IPCC reports[2] in 2019 looked at a 12-year horizon (i.e., a 2030 deadline) for reducing carbon emissions and making significant progress to implement carbon storage in order to prevent an overshoot of the 1.5°C global warming cited in the 2018 report. No single proposed IPCC carbon storage strategy is sufficient to sequester enough carbon to prevent exceeding a 1.5°C threshold individually; a suite of strategies is needed to meet that goal. This report explores the opportunities, challenges, and actions needed to enable biochar to fulfill its potential in mitigating atmospheric carbon loading.

It was noted at the 2019 US Biochar Conference that the data used in the 2018 IPCC report was based on a 2010 study of biochar[3], which was 9 years out of date by the time the report was published. As illustrated by the 2017 industry survey (Survey And Analysis Of The US Biochar Industry) and the increasing volume of current production and research, much progress has been made technologically, and as an industry. A more recent publication (Bates and Draper; 2019[4]) points out the potential for biochar in a host of direct and cascading applications, further highlighting the potential biochar offers as an end product and as a carbon sink.

Climate change, driven by atmospheric loading with greenhouse gasses, primarily carbon dioxide, along with methane and other heat-trapping chemical compounds, has become a contentious issue in the socio-political arenas, but the scientific evidence is widely accepted as compelling. Sequestering carbon to mitigate and reduce the build-up of atmospheric carbon compounds is also accepted as sound science yet the profitable application of many of the solutions remains elusive. Biochar is poised to fill a host of commercial needs while also providing a carbon sequestration solution.

Biochar, short for biological charcoal, is produced by heating organic feedstocks (woody material, grasses, agricultural residues including chaff, hulls, shells, and manures) in a limited oxygen atmosphere, a process known as pyrolysis. Biochars with varying characteristics are created from a variety of

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[1] International Panel on Climate Change Special Report, 2018 (https://www.ipcc.ch/sr15/).
[2] International Panel on Climate Change Special Report, 2019 (https://www.ipcc.ch/srocc/).
[3] Woolf, D., J.E. Amonette, F.A. Street-Perrott, J. Lehmann, and S. Joseph. 2010. *Sustainable biochar to mitigate global climate change*. Nature Communications,1(5), 1–9, doi:10.1038/ncomms1053.
[4] Bates, A.; Draper, K. Burn: *Using Fire to Cool the Earth*. Chelsea Green Publishing; 2019.

production techniques. The carbon content can range from 50 to 90+% and the specific chemical composition of the biochar determines its most appropriate end use. Historically, biochar has been used as a soil amendment. While there are numerous uses being researched and developed for biochar, its greatest volumetric use, to both store carbon for the long term and to restore depleted soils' carbon content, is in agricultural applications.

