Using Carbon to Achieve Chesapeake Bay (and Watershed) Water Quality Goals and Climate Resiliency: The Science, Gaps, Implementation Activities and Opportunities

STAC Workshop Report
May 25-26, 2023
Hershey, PA

STAC Publication 24-005

About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at http://www.chesapeake.org/stac.

Publication Date: June 20, 2024

Publication Number: 24-005

Suggested Citation: Hegberg, C., J. Egan, C. Brosch, J. Hubbart, P. Imhoff, D. Lueckenhoff, T. Miles, W. Teel, and D. Wood. 2024. Using Carbon to Achieve Chesapeake Bay (and Watershed) Water Quality Goals and Climate Resiliency: The Science, Gaps, Implementation Activities and Opportunities. STAC Publication Number 24-005, Edgewater, MD. 110 pp.

Cover graphic from: Yoni Cooperman, Deirdre Griffin. September 19, 2016. Biochar and Nutrient Management. University of California Agriculture and Natural Resource https://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=22132.

STAC Administrative Support Provided by:

Chesapeake Research Consortium, Inc.
645 Contees Wharf Road
Edgewater, MD 21037
Telephone: 410-798-1283
Fax: 410-798-0816
http://www.chesapeake.org

Workshop Steering Committee:
Jason Hubbart, Ph.D., * West Virginia University (Workshop co-chair)
Chris Brosch, Ph.D., * DE Department of Agriculture
Charles Hegberg, US Biochar Initiative/RES, LLC (Workshop Chair)
Jennifer Egan, Ph.D., UM Environmental Finance Center (Workshop co-chair)
Tom Miles, US Biochar Initiative/TR Miles Consultants, Inc.
Paul Imhoff, Ph.D., PE, University of Delaware
Wayne Teel, Ph.D., James Madison University
David Wood, Chesapeake Stormwater Network
Dominique Lueckenhoff, Sr. Vice President, Hugo Neu, Inc.
Kenneth Pantuck, USA EPA Region 3
**STAC member*

STAC Staff:
Meg Cole, STAC Coordinator, Chesapeake Research Consortium
Tou Matthews, STAC Projects Manager, Chesapeake Research Consortium

Acknowledgements:
The steering committee would like to thank the speakers and attendees in person and virtual of the workshop (Appendix B) for their constructive contributions. The workshop attendance breakdown is provided in Table Biochar Workshop Attendees. We also thank Meg Cole of the Chesapeake Research Consortium for her organization and execution of the workshop and Rachel Tardiff of Rachel Tardiff, LLC for her facilitation and execution of the workshop. The US Biochar Initiative support for a University of Maryland Chesapeake Conservation Corps student is gratefully acknowledged. We would also like to thank the US Biochar Initiative for providing travel/lodging accommodations for many of the biochar subject matter experts and guest speakers. Thank you to all the professional subject matter experts who took the time out of their busy schedules and traveled around the country to be a part of this very important and exciting workshop. It was amazing to have the breadth of knowledge, experience, and passion for the subject matter beyond what could have been imagined when this workshop was originally envisioned.

Biochar Workshop Attendees

	DAY 1	DAY 2
ROMOTE	82	92
IN PERSON	54	45
TOTAL	136	137

Biochar Technical Report Disclaimer
The field of biochar research is rapidly advancing, with 2,061 additional peer-reviewed technical papers being published between January 1 and May 31, 2024. Despite our efforts to provide the most accurate and up-to-date information possible, it is important to recognize that new developments may have emerged since the compilation of this report.

It is the responsibility of the reader to investigate the most recent technical information to ensure the accuracy and relevance of the data and conclusions presented. This report is meant to serve as a resource, but readers should consult the latest research and reviews to stay informed of the latest advancements and discoveries in biochar technology.

Table of Contents

Executive Summary

As the Chesapeake Bay Program (CBP) approaches the Total Maximum Daily Load (TMDL) 2025 endpoint, it is becoming increasingly evident that the region will miss its goal of reducing nutrient pollution in the Bay. Thus, discussions have shifted towards what is and is not working and the necessary changes to ensure a healthy and sustainable Chesapeake Bay. The 'Achieving Water Quality Goals in the Chesapeake Bay: A Comprehensive Evaluation of System Response (CESR)' (2023) report provides an honest assessment of the current restoration status and a commitment to making corrective decisions and actions to achieve the long-term vision of the Chesapeake Bay, even in challenging circumstances. The 2025 TMDL deadline presents an opportunity to explore a broader range of options and increase flexibility in promoting innovative approaches and technologies that can effectively restore the Bay.

The effectiveness of best management practices (BMPs) for pollutant reduction varies depending on the location. Therefore, there is a need to explore innovative approaches that can enhance the performance of each BMP in a transferable and environmentally sustainable way. Biochar, a durable charcoal-like substance produced by heating organic materials in an oxygen-deprived environment, is one such solution. Unlike compost, which decomposes, biochar can last for centuries, if not millions of years, as pure inertinite (Sanei et al., 2024). It acts as a carbon sink and has gained recognition as a negative emission technology by the Intergovernmental Panel on Climate Change (IPCC). The usefulness of biochar has attracted interest from corporations with environmental objectives, and it has gained global acclaim for its ability to address various environmental goals.

Since 2010, practitioners, researchers, government agencies, and non-profit organizations have actively led a significant increase in the Chesapeake Bay region's research initiatives and project installations related to biochar. The research shows that biochar yields environmental benefits such as improved water quantity management, enhanced water quality, and healthier agricultural and urban soils.

These initiatives have played a crucial role in advancing the evidence supporting biochar and the need to properly apply its use through developing protocols, standards, specifications, and accreditation in the Chesapeake Bay region. It is recognized that further practical field-based research is still needed to fill knowledge gaps, such as confidence in predicted outcomes of use, and improve implementation and standards for application. As part of their soil health program, the Natural Resources Conservation Service (NRCS) has recognized biochar's benefits in agriculture. It is actively promoting its use by issuing a nationwide conservation standard practice (CPS 336) for biochar as a part of the Soil Carbon Amendment (USDA, 2022) or as a component material in associated practices, which allows farmers to apply for financial assistance from United States Department of Agriculture (USDA).

The Science and Technical Advisory Committee (STAC) Workshop held in May 2023 in Hershey, Pennsylvania, focused on using biochar to achieve the Chesapeake Bay water quality goals and climate resiliency. The workshop discussed the science of biochar, identified research gaps, addressed misunderstandings, and explored opportunities to expand the use of biochar to improve

water quality. Attendees of the workshop reviewed biochar in research and practice, with this document summarizing the workshop and providing a research synthesis based on the workshop topics. This report and synthesis aim to help translate current research for integration into Chesapeake Bay protocols. The workshop outcomes included providing recommendations to the Water Quality Goal Implementation Team (WQGIT) regarding including biochar credits in existing BMPs and protocols to enhance water quality in the Chesapeake Bay. This report presents several recommendations from the workshop participants to accelerate and expand the use of biochar in agriculture, forestry, urban landscapes, and emerging toxic contaminants throughout the watershed. The four key recommendations for the CBP to consider are:

- Support pursuing biochar enhancement credit in approved BMP protocols.
- Recommend and support expanded applied research and knowledge filling, including outreach for NRCS practice code and funding for verification and validation.
- Support scaling up scientifically practical application of biochar use.
- Provide letters of support to expand collaborative partnerships.

1. Introduction

Since the early 2000s rediscovery of *Terra Preta* soils, also known as "Dark Earth" in the Amazon Basin (Lehmann J et al., 2006), the scientific community has published over 30,000 peer-reviewed biochar articles internationally, with a notable publication surge in the past decade—approximately 80% of these emerging in the last five years (Web of Science, 2024). Despite this research boom, the widespread adoption of biochar applications remains limited. Nonetheless, numerous studies have highlighted biochar's significant environmental benefits, potentially expediting the improvement of Chesapeake Bay Watershed health. This has brought global attention to biochar as a solution to various environmental challenges.

Biochar, a durable carbon-rich material akin to charcoal, is produced by thermochemically converting waste organic matter, such as wood, green waste, biosolids, and manures, in an oxygen-free environment. This ancient technique, known as *Terra Preta* in Amazon Basin cultures, was initially used to improve soil fertility before modern fertilizers. Unlike compost or other carbon sources, biochar remains stable in soil for thousands, more likely millions of years, serving as a long-term carbon sink. The Intergovernmental Panel on Climate Change (IPCC) recognizes biochar, alongside reforestation and soil restoration, as a "negative emission" technology (IPCC, 2018). According to the IPCC, biochar has the potential to remove up to 2.6 billion tons of carbon dioxide (CO2) annually on a global scale. Other Negative Emission Technologies (NETs) that offer nature-based opportunities, when combined with biochar applications, include afforestation and reforestation, soil carbon sequestration, and enhanced rock weathering on fields. These integrated approaches can significantly contribute to reducing atmospheric CO2 levels and mitigating climate change.

Various feedstocks, or "Feedstock of Opportunity", can produce biochar using various technologies. The properties of the resulting biochar depend on the type of feedstock used, temperature, and additives, enabling the creation of custom-made or "designer char" that can treat specific environmental constraints. It is important to note that not all biochar performs in the same way(s), so one must carefully select the appropriate source and apply biochar in the right place at the correct rate (Gelardi, DL, et.al., 2021; Aller, D, et.al., 2023). With this understanding, published research generally agrees on the benefits of biochar for soil health and environmental services when applied correctly (Schmidt et al., 2021).

The STAC Workshop, "Using Carbon to Achieve Chesapeake Bay Water Quality Goals and Climate Resiliency," focused on biochar's role in improving the Chesapeake Bay's water quality. The purpose of the workshop was to raise awareness, highlight current research, and discuss integration into the Bay's existing protocols. The 2023 report, 'Achieving Water Quality Goals in the Chesapeake Bay: A Comprehensive Evaluation of System Response,' presents a concerning outlook, indicating that the Bay will likely miss its nutrient reduction targets. Missing the goals poses significant challenges exacerbated by land use changes, population growth, economic development, and climate change effects. However, there has been a renewed determination to make the necessary changes and achieve a long-term vision for the Bay beyond 2025. Current Best Management Practices (BMPs) have limitations, and new better management practices, including biochar, can enhance the BMP performance (STAC, 2023; Hershman et al., 2017). This STAC Biochar Workshop aligned with the CBP's evolving focus on improving BMP performance to meet the Chesapeake Bay (CB) TMDL.

Workshop attendees generally supported biochar to follow the enhancement credit instead of the new expert panel route to existing water quality BMP practices in the Chesapeake Bay Watershed (CBW) (See Mentimeter responses, 26 for enhancement credit 8 for a new expert panel in Appendix D.) Attendees called for developing technical guidance, standards, specifications, and accreditation integration into approved Chesapeake Bay protocols. This report synthesizes the workshop's outcomes and current research to support recommendations for incorporating biochar into the Bay's environmental strategies.

2. Momentum behind Biochar

For approximately 15 years, biochar implementation has been increasing nationwide and throughout the Mid-Atlantic. Biochar activities in the Chesapeake Bay watershed commenced in 2007 when the first gasification system was established at Frye Farm in Virginia to process broiler litter. In 2010, the report titled "Advancing Biochar in the Chesapeake: A Strategy to Reduce Pollution from Poultry Litter" was published by Forest Trends (Incubator PCK et al., 2011), laying out a visionary roadmap. The first significant biochar project, the Anchorage Canal Drainage Area Retrofit, was undertaken by the Delaware Center for Inland Bays, the Town of South Bethany, and the Delaware Department of Transportation in the Inland Bays in 2014.

From 2015 to 2023, the installation of biochar projects increased significantly in variety and scale. Multiple research documents were completed during this period, highlighting the advantages, research, and knowledge gaps of utilizing biochar in stormwater Best Management Practices (BMPs), in-situ soil amendments, manure management, forest management, and climate sequestration. Some of these include:

- Performance Enhancing Devices for Stormwater Best Management Practices, Chesapeake Stormwater Network (Hirschman D. et al., 2017).
- Reducing Stormwater Runoff and Pollutant Loading with Biochar Addition to Highway Greenways, Final Report for the National Academies of Science, Transportation Research Board, NCHRP IDEA Project 182 (Imhoff P. et al., 2017).
- Performance Enhancing Devices for Stormwater BMPs: Biochar, Hirschman Water & Environment, LLC and Center for Watershed Protection, (Hirschman D. et al., 2018).
- Manure de Force Report, Institute of Rural Entrepreneurship and Economic Development, National Center for Resource Development, and Infinite Solutions (Metzler, T. et al., 2019).
- West Virginia's Phase 3 Watershed Implementation Plan for the Chesapeake Bay Total Maximum Daily Load (Gillies, N., et al. 2019).
- Forest Action Plan, Part I: Forest Resource Assessment, Maryland Department of Natural Resources, 2020.
- Montgomery County Climate Action Plan, Building a Healthy, Equitable, Resilient Community, 2021.

During the eight years, various documents presented the benefits of biochar in nutrient management within the watershed. Although innovative approaches, such as the Performance Enhancing Devices for Stormwater Management (Hirschman D. et al., 2017) and Performance Enhancing Devises for Stormwater Best Management Practices – Biochar for Roadside Ditch Management & PEDs (Hirschman, D., (2018) were developed with recommended crediting, and while nothing was officially implemented, they do provide an opportunity for technical updates and the expansion based on more recent research and implementation activities.

> *"…there are potential opportunities to utilize biochar sourced from wood waste throughout Maryland and the Chesapeake Bay Watershed as a tool to reduce stormwater and nutrient runoff. However, the uses of biochar are limited by approved crediting from the Chesapeake Bay Program. The Bay Program has not yet evaluated or approved biochar under the Bay Program's expert panel process and it is not currently eligible for credit in the Woodland (sic) (Watershed) Incentive Program (WIP) (MD DNR, 2020)."*

In the last five years, there has been notable progress in the appreciation of biochar's benefits across various sectors, including practitioners, academic circles, and governmental levels from federal to municipal and regulatory bodies. The Maryland Department of Natural Resources, in its *Forest Action Plan, Part I: Forest Resource Assessment* (2020), recognizes explicitly biochar's potential to mitigate stormwater runoff by enhancing soil water infiltration. This acknowledgment allows entities like the Maryland Department of the Environment (MDE) to consider biochar in strategies for reducing stormwater runoff and addressing Total Maximum Daily Loads (TMDLs). However, as of this writing, biochar has not yet been formally credited for these applications.

The year 2022 marked a significant milestone with the completion of the watershed's largest biochar project, aimed at mercury remediation in the South River and South Fork of the Shenandoah River. In the same year, the National Fish and Wildlife Foundation (NFWF), a pioneer in supporting biochar research and demonstrations, funded a three-year initiative titled "*Scaling Up Biochar Applications for Accelerated Stormwater Runoff Reduction in the Chesapeake Bay*" (Grant ID: 0602.22.074143). This initiative led to the Biochar Partnership for the Chesapeake (BPC). Comprising a team of technical biochar experts and a network of public and private implementation partners, the BPC is positioned to serve a crucial role in the watershed. Over the coming three years, the BPC will guide partner organizations in ready-to-implement projects, focusing on the optimal sourcing, usage, and application rates of biochar, encapsulated in the strategy of the '3 R's': right source, right use, and right rate (see Figure 1).

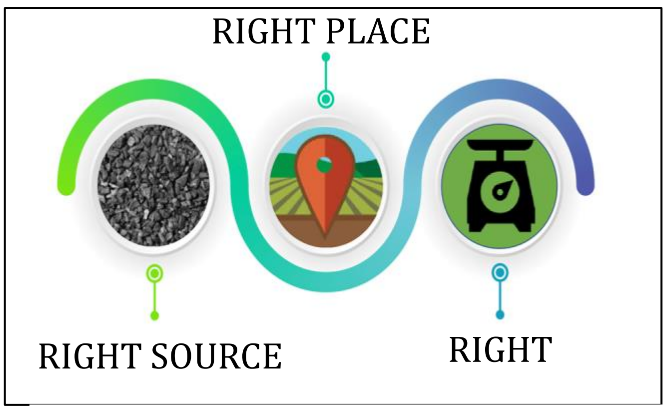


Figure 1. The 3 R's (Adapted from original graphics provided by K.M. Trippe, Ph.D. (2022).

Over a decade and a half of dedicated research, pilot demonstrations, and large-scale implementations in the mid-Atlantic region and Chesapeake Bay watershed, complemented by a global corpus of over 30,000 peer-reviewed publications, led to an application for the STAC workshop. The workshop was designed to synthesize the vast research findings, practical insights, and field experiences garnered over the years. The following sections detail the key findings and discussions from this workshop, shedding light on the current state of biochar science, identifying existing gaps in research, knowledge, and application, and exploring potential paths forward for its implementation in enhancing water quality and fostering climate resiliency in the Chesapeake Bay watershed.

3. Workshop Objectives and Format

3.1 Workshop Desired Outcomes:

The workshop's desired outcome was to provide recommendations to the Chesapeake Bay Program's Water Quality Goal Implementation Team and its workgroups as to whether,

- Biochar should be integrated into the Chesapeake Bay TMDL Watershed model for nutrients and
- Biochar credit should be included in existing BMP protocols.

The Steering Committee, in collaboration with the STAC sponsors and the Chesapeake Research Consortium, convened a workshop to integrate a substantial body of empirical evidence within the existing CBP framework. This two-day event, detailed in Appendix A, brought together various experts in agriculture, urban landscape management, and the science and application of emerging/toxic contaminants. Workshop attendees had the chance to hear from two keynote speakers, including Dr. Charles Glass, Ph.D., P.E, Executive Director of the Maryland Environmental Services entitled, "A Maryland State Change Agent's Journey to Produce and Utilize Biochar for Good", and from Mr. Jim Doten, Carbon Sequestration Program Manager for the City of Minneapolis, MN entitled "City of Minneapolis Biochar Story: Bloomberg Climate Challenge."

The workshop's attendees represented a diverse mix of professionals from federal and state agencies, private consulting firms, non-governmental organizations, and academic institutions. It featured national and local technical experts who provided a thorough overview of the latest advancements in biochar science, identifying existing gaps and proposing practical recommendations. These insights focused on aligning biochar and carbon strategies with Chesapeake Bay's GIT3 water quality strategies. Key areas of discussion included Climate Smart Agriculture and Forestry (CSAF), Urban Landscapes and stormwater management, emerging toxic contaminants (ETC), and Climate Resiliency.

In addition to focused discussions on GIT3 topics, the workshop offered a range of informative presentations. These covered various subjects, including projections for the Chesapeake Bay model post-2025, the general protocol process in biochar application, insights into the biochar industry, common queries and misconceptions, and keynote speeches. These keynotes highlighted ongoing work within the Chesapeake Bay watershed and throughout the United States.

The in-person and online attendees actively participated in the workshop and engaged in question-and-answer sessions, surveys, and group discussions. This engagement allowed them to share their unique perspectives and innovative ideas on managing and applying biochar technologies, thereby contributing to a richer understanding and potential utilization of biochar in environmental strategies.

The deliberate and concentrated effort of the workshop aimed to distill information for STAR and STAC needs and focused on the following questions:

- What are the specific and efficient ways to integrate biochar into current protocols and strategies?
- What are biochar's co-benefits to the Chesapeake Bay goals?
- How will biochar enhancement crediting be developed?
- What is needed to improve the integration?
- Who are specific programmatic partners that will benefit from this integration?
- As a carbon-negative technology, how can biochar be used in climate resiliency strategies in the forthcoming TMDL?

All presentation slides and workshop recordings can be accessed at the Workshop Website.

4. Introductory Workshop Presentation Summaries

The workshop's focus was Biochar's role in Climate Smart Agriculture and Forestry (CSAF), urban landscapes, and managing emerging toxic contaminants (ETC). The following sections will summarize the presentation and synthesize the current state of the science, addressing technical details not fully covered in the workshop's limited timeframe.

4.1 Biochar Industry – Myths, Fake News & Facts

Tom Miles (Executive Director, T.R. Miles Technical Consultants, Inc., US Biochar Initiative)
Chuck Hegberg (Senior Project Consultant, RES, LLC & US Biochar Initiative)

Figure 2. Anthropogenic Dark Earth (terra preta), Manaus, Brazil (Photograph by Manuel Arroyo-Kalin).

1) Biochar – An Old Technology, Re-Discovered

The term "biochar", conceived in 1989 and derived from the Greek words 'bios' (life) and 'char' (burn), is not a novel idea but a contemporary revival of an age-old tradition. *Terra Preta*, or "dark earth," dates back 7,000 to 8,000 years. Its presence was first recorded in the 16th century by Spanish explorer Francisco de Orellana during his exploration of the Amazon rainforest. He discovered advanced agricultural societies, which were later doubted and considered mythological after follow-up expeditions failed to locate these civilizations (Valev et al., 2022).

Rediscovery of *Terra Preta* soils occurred in 1870 by American naturalist James Orton, who observed vast expanses of fertile, dark soil distinct from the typical Amazonian soils. This finding sparked a series of explorations by researchers such as Charles B. Brown, William Lidstone, Charles F. Hart, Herbert H. Smith, and later Friedrich Katzer. These scholars investigated the possibility of indigenous peoples intentionally cultivating these fertile lands. Modern scientists now agree that *Terra Preta*, or "terra preta do indio" (Indian black earth) (Figure 2), was indeed a result of human cultivation, confirming Francisco de Orellana's initial observations. The lack of evidence for these ancient civilizations was later attributed to the devastating impact of diseases brought by European explorers, which significantly reduced the Amazonian population (Valev et al., 2022).

While initial studies primarily explored the origins of *Terra Preta*, a pivotal shift occurred in 1966 when Dutch soil scientist and agronomist Wim Sombroek published "Amazon Soils." This publication marked the beginning of research into the exceptional agricultural properties of *Terra Preta*. Sombroek's work identified that these soils contained up to 9% carbon from biochar, starkly contrasting the surrounding soils with only 0.5%-1.0% carbon (Valev et al., 2022). This discovery led to continuous research into these soils' complex characteristics and benefits. Johannes Lehmann, PhD from Cornell University, has been crucial in promoting global awareness and understanding of biochar's environmental significance in recent years.

Figure 3. Dark colored Iowa topsoil showing high levels of SOC (Photograph Todd Ontl/2012).

An example of naturally occurring biochar can be seen in the fertile soils of Iowa (Figure 3), formed during historical prairie fires. However, fire suppression practices in western regions, coupled with the impacts of erosion and industrial agriculture during the dust bowl, have significantly reduced biochar levels in the soil.

Moreover, several ancient civilizations, even older than those in the Amazon, practiced enriching soil fertility by incorporating biochar and other amendments. This practice was prevalent in regions like sub-Saharan Africa. Nonetheless, these anthropogenic dark earths (ADEs) only gained scientific recognition in the past 15 years, sparked by biogeochemical studies on ADE in Brazil (‘Terra Preta do Indio’) based on Wim Sombroek's pioneering work (Sombroek et al., 1966; Glaser et al., 2007).

As research into biochar expanded into temperate regions, biochar-carbon was found in similar dark earth soils resulting from human activity in Northern Germany, Australia, and Sub-Saharan Africa (Downie et al., 2011; Solomon et al., 2016; Wiedner & Glaser, 2015; Wiedner et al., 2015). The growing body of research underscores biochar's historical significance and potential in modern agricultural and environmental applications within the Chesapeake Bay watershed.

2) <u>Biochar is a new technology with low market awareness.</u>

The European Union utilizes biochar in various ways, such as in urban landscapes, stormwater management, structural soils, agriculture applications, animal feed, and building materials. With numerous production facilities across Europe, the demand for biochar has consistently grown, doubling each year for the past decade (EBI, 2023).

In 2018, the North American biochar production was estimated at 80,000 tons. A recent United States Biochar Initiative (USBI)/ International Biochar Initiative (IBI) survey reported production of 170,000 tons in 2023. It is projected to increase to 200,000 tons in 2024, with additional new capacity currently in development (USBI, 2023). Europe benefits from a market where the energy generated during biochar production can be converted to high-value heat and electricity. Moreover, the voluntary carbon market in Europe is thriving and expanding rapidly (EBI, 2023).

In the United States, the biochar market has experienced exponential growth due to the recovery of biochar from existing biomass energy facilities. New production facilities are in development. However, obtaining reliable information on the volume of biochar produced has been challenging due to the market's highly competitive and secretive nature. Unlike Europe, the United States faces more difficulty maintaining profitability, as the opportunities for heat repurposing are limited to a few industries. Low electricity prices and waste tipping fees for organic feedstocks pose further challenges.

Nevertheless, biochar sales are increasing in the United States, with early-entry companies benefiting from the growing voluntary carbon markets. The most considerable growth in the market can be observed in biomass energy facilities modifying their operations to extract high-carbon fly ash. In the mid-Atlantic region, several biomass power facilities that could produce biochar as a coproduct currently exist in Pennsylvania and Virginia, with more planned and under construction, expected to be operational during 2024. These facilities will process wood, biosolids, and manure. Currently, there are no commercial facilities in Maryland and Delaware. There are plans for a couple of facilities in Maryland. Delaware has a regulatory restriction to block incineration facilities, but the language also impacts the potential for pyrolysis and gasification. Other rapidly growing production facilities are in the southeast USA, including North Carolina, South Carolina, Georgia, and Alabama, and the upper east coast, primarily in Maine.

Despite the production and voluntary carbon market growth in the United States and the mid-Atlantic, awareness among possible end-users for biochar remains low. Efforts by the NFWF Scaling Up Biochar program are critical to raise biochar awareness and increase use for water quality projects, but progress will continue to be hindered until the CBP officially recognizes biochar and receives water quality enhancement crediting. However, communities focused on climate resilience consider using biochar to fulfill carbon reduction commitments.

3) <u>Biochar production systems and products are polluting, inconsistent, and energy-intensive</u>.

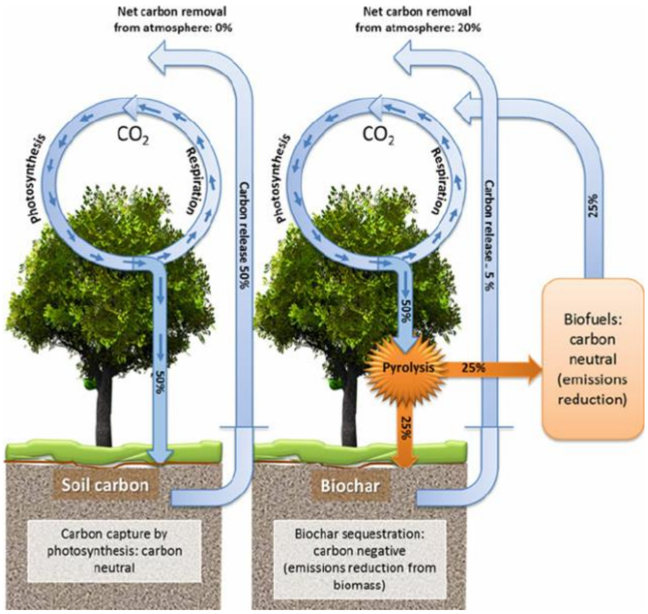


Figure 4. Biomass to biochar production, generation of bio-energy and sequestration of approximately 50% of the carbon from biomass in soil (Lehmann, 2007).

Biochar is a carbon sequestering agent that has a net positive effect on carbon emissions (carbon negative). When biomass is converted into biochar, approximately 50% of the original carbon remains in the char, along with mineral ash, while the other 50% is released as a gas and is often combusted to generate heat or power. Some systems can also produce bio-gases, bio-oils, and tars, which can be used as fuels, although commercially available options are limited (Lehmann et al., 2007).