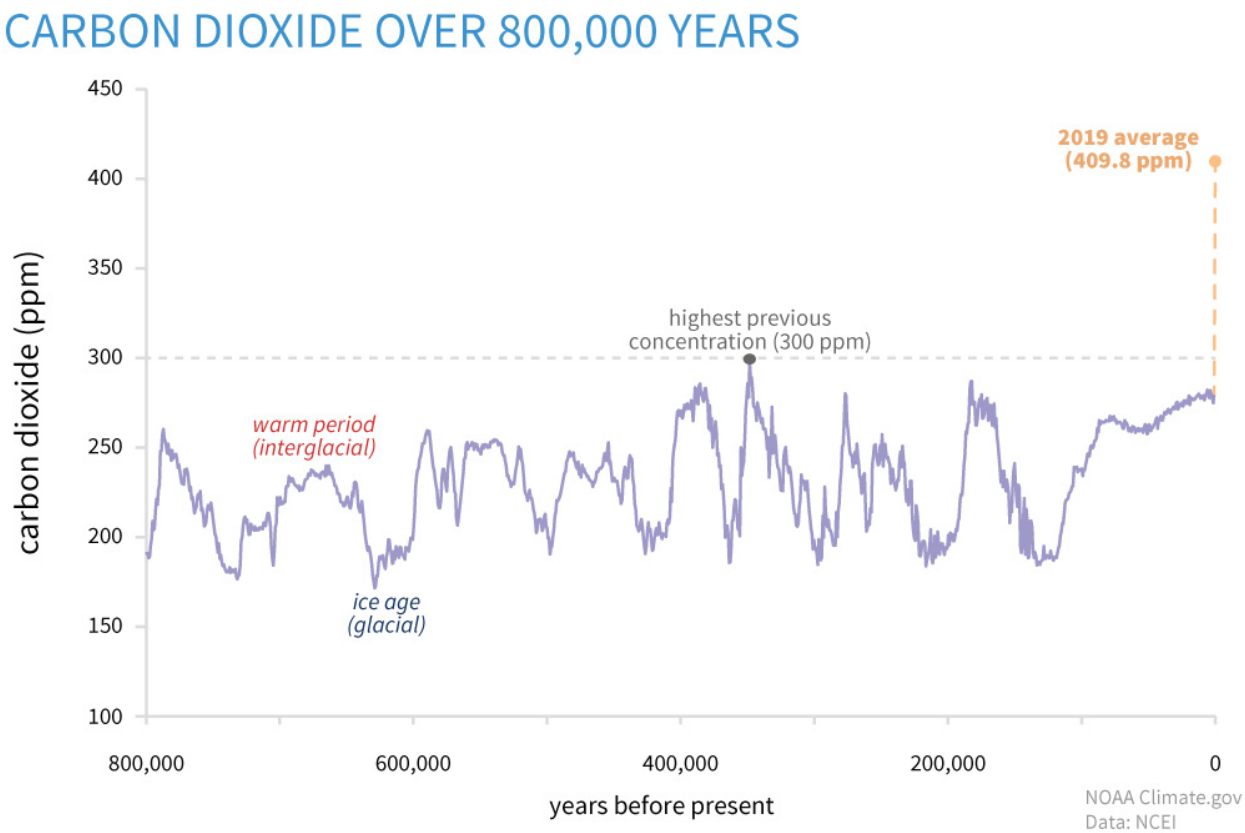
The timeframe needed to implement significant carbon mitigation action continues to be debated, but again, the science is clear as laid out in the IPCC's reports: the global biosphere will suffer increasingly dire consequences without meaningful action soon. While the timing of implementation of biochar-related technologies will not be addressed in this report, time *is* a critical factor for actions to be taken. Also worth noting, are discussions in scientific publications and in the editorial media that progress toward significant mitigation of carbon emissions is not possible without disruptions to the global economy. There have been calls for unprecedented changes to global cooperation, political alignments, social values, and cultural norms to smooth the anticipated turmoil. The wisdom in those observations--and the devastating effects from global-scale disruptions to the economy and populace--have been demonstrated with the COVID-19 Pandemic.

Carbon Mitigation versus Carbon Storage

There are two components to achieving the carbon balance needed to limit and reduce the build-up of atmospheric carbon: **storage and mitigation**. To understand this, it is easiest to consider Earth as a closed loop system. There were large quantities of carbonaceous materials (i.e., coal and oil) stored underground for millennia which have been released at an increasing rate over the last couple of centuries for energy and myriad products. Carbon has shifted from underground into the atmosphere as shown in Figure 1. To balance this shift, carbon needs to be returned to **storage**—preferably for the long term. Sequestering atmospheric carbon requires a paradigm shift in economic expenditures to underwrite carbon capture and its storage, as opposed to the historical practice of ignoring the downstream effects of burning and using fossil fuels.

The other component of the solution is **mitigation** of current and future carbon emissions. That means drastically curtailing or stopping carbon emissions via strategies ranging from increasing energy efficiency and sharply reducing or phasing out use of fossil fuels, to increasing materials recycling and changing human diets. Mitigation is expected to be economically disruptive, involving massive investment while balancing expenditures for increasing costs caused by changes in climate, sea level, and weather patterns. Stabilizing the global carbon in storage requires a paradigm shift in economic expenditures.

Figure 1: Millennial Atmospheric CO_2 Graph[5]



Overview of the Biochar Industry's Production Technology

Biochar has received increasing attention over the last decade, as both an economically viable product line with multiple uses[6] and as a topic of research[7]. The uses for biochar have moved beyond the initial but still dominant use as a soil amendment, to include stormwater treatment, toxic site remediation, animal feed supplement, animal bedding amendment, enhancement for nursery potting mixes and compost, and as a value-added filler in plastics, concrete, wood composites, tires, and pavement[8]. Biochar's most outstanding advantage (compared to other carbon sequestration strategies) is its existing research and production coupled with a proven ability to sequester carbon stably, with time periods in the hundreds to thousands of years.