During the process of creating biochar, indirect heat is used instead of burning, reducing biomass by 70-80%, leaving behind 20-30% char. The gases and oils produced can be captured and repurposed to provide heat for the pyrolizers, making the pyrolysis process autothermal (a form of gasification) (Lehmann et al., 2007). This reduces operating costs by 25% and allows for heat recovery. In fact, for some verification standards, high-tech plants must recover at least 70% of the heat to qualify for selling biochar carbon credits for CO^2 removal (Verra.org). Furthermore, plants that recover energy receive an "allocation" or credit during the life cycle analysis (LCA), which increases the Carbon Dioxide Removal (CDR) potential of the biochar (Puro. earth).

The feedstock and production parameters (see Figures 4 and 5) will determine the amount of fixed carbon and mineral ash in the final product. Biochar is made from a variety of feedstock, including:

- Hard and soft woods (sustainably grown),
- Wood waste products like sawdust, chips, and urban green waste,
- Agricultural waste from hemp, corn stover, hauls, nutshells, and other sources.
- Various types of grass (e.g., switchgrass),
- Other materials used to make biochar but with higher ash content include:
    - Manures: dairy, cattle, beef cattle, horse, swine, and poultry manure,
    - Biosolids and food waste.

Modifying production parameters creates biochar with specific properties, which is also called a "fit-to-purpose" product. Commercial pyrolysis and gasification systems can precisely control specific parameters to produce high-quality and consistent biochar. Production parameters

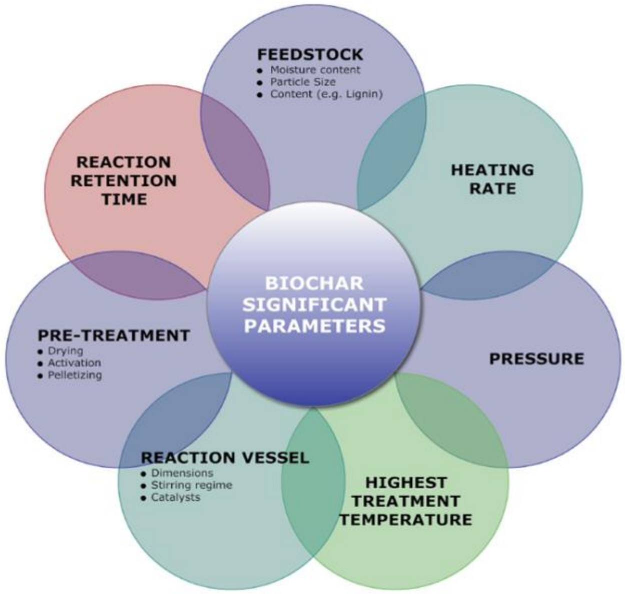


Figure 5. Biochar Significant Parameters, Graphic Adapted by Hegberg, C., 2016.

adjusted are priming amendments or additives, temperature and oxygen levels, moisture content, and processing time (see Figure 5). The 'fit-to-purpose' provides considerable opportunity to create new and innovative products in agriculture, water and wastewater, remediation, and building products while reducing society's carbon footprint.

As a fixed carbon product, biochar acts as a carbon sink, which the Intergovernmental Panel on Climate Change (IPCC) has identified as a negative emission technology (NET). When assessing the overall impact of a biochar production facility, it is found that for every ton of biochar produced, there is a net reduction of 2-3 metric tons of CO_2 equivalent. This makes biochar a green carbon-negative, cost-effective absorbent (Table 1) a valuable tool in mitigating climate change while offering various environmental benefits, including energy returns (Schmidt et al., 2018). Compared to activated carbon, primarily made from bituminous coal, lignite coal, and coconut shell, biochar is a climate-friendly "Green Carbon" with production and use that can contribute to a watershed's circular economy.

Table 1. Biochar a Green Carbon – Biochar(s) versus Activated Carbon.

	BIOCHARS	ACTIVATED CARBON
Energy Demand	6.1 MJ/kg	97 MJ/kg
GHG Emissions	-0.9 Kg CO_2e/kg	6.6 Kg CO_2e/kg
Carbon Credit Ratio/$	1 CO_2e/mt:1.8-2.5 CO_2e/mt Biochar ($180/MT) (cdr.fyi, 2024)	N/A – Carbon Positive
Iodine Number	500-700	500-1000+
Pore Size	Macro, Mesoporous	Macro, Meso, Microporous depending on the raw material
Density (kg/m3)	80-112 (high temp low ash)/ 352-561 (high mineral)	352-449
Ash	Wood – 10% +/- (low ash) / Manures – 40-60% (high mineral)	10-25% Coal / 10% Coconut
Est. Price	<$1.00/kg - $5.00/kg, ($0.46/lbs - $2.28/lbs)	$7.06/kg or $3.20/lbs (Global Trade, 2023)

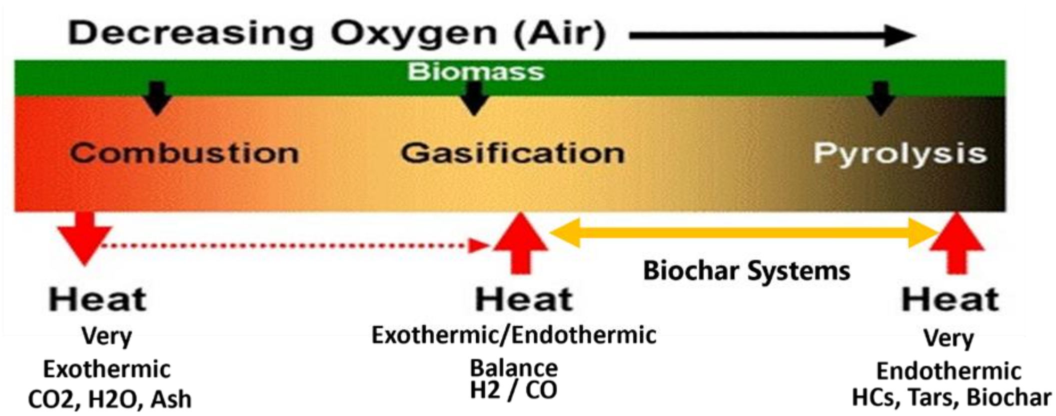


Figure 6. Biomass Thermochemical Stages.

Environmental regulators and the public often share concerns regarding the potential toxic pollutants associated with thermochemical processing of biomass waste streams in the production of biochar. These concerns include the presence of polycyclic aromatic hydrocarbons (PAHs), dioxins, furans, and metals from waste fuels, which are regulated and controlled through permitting and careful facility design and operations. Facilities that process non-wood feedstocks are required to use thermal oxidizers as part of their pollution control measures, along with biofilters and particulate capture systems as needed.

Numerous plant-based biochar production technologies exist, and at least eight full-scale technologies are capable of processing manures and biosolids while also recovering energy in the form of steam, heat, or electricity. These commercially available technologies can produce biochar at scale from a variety of feedstocks, ensuring both environmental safety and efficiency.

4) Biochar does not have quality certifications or standards.

The International Biochar Initiative (IBI), on May 29, 2013, officially launched the IBI Biochar Certification Program and the IBI Certified TM seal for the growing biochar industry. The first standardized protocol was released in May 2012, with the most recent being released in November 2015 as version 2.1 of the "Standardized product definition and product testing guidelines for biochar that is used in soil" (IBI, 2015). The "IBI Biochar Standards" provide recommendations to ensure that biochar is safe to produce and use but do not prescribe parameters for production and feedstock handling, nor do these provide thresholds or terms for defining the sustainability of the feedstocks or biochar products. The IBI standards provided the basis for the development of the European Biochar Certificate (EBC) and World Biochar Certificate (WBC), which are now managed by Carbon Standards International and provide the basis for biochar marketing and carbon trading (CSI). Last summer, global standards body Verra published a methodology for quantifying emission reductions and removals from biochar[1] (see Verra.com). The European standards use European laboratory methods. USBI is developing standards with the American Society of Agricultural and Biological Engineers (ASABE) and the American National Standards Institute (ANSI) with methods that are more commonly used in North American laboratories and lower cost for producers. USBI represents the United States on the International Standards Organization (ISO) working group on Biocarbon and Biochar (TC238 TG1) which is harmonizing standards for both biocarbons and biochars. Cobranding and certification will be available to industry organizations.

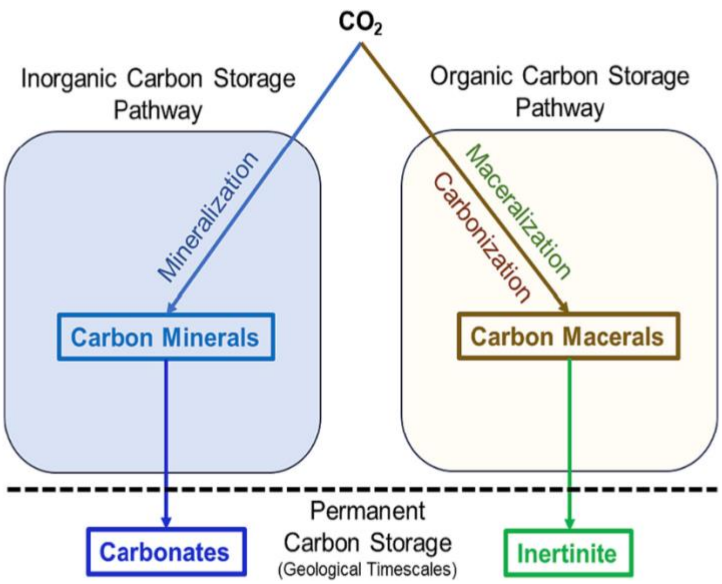


Figure 7. A simplified schematic representing carbon storage through natural inorganic and organic carbon pathways (Sanei, et. al., 2023).

5) <u>Biochar can last for millennia.</u> Biochar, a recalcitrant carbon compound, is known for its resistance to decomposition, which contributes to its prolonged presence in the environment. This quality makes biochar a key player in terrestrial ecosystems' carbon sequestration and long-term storage. Soil characteristics, such as pH, microbial activity, and moisture content, influence the effectiveness of biochar, impacting its longevity.

Biochar production emulates the geological organic carbon pathway. Pyrolysis rapidly carbonizes biomass, transforming it into inertinite maceral, suitable for long-term storage for thousands to millions of years. This process mirrors natural carbonization, thus aiding in carbon dioxide removal (Figure 7).

Organic geochemistry and petrology have established measurable parameters for preserving organic carbon in the Earth's crust. These parameters are also applicable in assessing the stability of biochar, particularly when compared to geological carbonaceous rocks (Peterson et al., 2023).

The stability of biochar is temperature-dependent. Different pyrolysis temperatures lead to varying carbon structures, influencing their stability and longevity in the soil. Biochar produced at certain temperatures can either contribute to labile carbon pools (H:C 0.4-0.7) or form stable carbon rings (H:C $\leq$ 0.4), which are integral to soil fertility and the global carbon cycle (Schmidt et al., 2022). Labile carbon, easily decomposed by microorganisms, is crucial for soil health and plays a significant role in the global carbon cycle (Figure 8).

[1] Early, C. 2023. Analysis: why biomass removals credits like biochar are luring investors. Reuters (https://www.reuters.com/sustainability/land-use-biodiversity/analysis-why-biomass-removals-credits-like-biochar-are-luring-investors-2023-11-15/)

Recent research led by Hamed Sanei (2024) proposes using an inertinite benchmark to assess biochar's permanence. This benchmark underscores the necessity for complete carbonization in biochar to ensure its long-term stability and uses inertinite[2] as a reference point. The study introduces methods for analyzing commercial biochar, determining carbonization temperatures, and estimating longevity, focusing on inertinite biochar's potential for extended stability.

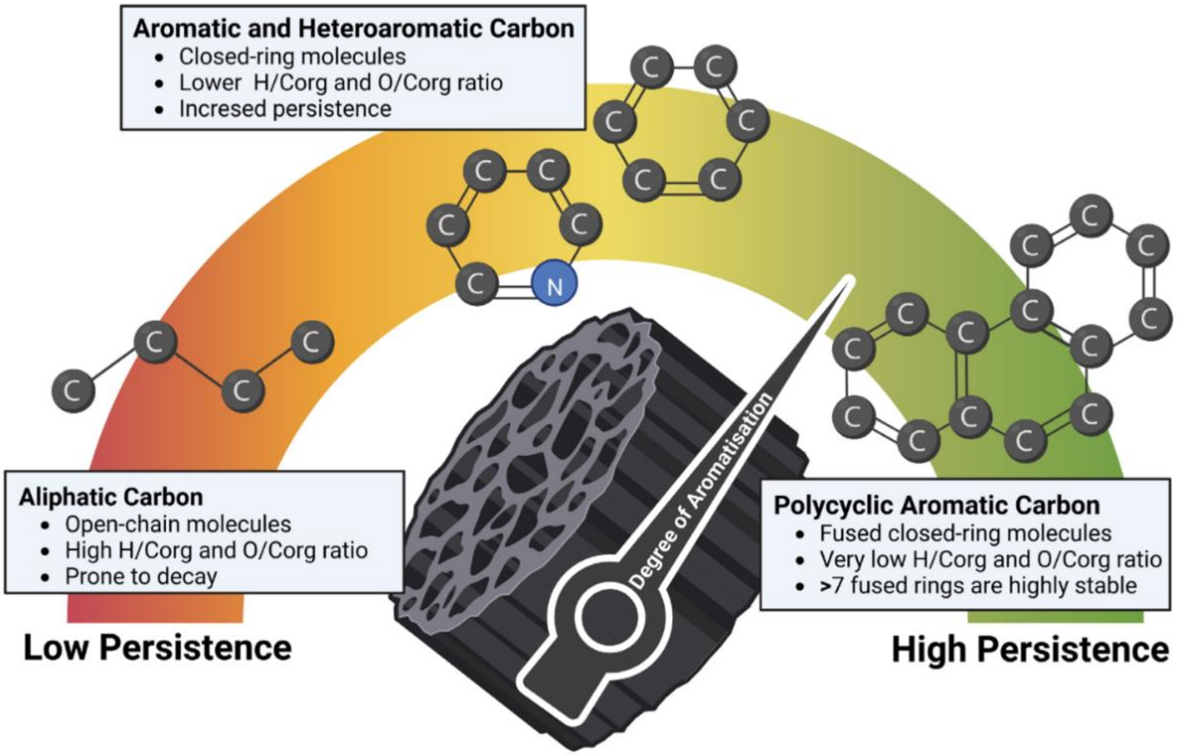


Figure 8. Schematic representation of different molecular forms of carbon in biochar (Schmidt et. al., 2022).