To better understand biochar as a product, here is a quick review of how it is made, and the technologies used to produce it. Biochar, short for biological charcoal, is produced by heating organic feedstocks (woody material, grasses, agricultural residues including chaff, hulls, shells and manures) in a limited

[5] Chart accessed from: https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

[6] Biochar 101: An Introduction To An Ancient Product Offering Modern Opportunities (2016) and Biochar As An Innovative Wood Product: A Look At Barriers To Realization Of Its Full Potential (2017)

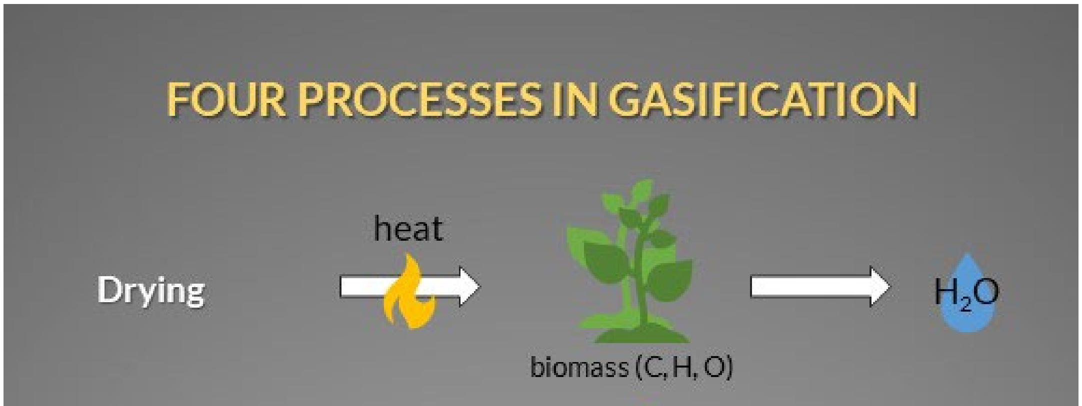
[7] Published papers dealing with biochar have increased from a few hundred per year in 2008 to more than 5000 in 2018 as catalogued by the International Biochar Initiative (IBI) Bibliography.

[8] Draper, K. *Biochar: If you make it, will they come?* Biomass Magazine; Sept/Oct 2019; 28-30.

oxygen atmosphere, a process known as pyrolysis. It is called "biological" charcoal because its historical use has been as a soil amendment and not as a source of heat for cooking or warmth. While there are numerous non-agricultural uses being researched and developed, its greatest volumetric use, to both store carbon for the long term and to restore depleted soils' carbon content, is in agricultural applications currently.

The combustion or burning of organic feedstocks progresses in four phases.: evaporation, gasification, combustion of the gasses, and combustion of the carbon (Figure 2). The first phase, evaporation, is when all or most of the water is evaporated, allowing sufficiently higher temperatures to move to the next phase: the generation of gasses or, technically, the vaporization of hydrocarbons. The third phase is the combustion of the gas vapor (which requires oxygen and produces visible flames). In the generation of charcoal this phase must be controlled; thus the pyrolysis process limits or excludes access to oxygen and eliminates the last phase where the carbon is oxidized, producing heat, carbon di- and mon- oxides, and ash. By pulling off the volatile gasses the "combustion" process is stopped, and the end product is largely carbon which can yield up to 50% by volume of the incoming fuel.

Figure 2. Four processes in gasification



Biochars with varying characteristics are created across a range of temperatures (from 300 to 1000 C) and residence times (time held at a target temperature), with the end product being charcoal or torrefied char at the lower temperature end of the continuum and—with some additional processing—activated carbon at the high end (for its extremely high porosity and exceptional absorptive characteristics.) The carbon content can range from 50 to 90+% and the specific chemical composition of the char determines its most appropriate end use.