The key findings of the study include:

1. **Biochar's Permanence:** The study stresses the importance of complete carbonization in biochar, using inertinite as a benchmark for permanence.
2. **Inertinite Benchmark:** It proposes a random reflectance (Ro) of 2% as the standard for quantifying the permanent carbon pool in biochar.
3. **Commercial Biochar Analysis:** The research indicates that 76% of commercial biochar samples qualify as pure and inertinite.
4. **Carbonization Temperature (CT):** CT is introduced as a critical indicator of biochar's stability and efficiency concerning production temperature.
5. **Longevity Estimation:** The study estimates that inertinite biochar could degrade over approximately 100 million years under certain conditions, signifying its long-term stability.

[2] Inertinite refers to a group of partially oxidized organic (mainly plant) materials or fossilized charcoals, all sharing the characteristic that they typically are inert (i.e. not altered) when heated in the absence of oxygen. https://en.wikipedia.org/wiki/Inertinite

6. **Organic Pools in Biochar:** Different organic pools in biochar are identified, affecting capacity and being measurable through geochemical pyrolysis and Ro methods.
7. **Methodological Approach:** A combination of re-pyrolysis, ultimate analysis, organic petrology, and other methods are utilized for a comprehensive biochar analysis.

The research underscores the potential of biochar, particularly inertinite biochar, to last up to 100 million years in specific environments, emphasizing its role in long-term carbon sequestration. The anticipated longevity of inertinite biochar could be even greater under less hostile conditions, positioning it as a formidable solution for carbon storage (Sanei et al., 2024). The implications for improving water quality and addressing carbon sequestration in the Chesapeake Bay watershed highlight biochar's potential as a long-term environmental solution.

6) (Is there) Enough Biochar research has been completed to approve its use in the Chesapeake Bay watershed (CBW).

Unsurprisingly, many, including those in academic circles, are unfamiliar with biochar. This lack of awareness often leads to the misconception that biochar is a relatively new concept with limited research. However, the reality is quite the opposite. The field of biochar research has expanded rapidly, with about 80 percent of all studies being published in just the last five years. From January 1, 1998, through December 31, 2023, researchers published 34,288 biochar-related publications and 3,005 meta-review articles (as illustrated in Figures 9 & 10) according to the Web of Science (2024).

The term "Biochar" first appeared in scientific literature in 1998. Before that, it was commonly referred to as "Agrichar," a term that fell out of use after being trademarked and legally restricted. Recognizing the growing importance of this field, the International Biochar Initiative was established in 2006, followed by the formation of the US Biochar Initiative in 2009.

Over the years, the scope of biochar research has broadened significantly. Publications have delved into various topics, encompassing carbon sequestration and mitigation, the role of biochar in managing contaminants, its benefits for soil health and sustainable agriculture, and its applications in biomass energy production. Additionally, research related to biochar production equipment and its uses in water and wastewater treatment, stormwater management, and even building materials has advanced.

This wealth of research underscores biochar's multifaceted applications and growing importance in environmental science and sustainable practices. Despite its historical roots, it is a field proving to be increasingly relevant in addressing contemporary environmental challenges.

A comprehensive search conducted in the Web of Science database from January 1, 1990, to December 31, 2022, reveals that biochar has garnered more published and reviewed articles than most used BMPs (Table 2). As discussed below in Section 5.2 – Urban (Stormwater) Landscapes, scientific publications of biochar applications in stormwater are approximately 0.5% of the total number of scientific biochar publications over the same time. Although biochar applications in stormwater BMPs are not large, many of the findings of biochar’s impact on agricultural soil are transferable to stormwater BMPs.

This surge in biochar research, particularly evident over the past decade, signifies its increasing relevance in environmental management, specifically in improving water quality, soil health, and stormwater management practices. Advancements in the development of specialized biochars also fuel this growing interest.

These are tailored from various feedstocks and enhanced for specific performance needs, broadening biochar's appeal as a solution for a range of emerging toxic contaminants. The depth and breadth of research in this field provide a robust foundation for effectively scaling and integrating biochar. This integration can significantly enhance the effectiveness of the current suite of BMPs.

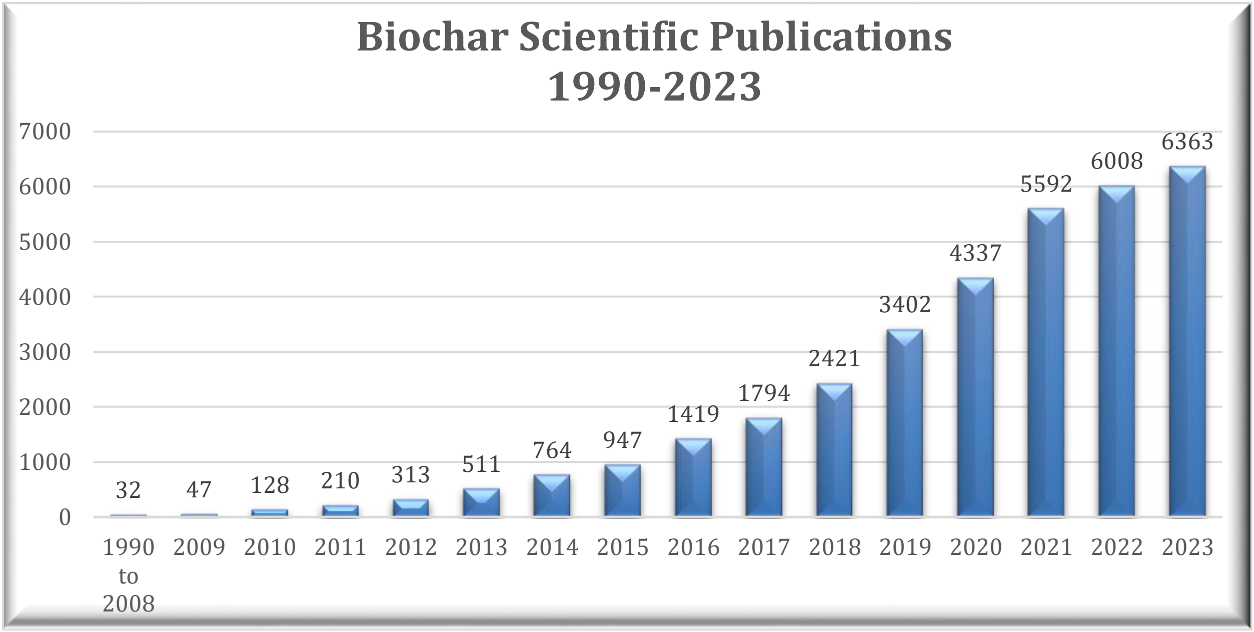


Figure 9. Number of Biochar Publications on Biochar in the Last 33 Years.

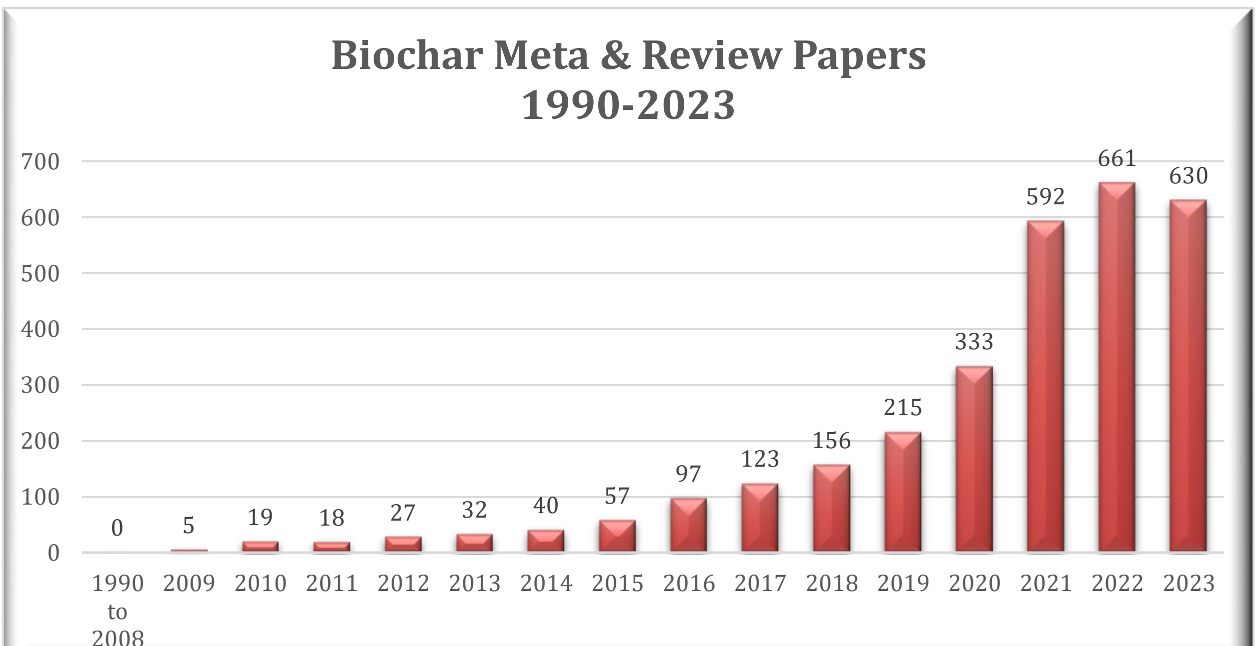


Figure 10. Number of Meta-Reviews on Biochar in the Last 32 Years.

The substantial body of research and knowledge amassed on biochar underscores its potential as a versatile tool in environmental management. Biochar can be a key component in future strategies to address various environmental challenges, particularly in water quality and soil health.

Table 2.Web of Science Biochar Research versus Approved BMPs (1990-2022).

WoS BMP Global Search	
STREAM PRACTICES	28,670
BIOCHAR	**27,925**
FOREST PRACTICES	27,800
INFILTRATION PRACTICES	15,837
ALTERNATIVE PRACTICES	8,449

STREAMS PRACTICES	
Channel Restoration	9,062
Stream Restoration	7,871
Channel Stabilization	7,350
Stream Stabilization	1,844
Urban Stream Restoration	1,212
Urban Channel Restoration	496
Streambank Erosion	434
Stream Daylighting	225
Streambank Stabilization	100
Urban Stream Stabilization	76

INFILTRATION PRACTICES	
Infiltration Basin	5,021
Rain Garden	2,506
Infiltration Bed	2,038
Grass Buffer	1,696
Grass Channels	1,364
Bioretention	1,324
Vegetative Filter Strip	528
Infiltration Trench	483
Seepage Pit	387
Dry Well	274
Dry Swale	122
Bioswales	94

ALTERNATIVE PRACTICES	
Street Sweeping	5,018
Urban Soil	1,633
Living Shorelines	933
Floating Treatment Wetlands	652
Woodchip Bioreactors	169
Impervious Disconnection	29
Regenerative Stormwater Conveyance	15

FORESTS PRACTICES	
Reforestation	8,320
Forest Buffer	7,829
Urban Tree Planting	6,238
Riparian Buffer	2,850
Tree Pits	2,533
Expanded Tree Pits	30

7) <u>Biochar lacks legislative and agency support.</u>

Government legislation, policies, and guidelines significantly impact the environment for better or worse. The 40-year Chesapeake Bay restoration efforts, alongside ongoing developments beyond 2025, highlight the pivotal role of government and interagency partnerships in environmental stewardship. The federal government often uses legislation to help move innovation, technology, and greener practices forward at a national level, including biochar. Since about 2010, the federal government, through various agencies, has been researching and testing biochar, including the US Forest Service, Department of Agriculture, Natural Resource Conservation Service, and the Department of Energy. Some more recent federal and state legislation activities include:

- Biochar in the Infrastructure Investment and Jobs Act, (H.R. 3684 – 117th Congress 2021-2022) $200 Billion Secretary of Interior & Agriculture,
- Biochar Act of 2021 (H.R 2581 – 117th Congress (2021-2022),
- National Biochar Research Network Act of 2022 (S. 4895 by Grassley, Tester, Thune, and Brown),
- 2023 US Farm Bill – US Biochar Coalition is working to get biochar and carbon credits into the next bill,
- NRCS 808/336 – Soil Carbon Amendments, USDA Climate-Smart Commodities, USFS Wood Innovations Program. Approved for use in all but six states.
- Washington State – SB/HR 5961(2021-2022) incentives state and local governments to use biochar in government contracts (Passed),
- Colorado State HBN23-1069 (2021-2022) – The Bill will study the use of biochar in abandoned gas/oil wells as part of capping (Passed).
- Other states working on biochar legislation include Maine, New York, Vermont, and Nebraska.

In 2023, the United States Biochar Coalition (USBC) was organized to service as a trade association for the industry and to support the advisement and development of biochar related legislation.

Other national biochar activities involve the three winners of the Bloomberg Philanthropies Climate Challenge – Cincinnati, OH, Lincoln, NE, and Minneapolis, MN, which will be replicating the successful Stockholm Biochar Project. Other cities building biochar production facilities from urban waste streams include Boulder, CO, Park City, UT, Baltimore City, MD, Bethel, PA (under construction); and Hanover, PA (In planning).

8) The Chesapeake Bay (Stakeholders) have already opened the door to biochar minus nutrient crediting.

Although biochar use in the Chesapeake Bay watershed might be seen as a new technology, its production and utilization go back to 2007. The Josh Frye Farm developed a demonstration system to process poultry litter to biochar. Since then, biochar has been gaining interest within a relatively small but growing group of pioneers demonstrating the use of biochar in both agriculture and urban landscapes within the Chesapeake Bay watershed. Initial studies with biochar were in the laboratory but have progressed to increasingly larger field trials in two of the six states in the Bay watershed.

Efforts began in 2009 with seed funding from the National Science Foundation for exploratory laboratory tests. Promising results from that study led to projects:

- 2011 Delaware Department of Transportation (DelDOT).
- 2014 NFWF and the Rutgers Center for Advanced Infrastructure and Transportation.
- 2015, the National Cooperative Highway Research Program and the National Science Institute Transportation Research Board received support from the North Carolina and California Departments of Transportation.
- 2018, the State of Pennsylvania (Borough of Hanover project); and

- 2019, the Maryland Transportation Authority (MdTA) and DelDOT.

In the early 2000s, the era of biochar in the Chesapeake Bay watershed began, marked by the publication of the first forward-thinking document by Forest Trends in 2011, titled "Advancing Biochar in the Chesapeake: A Strategy to Reduce Pollution from Poultry Litter"(Incubator PCK et al., 2011).

More recently, the "Scaling Up Biochar Applications for Accelerated Stormwater Runoff Reduction in the Chesapeake Bay" grant was funded by NFWF (#0602.22.074143), building upon their long-standing investment in biochar research and use within the Chesapeake Bay watershed.

The specific objectives of this grant are to 1) mature the Biochar Partnership for the Chesapeake (BPC) structure to ensure effectiveness and longevity through an ongoing Community of Practice, 2) Deliver unified education and outreach around the benefits of biochar, 3) Secure new implementation partners who are committed to formalizing the infrastructure for widespread use of biochar amendments, and 4) Provide technical assistance to implementation partners on sourcing certified, quality biochar; providing specifications for its use in a variety of urban applications; verifying and documenting increased infiltration capacity; and modeling the resultant water quality benefits (Center for Watershed Protection, 2021).

4.2 The TMDL for the Chesapeake Bay

Gary Shenk (Hydrologist, USGS)

Gary Shenk outlined the Chesapeake Bay Total Maximum Daily Load (TMDL), which aims to reduce nutrients and sediment reaching the tidal waters of the Bay to meet water quality standards for dissolved oxygen, clarity, and chlorophyll. The federal government, states, and the District of Columbia divide the reduction effort according to areas most effective at achieving water quality goals in the tidal Bay. Jurisdictions develop Watershed Implementation Plans (WIPs) to detail the policies to achieve the reductions. In 2020, the CBP evaluated the effects of climate change on water quality goals and increased the level of effort required to be addressed in the WIPs. The adjustment was small relative to the reduction effort that has already taken place and the amount left to meet the original goals. The Chesapeake Assessment Scenario Tool (CAST) is a model of the watershed that predicts the long-term effects of management practices on loads and is used to measure implementation progress toward the WIPs. CAST accepts information on practices that change nutrient availability from fertilizer manure and practices that restrict the flow of nutrients through the landscape. CAST presents opportunities to model the effects of biochar on nutrient delivery and to include biochar-related practices in WIPs.

Combined models provide a comprehensive understanding of factors affecting Bay conditions, requiring areas with greater inputs of pollutants to undertake more significant efforts to mitigate their contributions to the TMDL. The TMDL decision allocated state-basin quotas for nutrients and sediment, obliging localities to mitigate pollutant outputs based on tributary areas. The introduction of watershed implementation plans (WIPs) posed the question: How do we best reduce pollution sources, protect landscapes, install mitigation practices, and subsequently hit nutrient targets? TMDL discussions to occur in 2028 will continue the CBP's 40-year endeavor to improve the Bay's water quality, providing an opportunity for a new emphasis on nature-based solutions to reduce anthropic pressures and address nutrient overload and climate change.

Table 3 shows the Chesapeake Bay TMDL Milestones and the goals to achieve certain dissolved oxygen levels. The TMDL was a legal formulation to guide efforts to improve holistic Bay health. Climate change will wash more significant amounts of sediment and pollutants into the Bay, and heating the water lowers dissolved oxygen. There is a balance of effects of climate change on Bay dissolved oxygen, as Figure 11 shows with the weights on either side, with the increased weight coming from sea level rise and increased air temperature, more evapotranspiration, and oxygen in the water. However, more nutrients enter the Bay with increased water temperature, precipitation, and precipitation intensity to lower oxygen levels. The 2028 TMDL will account for these changes through estimated 2035 climate change and require increased reduction of nutrients and sediment. There are known areas where the transport of nutrients is high and those areas that need to do the most in the future (Figure 12).

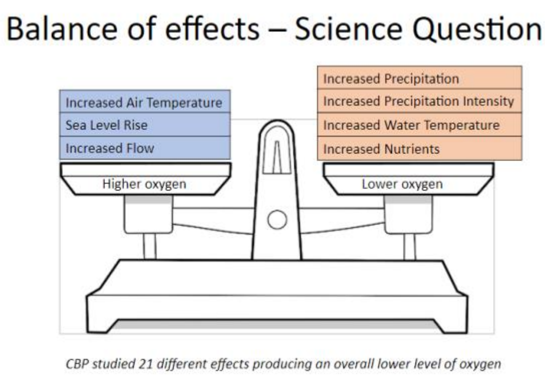


Figure 9. Future weather and conditions will change oxygen levels in the Bay.

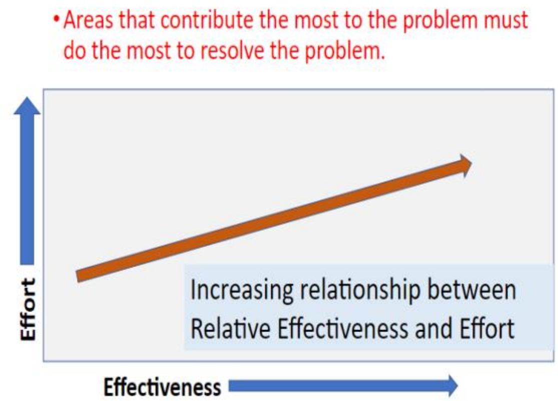


Figure 10. Areas in the Bay that have high nutrient input needed to do more to reduce inputs.

Table 3. Chesapeake Bay TMDL Milestones.

YEAR	MODEL VERSION	GOAL
1987	0	40% reduction (Watershed & Bay models unlinked)
1992	2	40% of controllable loads (forest, air, NY, DE, WV unincluded)
1997	4.1	Added Virginia Tributaries (Rappahannock, York & James with controls
2003	4.3	Reallocation of Tributary Strategies
2010	5.3.0	2010 Chesapeake TMDL
2011	5.3.2	Phase 2 WIP targets
2017	**6**	**Phase 3 WIP targets (You are here!)**
2028	7	TBD

4.3 Existing Protocol Review and Group Discussion

David Wood, Executive Director, Chesapeake Stormwater Network

While co-benefits like carbon sequestration and emerging toxic contamination mitigation are associated benefits of biochar, the Bay Program's BMP review process is to track nutrient and sediment reductions due to changes in management actions. These management actions can include land use changes, such as converting impervious cover to permeable surfaces, structural BMPs, bioretention or stormwater ponds, or programmatic practices that reduce inputs, such as urban nutrient management plans.

To be approved for use toward Chesapeake Bay TMDL requirements, all BMPs must undergo a thorough review process. The typical BMP Expert Panel Review procedure involves convening a team of researchers and practitioners to develop a report to recommend protocols for providing TMDL credits for a new BMP. This report establishes the formal definition of the practice, all qualifying conditions that must be met in the design and operation to be eligible, the nutrient and sediment removal rates for the practice, and the tracking, reporting, and verification requirements. Following the development of the Expert Panel's report, a series of Chesapeake Bay partnership workgroups each review and approve the recommendations to assess the scientific qualifications of the practice, how it fits within the Bay Program's modeling framework, and the practical and policy implications for the states to apply these BMPs. The Procedures for BMP Expert Panel Assessments detail the time to develop and approve recommendations. The process can take several years.

Because a full BMP Expert Panel review requires considerable time and resources, the Urban Stormwater Workgroup adopted a Process for Handling Urban BMP Decision Requests (Schueler 2016) to assess modifications to existing BMPs that have already received credit approval. The Interpretation Policy allows for streamlined review if the science is sufficient and the practice can be tracked and recorded similarly to an existing practice. The process should clarify and reinforce the existing BMP expert panel protocol and process and never be used to undercut or re-open an existing urban BMP expert panel. The BMP must represent a fundamental change on the ground that occurs in the present day (e.g., no historic BMP discoveries). The proposed BMP must have verification procedures that are at least as stringent as the "parent" BMP (i.e., no walking back instated commitments and procedures). The proposed BMP should not create problems reporting it in the CB model Scenario Builder.

4.4 Summary of Options for Pursuing TMDL Reductions for Biochar

Biochar would have to undergo a formal review and approval process to be approved by the CBP and be eligible for Bay TMDL reductions. Workshop attendees discussed two options:

Option 1: BMP Expert Panel Process

Considerations: Establishing a full BMP Expert Panel would provide the most thorough review of biochar as a BMP and provide the opportunity to establish credit for a broader range of applications. For example, an expert panel could be convened to assess biochar as an amendment to existing urban BMPs, an agricultural BMP, or an in-situ soil amendment. This process would require 2-3 years from the initial proposal to final approval but would result in the most robust recommendations.

Option 2: BMP Interpretation Policy

Considerations: This policy would require the proposal team to identify an existing, approved urban BMP that could be easily modified by adding biochar (ex., BMP Retrofit, Runoff Reduction practices). A white paper would be drafted to outline the justification for the approach, and it would be proposed to the relevant CBP Workgroup (ex., Urban Stormwater workgroup for BMP retrofit), which would decide whether the Interpretation can be used or if a full Expert Panel review is warranted. If the Interpretation Policy is used, it would significantly limit the scope of the effort but would speed up the process, requiring 8-10 months from initial proposal to final approval.

Whichever option is pursued, there are a series of pitfalls in developing a crediting proposal that the team should consider. The crediting scheme should be simple, straightforward, and supported by scientific data. The options for crediting should be simple in a range or percentage, and excessive options should be avoided. The scope of the credit should be narrow to ensure it aligns directly with the scientific literature and mechanics of biochar’s functions in certain soils. The crediting proposal should provide scientific justification for incorporating into the model and avoid overly complicated applications.

5. Workshop Presentations and Research Synthesis on the State of the Science of Biochar

The restoration of the Chesapeake Bay watershed faces diverse challenges across agriculture, urban development, and the management of emerging/toxic contaminants, as detailed in STAC's 2023 reports. These reports emphasize the need for innovative solutions in nutrient management, effective stormwater management, and enhanced monitoring of nutrient dynamics. Biochar, a product from biomass, is emerging as a solution. Research summarized in this Section shows biochar use in agriculture, stormwater, and emerging toxic contaminants.

Climate Smart Agriculture and Forestry (CSAF) Work Group
Brandon R. Smith, Ph.D., President, Allied Soil Health, LLC

(Reader note: This section includes workshop material and research synthesis supporting the current state of the science, addressing technical details not fully covered in the workshop's limited timeframe.)

Restoration efforts in the Chesapeake Bay watershed are tackling a complex environmental challenge, as detailed in the 2023 STAC reports, "Achieving Water Quality Goals in the Chesapeake Bay: A Comprehensive Evaluation of System Response" and “Evaluation of Management Efforts to Reduce Nutrient and Sediment Contributions to the Chesapeake Bay Estuary." These reports pinpoint agricultural activities as the primary source of water quality issues. Despite significant efforts to curb agricultural nonpoint source pollution, a notable gap remains in achieving desired water quality improvement goals, highlighting the need for enhanced agricultural pollution management.

Agricultural practices in the Chesapeake Bay watershed, particularly the overuse of fertilizers and manure, were identified as the primary source of excess nutrients negatively affecting the Bay. Innovative agricultural management strategies, including advanced manure handling technologies like thermochemical conversion, are needed. This technology transforms most organic nitrogen into atmospheric nitrogen (N_2) while the minerals and fixed carbon are retained in a more stable and easily transportable form called biochar. To manage the Bay’s excess manure, centralized regional treatment systems, such as the large commercial organic processing facility in Bethel, PA, could be established. However, the transition to centralized treatment systems would demand significant investment and innovation, which are just beginning to be realized within the watershed.

The potential approval of biochar use by the CBP could be particularly transformative for the agriculture and forestry sectors in the Bay watershed. A self-sustaining circular economy could be established by using excess biomass waste from agriculture and forestry to produce biochar locally. This approach would help tackle water quality issues and offer other synergistic benefits, including climate adaptation and waste management opportunities. In addition to the potential benefits of biochar in rural environments and as a new avenue for farmers to contribute actively to environmental solutions, there is wide-ranging and extensive research on biochar use in urban landscapes, including for emerging and toxic contaminants.

Moreover, the production and use of biochar in Climate Smart Agriculture and Forestry (CSAF) is receiving legislative support and funding through various federal and state programs, as highlighted in Section 3.1.7 of this report. This political and financial support further validates biochar's role as a versatile, effective solution in the Chesapeake Bay watershed restoration strategy.

5.1 Climate Smart Agriculture and Forestry (CSAF) and Opportunities for Biochar

During workshop presentations and discussions, the importance of biochar was highlighted in the USDA's CSAF initiative, which merges advanced agricultural methods with sustainable forestry to address food security and climate change. This initiative transforms watershed restoration by emphasizing water quality and focusing on healthy soils, forest health, natural carbon sequestration solutions, effective waste management, and circular bio-nutrient economy principles. Biochar's incorporation into CSAF highlights its essential role in enhancing water quality and overall watershed ecosystem health.

The CSAF strategy resonates with the permaculture's "solution in the problem" principle and is particularly impactful in areas like the Chesapeake Bay watershed, where agriculture contributes to nutrient and sediment pollution. This approach includes converting agricultural waste such as manure into a multipurpose resource like biochar, demonstrating a carbon-negative circular economy model.

Integrating biochar into CSAF practices would position agriculture as a key solution provider, boosting the sector's sustainability and concurrently addressing broader environmental issues, including supporting those in urban settings and concerning emerging toxic contaminants. This comprehensive biochar application and CSAF improve the Chesapeake Bay watershed's health, showcasing innovative, sustainable solutions through integrated environmental problem-solving.