Heating biomass in a limited oxygen atmosphere means it will not support combustion, however, the gas must go somewhere—either vented to the atmosphere or be combusted outside the pyrolysis chamber, typically as a self-sustaining energy source. Some techniques use the gas (known as syngas, short for synthetic gas) for process heat, some flare it off, and some vent it. Other processes, using the same basic technology, focus on converting or capturing the syngas to produce chemicals and fuels without producing biochar.

The biochar production techniques currently used fall into these broad categories:

1. Open top retort (flame-capped kiln or with a controlling air curtain to oxygen starve the zone containing the carbon and prevent its oxidation.)
2. "Sealed" retort (with or without syn gas recycle)
3. Gasification unit, (which captures or uses the gas for secondary purposes, like feedstock drying or process heat)
4. Power boiler (usually a gasification unit, tuned for biochar production in addition to energy generation.)

Additionally, the process generates combustible gasses which can produce heat and energy at a fraction of the carbon emissions from fossil fuels. These benefits make biochar production an attractive technology on at least four counts:

1. Uses renewable low- to no-value feedstocks (aka, by-products of growing, managing, or manufacturing a target crop)
2. Produces an economically viable product
3. Product has a proven long-term carbon sequestration ability
4. Process can generate process heat or base load electricity (co-generation).

What Factors Limit the Use of Biochar?

A 2017 survey of the biochar industry's producers and users found there was ample capacity, but a lack of buyers (Dovetail, 2018). Buyers' unfamiliarity with biochar and its benefits were cited as a significant barrier to expanding sales. This issue was reinforced during an October 2019 International Biochar Initiative webinar discussion during which industry participants cited insufficient demand, not the lack of feedstock nor insufficient processing capacity as the constraint. In general, few biochar producers indicated they had the capacity to actively research markets (or new uses for biochar) or a sales force to pursue leads. Most manufacturers indicated they target a few known markets and depend on word of mouth for new sales. That strategy can lead to saturation of relatively narrow market segments and forsaking other, potentially more lucrative markets.

Research into biochar's uses and mechanisms has been accelerating over the last decade, as have mentions of it as a potentially useful product in the mass media. Despite the growing recognition of biochar by the public-at-large, the lack of understanding biochar's value is its biggest barrier to reaching significant scale from a production standpoint. Cost was cited by surveyed users as a barrier, however that could be viewed as either a real or perceived barrier without further analysis. Quality biochars are available currently at consistent rates in bulk, and the processing methods and equipment currently in use are relatively stable technologically. The most frequently cited variable costs were feedstock cost and shipping—both of which are transportation related.

The issues with feedstocks are their widespread location and relatively low density. Woody biomass yields between 30 and 60% char depending on the processing technology and whether it is derived from softwood or hardwood. Woody feedstocks have a bone-dry density of 150 to 384 kg/m^3 (10 to 25 pounds/ft^3)[9], but wood is rarely bone dry, so the amount composing a load is limited by weight, not volume. For grasses and agricultural waste (like corn stover, straw, or nut shells) the moisture is typically low, but the densities are low also (in the 5 to 15 kg/m^3 range) and the char products are equally low in density and yield; for instance, switchgrass yields about 10% char.

It is expensive to transport low density or high moisture materials. While common feedstocks like woody debris, manures, sludges, and grain chaff cost little in-situ, they are either high in moisture or low in density—both conditions making transportation distance a major factor in the feedstock's delivered cost. Biochar itself, while a low moisture content product, is not a high-density product unless densified, so the shipping cost to the customer further inflates the end-use cost.

A Closer Look at Woody Biomass Feedstocks

Since forest harvest and wood processing residues have been the major source of biochar feedstock, we will take a closer look at America's forests. As recent wildfire history has demonstrated, active forest management is necessary to reduce forest fire risks as well as to provide a supply of construction products, fiber, and fuel. Managed forests can be more resilient and supply end products, while also improving or restoring habitats, conserving watersheds, and storing carbon. However, in purely economic terms, non-product related benefits are without historic value and the feedstocks for biochar, which derive largely from low value woody biomass, are expensive to transport to centralized biochar processing facilities. Additionally, much of the woody debris desirable as a biochar feedstock is widely dispersed in hard to reach areas, making the cost of removal and transport prohibitively high.

There has been considerable development in small- to medium-scale technologies which allow biochar to be made closer to the source of its feedstock, but those systems are relatively expensive, require frequent moving and, being mobile, are limited in their production capacity. Additionally, the heat component of the process is usually "wasted" since there are typically no local needs for it, thus increasing the unit cost of the biochar and reducing the carbon mitigation benefits of the end product.

[9] Gendek, Arkadiusz & Aniszewska, Monika & Chwedoruk, Kinga. 2016. *Bulk density of forest energy chips*. Ann. Warsaw Univ. Life Sci. – SGGW, Agriculture. 67. 101-111.

Better Understanding the Value of Biochar

While biochar has value as a carbon sequestration strategy, the value of that environmental service has not been defined.[10] Ultimately, biochar's widespread usage will depend on its holistic value proposition. Biochar's value proposition as an end product--from the users' standpoint--is becoming clearer as the biochar manufacturing and characterization technology matures. It is possible now for many custom chars to be made to meet specific needs. That demand has been relatively small but is growing as research identifies the process parameters and post processing steps required for specific end uses. Large-scale producers are looking for high volume demands to utilize existing capacity fully, underwrite expansion, and increase the exposure of biochar as an attractive solution to a variety of problems. In the larger picture too, the need for carbon storage requires large volumes of char to be used in permanent locations (as a concrete or pavement additive, as a plastic filler/binder, or in the soil.) By far, the most developed market, also with the largest potential volumetrically, is agriculture. To illustrate its potential, to raise the carbon content of all US cropland by one percent would take on average, 9.4 US tons of biochar per acre, requiring a total of 3.6 billion tons—which is equivalent to mitigating 8.3 billion tons of carbon dioxide. Using woody biomass as the primary feedstock for this scenario could consume from 7 to 40 billion tons of feedstock depending on the production technology and its yield[11] as well as contribute to long-term sequestration of carbon in the soil.

The ultimate value proposition of biochar is a function of its carbon content and its chemical composition in relation to its intended end use. At this time, there is no definitive matrix of characteristics which match specific uses, but that knowledge is being developed via research and experience. The IBI bibliography (https://biochar-international.org/) provides a compendium of the latest published research and articles about biochar. Domestically, there were presentations at the 2019 U.S. Biochar Conference which covered a range of research topics, from agricultural to biomedical[12], and there were frequent exchanges of anecdotal information on biochar production technologies and its various uses. Among smaller scale producers there was an especially high interest in biochar-enhanced compost and the beneficial effects on mycorrhizal growth and observed improvements in pile heating times.

Most published research is publicly accessible, but collating the relevant parts into a "buyers guide" format for specific markets would be helpful to educate buyers and to build demand. The experiential knowledge is currently held mostly by individuals and individual companies, and the "higher-end" knowledge is held as proprietary intellectual property. Conferences and study trips sponsored by the US Biochar Initiative and the International Biochar Initiative currently provide the best opportunities to share knowledge and research outcomes.

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[10] The International Biochar Initiative (IBI) along with partners developed and submitted a biochar carbon offset methodology for approval by the American Carbon Registry (ACR).In late March 2015, ACR listed the methodology as inactive after the peer review panel reached the conclusion that there was insufficient scientific evidence to support the test method for carbon stability (https://biochar-international.org/protocol/ and https://www.biochar-international.org/wp-content/uploads/2018/04/IBI_Report_Biochar_Stability_Test_Method_Final.pdf).

[11] USDA Forest Service. 2005. *A strategic assessment of forest biomass and fuel reduction treatments in Western States*. Gen. Tech. Rep. RMRS-GTR-149. Fort Collins, CO: U.S. treatments in Western States Department of Agriculture, Forest Service, Rocky Mountain Research Station (http://www.fs.fed.us/research/infocenter.html).

[12] U.S. Biochar Conference: https://biochar-us.org/conferences-events

What Factors Limit How Biochar Can Be Better Promoted as a Carbon Storage Tool?

In order to advocate for biochar's carbon sequestration capability and to capture carbon credits as they become monetized, there needs to be a clear protocol to assess a given biochar's characteristics and how to allocate "credit" for its carbon sequestration while subtracting the "costs" as a result of creating the char. A life cycle assessment (LCA) would be a reasonable starting point, but with a product generated by multiple technologies for multiple end uses, that's a daunting undertaking. Pacific Biochar debuted an open-source spreadsheet (The Big CA Biochar Model[13]) in an October 2019 IBI webinar which provides a model for a power-generation-with-biochar carbon accounting protocol. To avoid bogging down implementation, however, any protocol will require widespread review and critique to assure scientific validity and appropriate accounting. As time is critical to meet the IPCC's cited 2030 deadline this is a high priority action.