The CBP's endorsement of biochar would foster a circular economy in the agriculture and forestry sectors by utilizing surplus biomass for biochar production and play a crucial role in supporting sustainable agriculture while mitigating the many environmental challenges in the watershed. (See Section 3.1.1 in this document). The contemporary relevance of biochar is underscored by extensive modern research and numerous patents, alongside the National Resource and Conservation Service's (NRCS) recognition through the development of practices supporting the use of biochar and the awarding of biochar-related Conservation Innovation Grants (CIGs) at both the national and state levels. This collective acknowledgment and support underscore the pivotal role of biochar in advancing sustainable agricultural practices and environmental stewardship, as evidenced by the growing appreciation of its multifaceted benefits.

5.1.1 Scientific Summary of Biochar in CSAF

The research article "Biochar in Agriculture – A Systematic Review of 26 Global Meta-Analyses" by Schmidt et al. (2021) stands as a comprehensive assessment of the use of biochar in agriculture. This paper synthesizes the findings from an extensive literature search and critically analyzes 26 meta-analyses published between 2016 and 2020. This review consolidates the current understanding of biochar and highlights its profound agronomic and environmental benefits (Figure 13), underscoring the necessity for standardized biochar analysis and acknowledging the swift progress in biochar-related agronomic research.

The review brings to light several key findings, particularly relevant to restoration efforts in the Chesapeake Bay watershed:

1. **Soil Water Efficiency and Bulk Density:** Meta-analysis by Omondi et al. (2016) found that biochar's application significantly improves soil structure and functionality. "On average, soil bulk density significantly decreased by 8% after biochar amendment. Soil porosity significantly increased, aggregate stability increased by 8%, available water-holding capacity by 15%, and saturated hydraulic conductivity by 25% Omondi et al. (2016)". The effect of biochar on plant available water efficiency varies by soil texture, with the most remarkable improvements seen in coarse-textured (sandy) soils, with a 47% increase in available water, compared to a 9% increase in medium-textured soils, and negligible effects in fine-textured (clayey) soils (Razzaghi et al., 2020). Based on soil texture, the tailored use of biochar optimizes water relations and maximizes its benefits.

2. **Soil Organic Matter (SOM) and Priming Effects:** The interaction between and impact on the mineralization rates of native SOM by the addition of pyrogenic organic matter (biochar) is called priming (Kuzyakov et al., 2000). Biochar additions have been found to result in both positive priming and increasing the rate of SOM mineralization, as well as negative priming, slowing down decomposition and contributing to the accumulation of SOM in soil (Joseph et al., 2021). However, the positive priming impacts are short-term (< 2 years) (Maestrini et al., 2015; Ding et al., 2018), followed by negative priming over the long-term (> 2 years) (Wang et al., 2016). This resulted in a significant increase in native soil organic carbon (SOC) content, with soils showing a 40% higher SOC content after three years of biochar application than soils without biochar (Ding et al., 2018). Furthermore, a study by Bai et al. (2019) highlighted biochar's superiority among various climate-smart agricultural practices, noting a 39% increase in SOC, significantly surpassing the increases observed with other methods.

3. **N_2O Emissions and NO_3^- Leaching:** Biochar applications have been linked to considerably reducing nitrous oxide (N_2O) emissions and nitrate (NO^3-) leaching, addressing two critical environmental concerns in the Chesapeake Bay watershed. A field study reported an average N_2O reduction of 12.4%, and a broader analysis covering 88 studies observed a 38% reduction in N_2O emissions **in the first year**, emphasizing the role of biochar in mitigating greenhouse gas emissions (Borchard et al., 2019). A study by Bekchanova et al. (2024) found that N2O emissions decreased 29% in sandy soils. Similarly, biochar has been shown to decrease NO^3 significantly losses from soil, with reductions **averaging** from 26% to 32% in studies with observation periods of at least 30 days (Borchard et al., 2019).

4. **Nutrient Availability:** Biochar significantly enhances nutrient cycling and efficiency, particularly by increasing soil phosphorus and nitrogen availability. A meta-analysis by Gao et al. (2019) found that biochar applications increased available phosphorus in the topsoil by 45% and phosphorus in microbial biomass by 48%, which is especially beneficial in phosphorus-limited soils. The same study noted a 12% reduction in topsoil NO3- and an 11% decrease in ammonium content, showcasing biochar's capacity to improve nutrient use efficiency and reduce the need for fertilizers.

The systematic review by Schmidt et al. (2021) effectively delineates the multifaceted benefits of biochar in agriculture, spotlighting its significant impact on soil properties, nutrient cycling, and carbon sequestration. These advantages not only bolster agricultural productivity but also offer substantial ecological benefits, making biochar an essential element in sustainable agricultural practices and environmental conservation efforts, particularly in the Chesapeake Bay watershed restoration context. Through its detailed analysis and comprehensive synthesis, the review is a resource for researchers, policymakers, and practitioners in sustainable agriculture and environmental management.

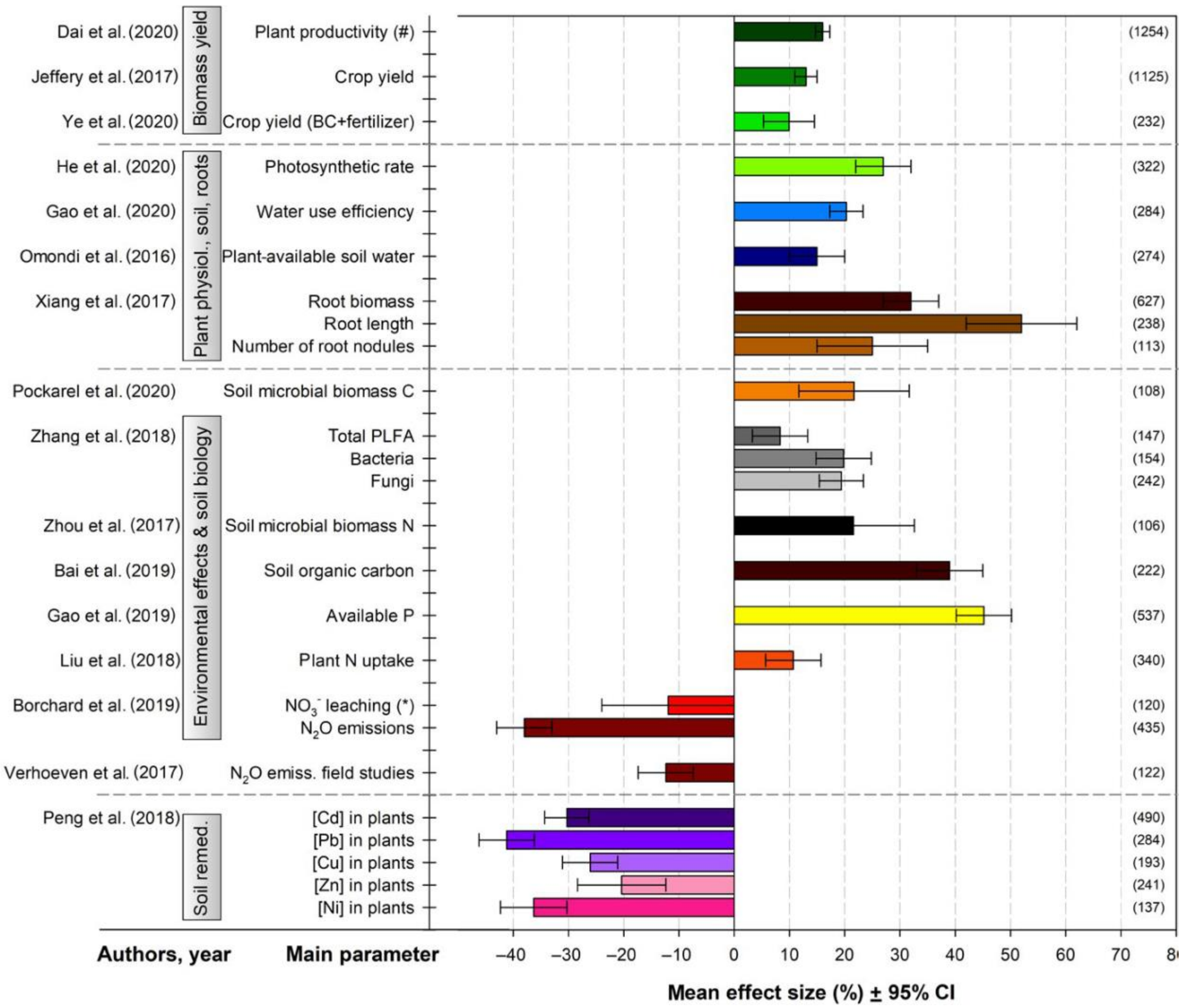


Figure 11. Selected parameters with the highest agronomic relevance were investigated in the 26 reviewed meta-analyses. The mean overall effect size (% change) and 95% confidence intervals are given as reported in the original studies. The parentheses numbers indicate the pairwise comparisons used for that specific parameter (Schmidt et al., 2021).

Soil Carbon Amendment Practice Standard

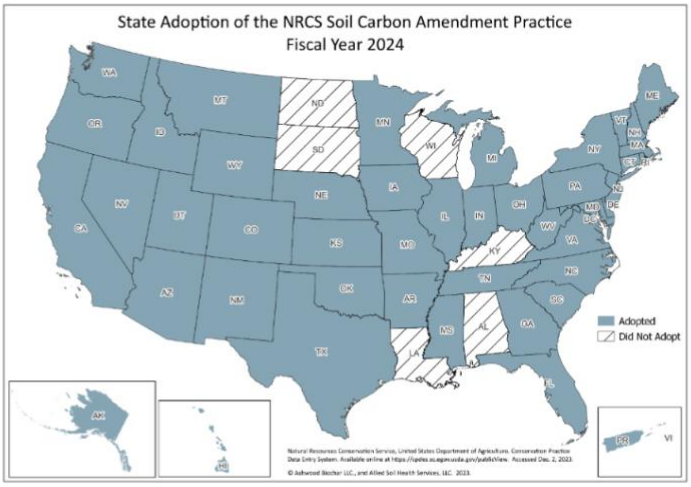


Figure 12. State Adoption of CP-336 FY 2024.

For the Chesapeake Bay watershed, one of the more substantial federal practices recently developed by the USDA-NRCS is the *Soil Carbon Amendment Practice Standard,* which provides financial and technical assistance for applying carbon-based amendments, specifically targeting biochar and compost. The practice can also be combined to enhance the performance of other NRCS practices as a component material. The interim Conservation Practice Standard (CPS 808) became a national practice (CPS 336) in November 2023. As of the federal fiscal year 2024, all but six states in the U.S. have adopted the practice with established payment schedules (Figure 14 and Table 4). In 2023, the U.S. Biochar Initiative provided several training opportunities on using CPS 336 and developed a quick guide to help farmers interested in applying for support.

CPS 336 reimburses qualifying farmers for applying carbon-based amendments derived from plant residues or treated animal byproducts. The practice must accomplish one or more of the following purposes: improved, maintained, or sequestered soil organic carbon, enhanced soil carbon stocks, improved soil aggregate stability, and improved habitat for soil organisms. Approved amendments include compost, biochar, and other carbon amendments such as waste plant materials that would otherwise not benefit conservation (e.g., harvested invasive species) and forest/woodland health management or wood chips.

Table 4. CPS 336 biochar scenarios for the six states in the Chesapeake Bay watershed and Unit Pricing for FY 2024. Rates subject to change and may vary by state.

NRCS Code 336 Biochar Scenarios					
State	**100% Biochar/ 0% Compost**	**80% Biochar/ 20% Compost**	**60% Biochar/ 40% Compost**	**40% Biochar/ 60% Compost**	**20% Biochar/ 80% Compost**
DE	X	X	X	X	X
MD	X	X	X	X	X
NY	X	X	X	X	X
PA	X	X	X	X	X
VA	X	X	X	X	X
WV	X	X	X	X	X

Typical Payment Rates per Acre*

Based on IA Scenarios. Individual state rates may differ ± 5% based on state COLA.

Assumes 4 cubic yards per acre.

*New England payment rates are per cubic yard, not per acre, and differ from what is shown below.

Biochar Component Cost $201 per cubic yard

Practice Reimbursement	**Scenario**				
	100% Biochar/ 0% Compost	**80% Biochar/ 20% Compost**	**60% Biochar/ 40% Compost**	**40% Biochar/ 60% Compost**	**20% Biochar/ 80% Compost**
100%	$1,016	$945	$840	$736	$632
90%	$914	$851	$756	$662	$569
75%	$762	$709	$630	$552	$474

Information compiled by Dr. Brandon Smith, Allied Soil Health Services, LLC, 2024

This NRCS practice details the rules for what one needs to do to implement a practice. The USDA-NRCS also developed the ‘Dynamic Soil Properties Response to Biochar’ tool in their widely used Web Soil Survey (WSS) tool. It considers soil and site property information, including soil pH, cation exchange capacity (CEC), slope, flooding, ponding, bulk density, saturated hydrologic conductivity, and available water capacity to assess how a particular soil type will respond to corn stover or manure-based biochar amendments. Figure 15 shows where the biochar tool can be found in the WSS tool. The central aspect of this data and information is that the focus is entirely on soil health when biochar is applied based on the latest biochar research. The data show that 42% of the soil within the Chesapeake Bay watershed would respond positively to biochar application. While that might seem low, that equates to nearly 19 million acres that would see some form of a benefit, with 9.2 million acres (49.6%) having an Excellent/Good Rating and 9.4 million acres having (50.4%) Fair/Low (Table 5).