Many life cycle assessments of biochar production have been completed. Results indicate that impacts over the full cycle of raw material procurement, transport, production of biochar, and use as a soil amendment are highly dependent on the type of biomass used, transport distances, and the production process. Most studies show significant life cycle GHG (greenhouse gas) benefits.

Examples of studies include a 2010 assessment of biomass pyrolysis with biochar returned to soil examined biochar production from corn stover, yard waste, and switchgrass energy crops.[14] Results showed GHG benefit for biochar made from corn stover and yard waste, but (i.e. net negative emissions), but that switchgrass biochar is a net C emitter. The net CO2 equivalent (CO2e) GHG emissions for corn stover and yard waste were determined to be in the range of 0.86 to 0.89 metric tons per metric ton of dry feedstock, respectively. It was also observed that biochar would likely only deliver climate change mitigation benefits and be financially viable as a distributed system using waste biomass.

A 2011 study in the UK[15] considered ten biomass feedstocks for pyrolysis biochar production including straw, sawmill residues, forestry residue chips, small roundwood, short rotation coppice crops, short rotation forestry crops, miscanthus, and Canadian forestry residue chips. The study also considered small, medium, and large process chains and

[13] The Big California Biochar Model: https://pacificbiochar.com/resources/the-big-california-biochar-model/
[14] Roberts, K.; et al. 2010. *Life Cycle Assessment of Biochar Systems: Estimating the Energetic, Economic, and Climate Change Potential*. Environmental Science and Technology 44(2): 827–833. (http://www.css.cornell.edu/faculty/lehmann/publ/ES&T%20published%20online,%202009,%20Roberts.pdf)
[15] Hammond, J.; et al. 2011. *Prospective life cycle carbon abatement for pyrolysis biochar system in the UK*. Energy Policy, 39, pp. 646–655. (https://www.biochar.ac.uk/abstract.php?id=35&pr=a)

evaluated carbon abatement and electricity production. Assumptions included a biochar carbon content of 75%, biochar carbon stability of 0.68 over a 100-year period, and a biochar application rate to soil of 30 metric tons per hectare. The greatest carbon benefit was found to be carbon stabilization in biochar (about 40% of total carbon abatement). Study authors described carbon benefits of carbon in the soil as indirect and less certain but ascribed 28-29% of mitigation benefit to this factor. Negligible benefits were attributed to decrease of fertilizer use and N2O emissions. Findings indicated pyrolysis-produced biochar yields greater carbon benefits than combustion of biomass to energy systems assuming typical biomass energy systems efficiency, even without beneficial effects on soil organic carbon levels from biochar application.

Another study which compared biochar production in remote locations in the U.S. Pacific Northwest with winter burning of logging slash[16] found that despite the many challenges linked to remote production of biochar, the fact that long term storage of recalcitrant carbon could be achieved would be a complimentary benefit. It was also noted that significant scale-up could yield substantial benefit through reduction of fire risk by providing a way to utilize large amounts of waste wood.

Several studies have concluded that conversion of biomass to biochar in an optimized pyrolysis system, which includes energy production as a coproduct, yields greater carbon benefits than direct production of energy and energy products from biomass.[17,18] Findings in both cases indicate greater C benefit from sequestration of stable carbon in the soil than from offset of fossil fuel emissions through use of biomass fuels for energy production. One study, in fact, found that avoided emissions are between 2 and 5 times greater when biochar is applied to agricultural land than when used solely for fossil energy offsets.[19]

A recent systematic review of a number of life cycle assessments of biochar[20] concluded that while direct comparisons of various studies was not possible due to differences in context and characteristics, "… it is still obvious that the application of biochar [to agricultural land] brings significant benefits, either to neutralize the greenhouse gas emission of agricultural production or as a carbon capture method. There is also a great potential for energy production by utilizing the co-products – syngas and bio-oil.