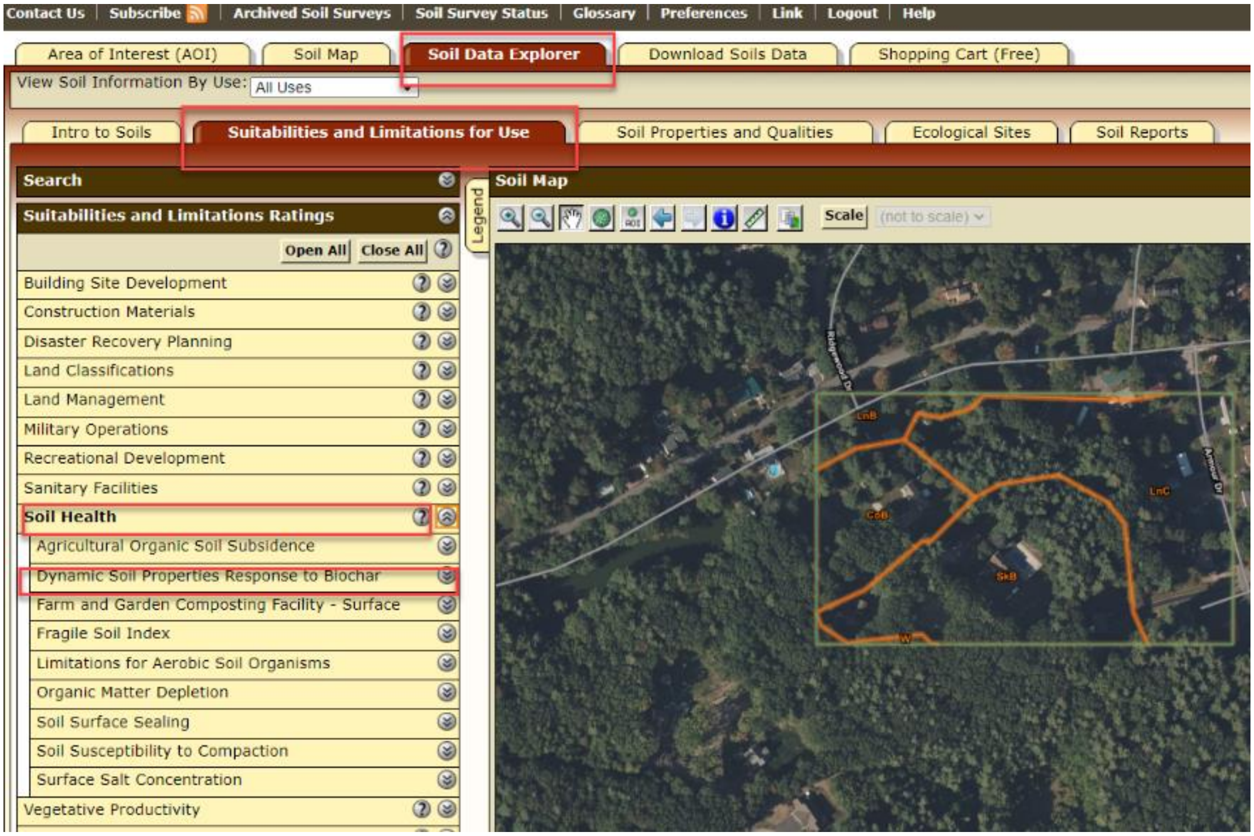


Figure 13. USDA Web Soil Survey - Dynamic Soil Properties Response to Biochar.

Table 5. USDA Soil Health Dynamic Soil Properties Response to Biochar.

USDA Soil Health - Dynamic Soil Properties Response to Biochar								
	Delaware	Maryland	New York	Virginia	Pennsylvania	Washington DC	West Virginia	Totals
Dynamic Soil Properties Rating	Acres	Acres	Acres	Acres	Acres	Acres	Acres	Acres
Excellent	188,405	772,554	53,177	1,360,295	167,624	1,342	3,285	2,546,683
Good	41,289	1,786,528	449,315	3,140,234	1,074,121	335	161,446	6,653,268
Fair	5,319	614,195	1,141,060	2,407,422	1,807,790	646	289,012	6,265,445
Low	74,437	593,757	1,112,457	456,180	642,372	-	200,745	3,079,947
Total (including not suited and not rated)	547,741	7,424,887	4,114,057	14,822,035	14,600,161	2,887	2,395,878	43,907,646

Further, the USDA Agricultural Research Service (ARS), USDA-NRCS, and others have been developing the Pacific Northwest Biochar Atlas, a comprehensive website to assist farmers in determining the 3 R's (right source, right place, right rate) for biochar applications. Such tools include the soil data and biochar property explorer, biochar selection, cost-benefit analysis, and soil carbon amendment implementation tool. While currently specific to the Pacific Northwest of the U.S., this tool is being expanded nationally and demonstrates what could be created for the Chesapeake Bay watershed with a heavy focus on nutrient and runoff management.

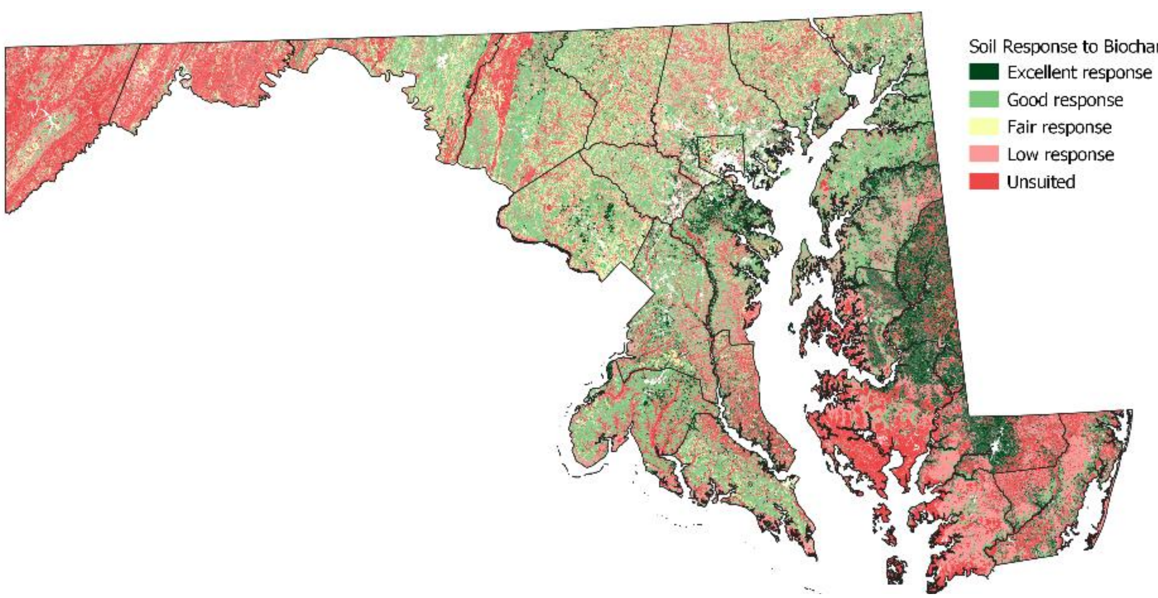


Figure 14. Maryland Dynamic Soil Properties Response to Biochar Application.

demonstrate biochar's direct and indirect benefits, immediate uses exist. For example, focusing efforts on Maryland and Virginia could significantly improve soil health and water quality on a large scale. Additionally, implementing NRCS water quality BMPs with biochar offers further benefits, such as maximizing nutrient runoff reduction services. Even in regions where soil properties are less responsive to biochar and provide lower agronomic benefits, implementing biochar-enhanced NRCS water quality BMPs would significantly improve the performance of these practices, getting maximum nutrient and runoff reduction services.

Table 6. NWQI Codes + Soil Carbon Amendment 336.

National Water Quality Initiative Practices				
Core Practice	***Code***	***Avoiding***	***Controlling***	***Trapping***
Composting Facility	317	■	■	
Conservation Cover	327	■		■
Cover Crop	340	■		■
Critical Area Planting	342		■	■
Denitrifying Bioreactor	605			■
Drainage Water Management	554		■	
Field Border	386		■	■
Filter Strip	393		■	■
Grassed Waterway	412		■	
Nutrient Managaement	590	■		
Riparian Forest Buffer	391			■
Riparian Herbaceous Cover	390			■
Tree/Shrub Establishment	612	■		■
Waste Storage Facility	313	■	■	
Waste Treatment Lagoon	359		■	

The NRCS National Water Quality Initiative (NWQI) practices aim to avoid, control, and trap pollutants, and when CPS336 is coupled with NWQI, they can provide net positive environmental benefits. Table 6 provides key biochar-coupled water quality practices that should be of primary focus for implementation. Additionally, to build community buy-in for this conservation approach, agencies, and private entities are marketing biochar to farmers by highlighting the potential cost savings derived from improved nutrient use efficiency and the resulting decrease in external inputs.

The proposed NRCS reimbursement structure for CPS 336 focuses on soil health and maximizing soil carbon. The practice does not claim additional co-benefits, which are of interest in many ecosystem services markets. The benefit of implementing the CPS 336 protocol in the Chesapeake Bay watershed would include stacking co-benefits and credits in marginal and productive lands. Biochar-enhanced soil co-benefits, such as water retention and infiltration, improved water quality from nutrient retention, runoff reduction, erosion prevention (sediment reduction), improved biodiversity and wildlife habitat, and carbon sequestration could provide for enhanced or stacked credits.

5.1.2 Forest Conservation and Woody Biomass Conversion

The Chesapeake Bay watershed, esteemed for its expansive forests, which cover about 55% of its total area, offers ecological and economic stability to the region, functioning as a natural purifier by filtering rainwater and serving an instrumental role in maintaining the pristine water quality of the Chesapeake Bay. However, despite their crucial importance, these forests have many challenges, including fragmentation from development, the imminent threats from climate change leading to drought and flood cycles, and the increasing pressures from invasive plant species, pests, and diseases. As noted by the Maryland Department of Natural Resources (MD DNR), the region's forest health is deteriorating as many forests age and face continuous new threats from invasive pests such as the emerald ash borer, spotted lantern fly, gypsy moth, and southern pine beetle, posing significant risks due to their interactions with seasonal weather, biocontrol organisms, and drought stress (MD DNR, 2020).

Despite these region-wide challenges, the forests significantly contribute to the local economy. States within the watershed, namely Maryland, Virginia, Pennsylvania, and New York, are home to robust forestry departments that diligently manage timber resources. Integral to this sustainable management is the approach to wood waste, a byproduct of timber harvesting, sawmill operations, and urban development. There is a concerted effort to minimize, repurpose, or utilize available biomass effectively, transcending mere waste reduction to embody the principles of a circular economy, thus ensuring the efficient and sustainable use of every bit of resource.

According to the Alliance for the Chesapeake Bay, a non-profit working in the Bay, the ownership structure of forests within the Chesapeake Bay watershed is fragmented, with nearly 80% of the total forests under private family ownership, most owning less than 25 acres. This significant aspect of private ownership plays a pivotal role in the region’s management, conservation, and utilization of forest resources. Consequently, advocating and implementing sustainable forestry practices is paramount.

The markets for locally sourced forest products have experienced a downturn, mainly post the COVID-19 pandemic, due to various factors such as a dwindling labor force, reduced availability of log truck drivers, low-valued timber, and the closure of saw and paper mills (MD DNR, 2020). This downturn has necessitated the expansion of existing markets, like poultry bedding, and the exploration of new markets, including wood biomass for thermal and electrical energy production, carbon credits, and biochar. Legislative backing and incentives promoting broader development CSAF could rejuvenate the forest products industry, provide income to landowners, and promote sustainable forest management.

5.1.3 Biochar: A Transformative Solution for Forest Conservation

In addition to the forest industry's complex business challenges, innovative solutions are paramount. Biochar is a versatile tool that significantly aids forest management and environmental conservation. The science behind biochar, particularly its relation to wood as the primary feedstock, has been previously discussed in this document.

Over the last ten years, Delaware and Maryland have primarily focused on the research and application side of biochar as a soil amendment and for stormwater practices. Virginia has recently emerged as the epicenter for biochar production, and Pennsylvania is trailing behind in production and application. As of this writing, commercial wood-based biochar production in Delaware and Maryland remains unreported, with these states being primary consumers within the urban landscape and agricultural sector.

Virginia Biochar Initiative

Virginia is swiftly establishing itself as a leader in biochar production within the Chesapeake Bay watershed and the broader mid-Atlantic region. The state boasts three operational facilities producing approximately 6,000 tons of biochar, with more new facilities to come online. In 2024, Virginia plans to augment its biochar production capacity significantly. The state anticipates exceeding an annual production of 20,000 tons of biochar. This growth is not merely about quantity; it represents a strategic alignment with the evolving dynamics of the wood industry and the broader economic landscape, fostering new opportunities for forest conservation, carbon credit markets, and products and promoting local circular economic practices. The Virginia Department of Forestry is at the forefront of these efforts, leading educational programs, fostering grant partnerships with the private sector, and demonstrating on-site biochar production in collaboration with the US Forest Service using the Air Burner CharBoss.

West Virginia's Biochar Initiative

Although not yet home to commercial biochar production, West Virginia is significantly engaged in field-scale research and development, spearheaded by the Mid-Atlantic Sustainable Biomass Consortium (MASBio). This private-public consortium, led by West Virginia University with substantial funding from the USDA National Institute of Food and Agriculture (NIFA), is committed to establishing a sustainable and economically viable biomass system in the Mid-Atlantic region. West Virginia has over 10 million acres of mined and marginal agricultural lands and the availability of over 8 million dry tons of forest residues, which provides the opportunity to create a sustainable carbon-negative economy in the region.

Pennsylvania Biochar Initiative

In Pennsylvania, biochar production and use are in their infancy, with a handful of actual producers of wood biochar, primarily small or mid-sized, producing several thousand tons annually, supplemented by a few biochar retail or broker service providers. Interest in biochar's use is growing among all sectors, with academic and regulatory agencies taking note and investing in related research projects, particularly those concerning water quality for the Chesapeake Bay watershed. Biochar use will increase through USDA-NRCS programs, carbon markets, and pending TMDL credit approval from the Chesapeake Bay Program.

Maryland and Delaware Biochar Initiatives

Maryland and Delaware have followed similar biochar utilization and research paths, primarily focusing on soil amendments for degraded urban soils and biochar-enhanced bioretention mixtures. The research, initiated by the University of Delaware (UD) in 2012 and later expanded into Maryland, has drawn considerable attention regionally and nationally.