To promote the carbon storage benefit of biochar in the US there must be significant domestic policy change to both acknowledge the scientifically based predictions of the consequences of atmospheric carbon loading and to deal with them substantively. Biochar markets are growing slowly, but to significantly increase usage, biochar must be seen as a carbon sink, and that requires policy (or the growth of private carbon markets). For policies to be enacted, or for private markets to develop, enough people must believe there is sufficient need-to-act to be a priority. Dealing with that will take a broad educational effort coupled with funding and support. Given the potential focus on agricultural

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[16] Puettmann, M.; et al. *Life Cycle Assessment of Biochar from Postharvest Forest Residues*. Waste to Wisdom: Subtask 4.7 (http://wastetowisdom.com/wp-content/uploads/2018/08/4.7.5-W2W-Report-Biochar-LCA.pdf).

[17] Dutta, B.; Raghavan, V. 2014. *A life cycle assessment of environmental and economic balance of biochar systems in Quebec*. Int J Energy Environ Eng 5, 106.

[18] Gaunt, J.L. and Lehmann, J. 2008. *Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production*. Environmental Science & Technology, 42, pp. 4152–4158. (https://www.researchgate.net/publication/5263646_Energy_Balance_and_Emissions_Associated_with_Biochar_Sequestration_and_Pyrolysis_Bioenergy_Production)

[19] Dutta, B.; Raghavan, V. 2014.

[20] Matuštík, J.; et al. 2020. *Life Cycle Assessment of Biochar-to-Soil systems: A Review*. Journal of Cleaner Production Vol 259, June, 120998. (https://www.sciencedirect.com/science/article/abs/pii/S0959652620310453)

applications, there is a policy leadership opportunity for the USDA to articulate the potential for biochar to reduce the carbon footprint of the agricultural sector.

The biochar industry also needs to be aware of developments in the legal[21], insurance, and financial sectors with respect to "claims" made about biochar's carbon sequestration capacity. These sectors are critical to the long-term ability of biochar producers to fully capitalize on potential carbon credits. The legal caution stems from recent actions against the fossil fuel industry for misrepresenting their impact on the changing climate and the expected follow-up by insurance and financial firms[22], resulting in slowed investment due to higher perceived risk and liability issues.

While there continues to be significant research into how to make various carbon capture and storage technologies profitable, biochar is positioned to provide that service immediately. Scaling up the industry's production capacity is feasible by developing current markets further, however a carbon credit for biochar's sequestration capability would stimulate that growth significantly. Credits for using renewable resources already exist in the power generation and liquid fuels arenas, and similar investments would be stimulated by extending those credits for producing carbon-storing products and for using carbon storing products in long-term applications. Even the International Monetary Fund (IMF)[23] has proposed support for carbon tax as a tool to invigorate the carbon storage markets—and to reduce the risks to the global economy from atmospheric carbon loading-induced climate changes.

Examples of that thinking currently exist in China's extensive rice waste-to-biochar/energy-back to field movement,[24] and the support for eliminating fossil fuels in order to convert to renewable energy sources in various European Union countries[25]. While legislative efforts in the US tend to lag public opinion, the momentum seems to be building for action and a carbon credit system is a logical next step. As noted in the 2018 IPCC report, the fact there is an estimated 30-year inertial effect between reducing atmospheric carbon and seeing a difference in climate changes makes the need for rapid action imperative. Even if there is legislation and or some other motivation to start storing carbon with biochar immediately, there needs to be time to ramp up investments in production capacity, then to build the infrastructure, develop storage methodologies acceptable to biochar buyers and users, as well as to develop the supportive infrastructure to enable the industry to function efficiently (feedstock supply, high-temperature equipment to produce biochar with or without energy capture or other by-products, transportation infrastructure, distribution networks, field application equipment, etc.)

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[21] Marjanac, S. and Patton, L. 2018 *Extreme weather event attribution science and climate change litigation: an essential step in the causal chain?* Journal of Energy & Natural Resources Law, 36:3, 265-298, DOI: 10.1080/02646811.2018.1451020.

[22] Keenan, J.M. *A climate intelligence arms race in financial markets*. Science. 20 Sep 2019: 1240-1243 (https://science.sciencemag.org/content/365/6459/1240).

[23] Parry, I. *Putting a Price on Pollution. International Monetary Fund Finance & Development*. December 2019. Vol 56, No. 4 (https://www.imf.org/external/pubs/ft/fandd/2019/12/the-case-for-carbon-taxation-and-putting-a-price-on-pollution-parry.htm).

[24] Pan, G. *China Biochar Story: From crop straw to biomass industry*. Presentation to the US Biochar Initiative, 2018 (https://biochar-us.org/presentation/china-biochar-story-crop-straw-biomass-industry).

[25] European Union 2050 Long-Term Strategy: https://ec.europa.eu/clima/policies/strategies/2050_en

Bottom Line

There is a long history of the effectiveness of government policy in growing technologies important to the commonwealth, and climate mitigation efforts will continue to increase in importance as the atmospheric carbon content increases. To spur growth in the biochar industry, which will simultaneously support scaling-up carbon sequestration actions from all the IPCC identified technologies, science-driven policy change is of paramount importance. For example, carbon credits would increase the appeal and value proposition of biochar which, in turn, should spur investment in increasing biochar production capacity. More broadly, carbon credits will provide support for both green economic growth and for the implementation of carbon mitigation and capture and storage technologies.

Progress is already being made with biochar characterization, standards, market, and technology development, and understanding which chars are best suited for which applications. Biochar has recently found its way into the USDA's NRCS (Natural Resources Conservation Service) conservation practices[26], which will hopefully serve as an entrée to wider policy-based recognition, such as with approval for biochar as an animal feed supplement in the US. For the industry to be even more successful, there is a need for further public education (i.e., beyond marketing materials, such as technical education short sessions designed for target markets and for varying levels of understanding.) as has been successful with other "developing" industries[27], increased collaboration and cooperation within the biochar community will help maximize market growth and stimulate promoting biochar as a carbon sequestration solution.

The effort to achieve widespread enhancement of the biochar industry has been led by the International Biochar Initiative and, for individual countries, through similar open source, volunteer organizations. Beginning in spring 2020, USBI (United States Biochar Initiative[28]) undertook major fundraising efforts to provide increased outreach and public education with a staffed organization as well as with organized research projects nationally. IBI has also hosted study trips abroad to improve collaboration and share knowledge globally. The open source model adopted by the domestic and global biochar communities has allowed this industry to accelerate its maturation over a more conventional competition-focused model, however the need for carbon sequestration solutions require an even faster pace to achieve meaningful results.

[26] USDA Conservation Steward Ship Program, Practice E384135Z Biochar production from woody residue: https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd1311343&ext=pdf

[27] Such as pellet fuels, organic produce, community supported agriculture, pastured poultry, grass fed, and certified angus beef

[28] U.S. Biochar Initiative: https://biochar-us.org/

Appendix A

Seven Carbon Capture and Storage Technologies named by the International Panel on Climate Change

(Summary from Scientific American; Jan 2019, p54-59; based on Negative Emissions—Part 2: Costs, Potentials and Side Effects," by Sabine Fuss et al., in Environmental Research Letters, Vol. 13, No. 6, Article No. 063002; June 2018)

1. Afforestation and reforestation: lowest cost option at 0 to $40/ton with potential for 0.5 to 3.5 Gigatons of Carbon Equivalent (GTCe) per year in 2050.
2. Bioenergy with Carbon Capture and Storage (BECCS): energy generation using renewable resources as the fuel but requires tailpipe carbon capture and underground storage. Modestly expensive at 100 to 200$/ton, with the potential to store 0.25 to 4GTCe/yr by 2050.
3. Biochar: from primarily soil incorporation; $38 to 120$/ton with the potential to sequester 0.25 to 2GTCe/yr by 2050.
4. Enhanced Weathering: A relatively expensive solution at $50 to $600/ton but with the potential for up to 5.25GTe storage in 2050.
5. Direct Air Capture: assuming the technology can be developed, costs of 100 to 300$/ton are projected with the potential to store up to 5GTCe/yr.
6. Ocean Fertilization: is relatively inexpensive ($30/ton projected) with relatively high potential of up to 12GTCe/yr by2050, but the technology presented sufficient environmental risks the option was dropped from detailed consideration in Fuss' study.
7. Soil Carbon Sequestration: A highly variable cost of 0 to $200/ton, but with the potential for up to 6GT storage in 2050.

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