UD's research on biochar's impact on water retention, nitrogen removal, and runoff reduction has spurred widespread interest and application. Further details from the research conducted by UD can be found in Section 5.2 below. UD’s findings, along with other national studies, have prompted entities like the Delaware Department of Transportation (DelDOT), Maryland Transportation Authority (MDTA), Washington D.C. Department of Environment and Energy (DOEE), and several field-oriented non-profits to begin incorporating biochar in urban landscapes.

In Maryland, the exploration and utilization of biochar is intensifying. The U.S. Forest Service in Baltimore is actively investigating potential sources of wood waste for biochar production aimed at soil amendments for greening vacant lots. Simultaneously, the University of Maryland's Environmental Finance Center (UMD EFC) is at the forefront of research into waste management systems capable of supplying marketable products like biochar and evaluating the cost-benefits of its use. These initiatives are part of a broader strategy to harness biochar's potential for biomass waste reduction and soil enhancement, acknowledging that biochar can significantly improve soil quality by enhancing nutrient retention and water runoff. More recently, state permits have been filed for a new biochar facility built in Alleghany County, Maryland, at a former paper mill plant.

5.1.4 Animal Waste Technologies (AWT)/MTT Protocols

Excess volumes, seasonality, weather constraints, or quality concerns increasingly limit manure use in agricultural fields. However, opportunities exist to turn it into valuable soil and water treatment products. This approach capitalizes on otherwise underutilized resources and significantly reduces the volume of nutrients applied to land, aligning with sustainable waste management and environmental conservation strategies.

The September 2016 report titled "Manure Treatment Technologies: Recommendations from the Manure Treatment Technologies Expert Panel to the Chesapeake Bay Program's Water Quality Goal Implementation Team to define Manure Treatment Technologies as a Best Management Practice" is a comprehensive document that delves into manure treatment technologies, their efficacy, and their role in the CBP. Central to the report is the discussion on treatment technologies designed for stabilizing manure organic matter, facilitating handling, and generating on-farm energy, with a pronounced focus on how these technologies alter nutrient flows in farms and the broader environment.

The report explores six technologies, highlighting biochar primarily in the context of Thermochemical Conversion (TCC). However, proponents suggest that biochar's utility could extend beyond TCC and merits consideration across all technologies. For concise analysis within this report, the discussion focuses on two technologies—TCC and co-composting—identified for their immediate and profound benefits to the Chesapeake Bay watershed.

TCC and co-composting are instrumental in mitigating nitrogen volatilization and facilitating the segregation and subsequent off-farm use of nitrogen and phosphorus. This capability is valuable for addressing ETC challenges, particularly in urban areas, brownfields, and locales impacted by acid mine drainage and mine reclamation. Additionally, the report illuminates the role of these technologies in converting nutrients into forms more readily assimilable by plants, highlighting their potential to significantly improve soil fertility and ecosystem health.

The report succinctly introduces manure-based biochar within the realm of TCC, using manure, which in many cases has considerable plant-based biomass (e.g., poultry litter). The TCC process notably enhances nutrient management by achieving up to 85% nitrogen mass transfer efficiency. This efficiency stems from the strategic alteration of nutrient flows within the system. The assessment hinges on meticulously analyzing the mass of nutrients entering and departing the treatment system. Within this framework, specific transfer efficiencies pertinent to TCC are quantified, encompassing metrics such as Nitrogen Volatilization Efficiency (NVE), Nitrogen Separation Efficiency (NSE), and Phosphorus Separation Efficiency (PSE), thereby offering a comprehensive evaluation of the process's effectiveness in nutrient management.

Only two commercial-scale TCC manure processing facilities have been established within the Chesapeake Bay watershed. Unfortunately, one of these facilities has ceased operations. The remaining facility, situated in Bethel, Pennsylvania (Figure 17), is a substantial organics processing unit with a capacity to process 80 dry tons of organic material daily. This facility is adept at handling various complex biomass waste streams, including manure. As a waste disposal system, the operation minimizes waste volumes and mitigates environmental impacts. It notably accommodates excess manure deemed unsuitable for land application, often due to seasonality, adverse weather conditions, or quality-related issues, thus contributing to sustainable waste management practices in the region.

Figure 15. Dual 40 ton/day/Gasifiers (Photograph Credit – Earthcare, LLC).

While the report touches upon the utility of manure-based biochar, primarily recognizing its role as an alternative fertilizer or a carbon-based organic soil amendment, it stops short of delving into the broader spectrum of biochar's potential. There is a wealth of untapped potential in harnessing biochar more comprehensively to optimize the nutrient cycle. This could be achieved by seamlessly integrating biochar into existing manure treatment technologies, such as composting, anaerobic digesters, and the treatment of liquid effluents (Figure 18). The opportunity extends beyond mere agricultural benefits, reaching into markets beyond the farm, particularly those connected to urban landscapes and the management of ETC. This multifaceted potential of biochar represents a significant yet underutilized avenue for sustainable waste management and environmental remediation.

5.1.5 Co-composting with Biochar

Recent investigations have shown the versatile role of biochar as a compost additive, marking significant strides in mitigating odor emissions and advancing nutrient cycling, improving compost quality, and bolstering carbon sequestration in soil.

As the linchpin of sustainable waste management, composting transforms organic waste into a nutrient-rich fertilizer. However, this conventional method confronts formidable challenges, notably leachate runoff, substantial nutrient loss, and insufficient carbon capture. In this context, biochar emerges as a beacon of innovation—a stable, carbon-rich byproduct of pyrolysis renowned for enhancing nutrient retention and amplifying carbon storage in compost, thus

Figure 16. Closed Loop Single-Step Model for Animal Operations (RED Garner).

providing a holistic solution to these pervasive challenges. Lehmann et al. (2006) illuminated the profound impact of biochar, demonstrating its capacity to secure carbon in the soil for millennia, thereby establishing it as a critical component in strategies to foster carbon-negative practices.

Incorporating biochar into the composting processes profoundly influences nutrient dynamics, especially regarding nitrogen and phosphorus (Figure 19). Nguyen et al. (2023) highlighted biochar's role in diminishing nutrient losses, attributing this to its adsorptive properties and ability to catalyze microbial activity. Their research revealed that integrating a mere 10% biochar into compost mixtures could curtail nitrogen loss by as much as 50% and elevate phosphorous availability for plants by 18%. Biochar's porous structure creates a conducive habitat for microorganisms, facilitating the transformation and stabilization of nutrients within the compost (Thies and Rillig, 2009). Similarly, Steiner et al. (2014) documented a staggering 64% reduction in ammonia (NH_3) emissions with a 20% biochar inclusion in compost.

Biochar's distinct properties, including high porosity, hydrophobicity, and substantial carbon content, render it an efficacious sorbent for odorous gases. Nguyen et al. (2023) observed a notable 30-50% decrease in NH_3 and hydrogen sulfide (H_2S) emissions following a 10% biochar amendment. Moreover, they also reported a 45% reduction in overall odor emissions in composts amended with biochar compared to those without such amendments.

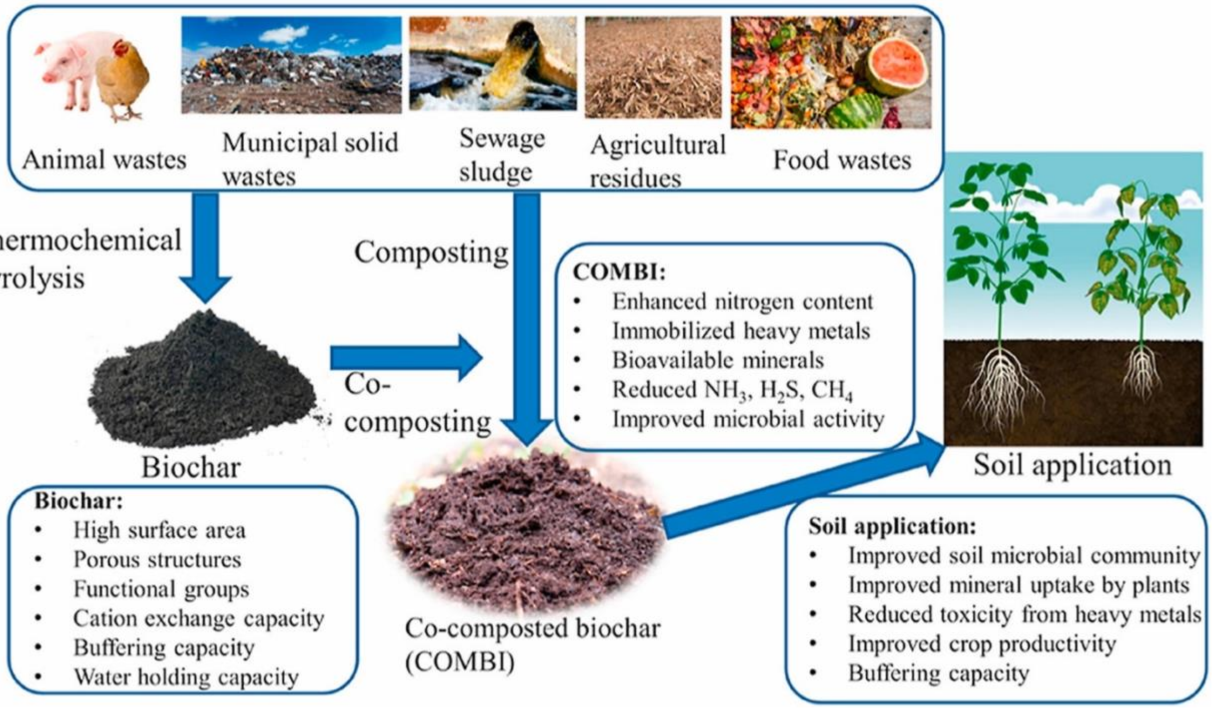


Figure 17. The Benefits of Biochar and Co-Composting Different Compost Wastes (Antonangelo, J.A. et al, 2021).

The integration of biochar in compost extends beyond nutrient retention; it also refines the nutrient composition of the compost. Research spearheaded by Waqas et al. (2018) suggests that biochar modulates pH, electrical conductivity, and organic matter decomposition in compost, influencing nutrient availability and form. Their findings indicate that biochar amendments precipitated a 35% decrease in organic matter loss and significantly stabilized pH levels throughout the composting process. Waqas et al. (2018) also observed that biochar amendments bolstered the overall compost quality, with a 20% surge in nutrient retention and a 35% enhancement in microbial activity. Biochar's intrinsic richness in stable carbon positions it as an excellent candidate for carbon sequestration. The amalgamation of biochar in compost enriches soil fertility and fosters long-term carbon storage.

Biochar's pivotal role in fortifying nutrient cycling, optimizing compost quality, and sequestering carbon underscores its immense potential as a valuable amendment in composting processes. Positioned as a sustainable and efficacious solution, biochar harbors the capacity to revolutionize waste management practices, nurture sustainable agriculture, and aid in climate change mitigation. The palpable advantages in nutrient management and carbon sequestration accentuate biochar's potential as an indispensable element in future sustainable practices.

5.1.6 CSAF Closing Statement

The endorsement of biochar by the CBP could catalyze a transformative shift within the agricultural and forestry sectors across the entire Chesapeake Bay watershed. Such approval would pave the way for establishing a comprehensive circular economy, where the community produces an array of biochar products and utilizes them locally. This approach would address numerous water quality challenges and offer climate mitigation and adaptation avenues.

Harnessing the wealth of biochar research, this initiative aims to transform surplus biomass waste from agricultural and forestry operations, such as manure and forestry residues, into a range of biochar products within the Bay watershed. This approach is set to catalyze the local production of various biochar types, specifically tailored to meet the demands of the urban landscape and address the challenges ETC poses. Crucially, this strategy empowers the farming community, establishing them as pivotal players in improving soil health and water quality within the watershed. It not only bolsters the sustainability of the local agriculture and forestry sectors but also fortifies the region's defenses against ecological adversities. The proactive move to expand biochar use in the Chesapeake Bay watershed is a substantial leap toward fostering a future where sustainability and self-sufficiency are at the forefront.

5.2 Urban Landscapes (Stormwater) Workshop Group

Paul T. Imhoff, Ph.D. (Environmental Engineer, University of Delaware)

(Reader note: This section includes workshop material and research synthesis supporting the current state of the science, addressing technical details not fully covered in the workshop's limited timeframe.)

The rapid growth of urbanization in the Chesapeake Bay watershed poses an incredibly difficult challenge, if not impossible, to meet the TMDL nitrogen, phosphorous, and sediment reduction targets by 2025. However, this rapid urbanization growth exacerbates environmental impacts beyond the TMDL targets, including increased susceptibility to flooding, increasing ETCs, decreasing vegetation cover, biodiversity loss and habitat fragmentation, and climate change, such as urban heat island effect increasing human health risks and primarily affecting environmental justice communities (Liao et al., 2023).

Urbanization fundamentally shifts the terrestrial water cycle (precipitation recycling), reduces evapotranspiration, increases the rate and volume of stormwater runoff produced, and deteriorates the water quality of the receiving water body, in this case, the Chesapeake Bay watershed (Tirpak et al., 2020). Green infrastructure (GI) is the management of stormwater runoff using natural ecosystems or engineered systems that mimic natural systems and have seen increasing deployment in urbanized areas as a nature-based solution (NbS) to mitigate urban environmental impacts (Liao et al., 2023).

GI is a significant tool for many urbanized communities but is expensive to implement and requires long-term operations and maintenance on hundreds, if not thousands, of small-scale BMPs. "The high cost of urban stormwater BMPs has been a major limiting factor for communities with limited funds and competing priorities, along with site constraints (e.g., poor soils, utilities) that further drive up the cost or make BMPs infeasible. Lack of available space to install enough stormwater BMPs to meet TMDL requirements is another challenge, especially for highly impervious municipalities where most of the land is privately held (CWP, 2021)."

Due to climate change, future increases in rainfall (10%+/-) (USGCRP, 2017) are expected across the Bay watershed. This calls for a more holistic, cost-effective NbS for urban communities. Climate change conditions are already evident, requiring Bay communities to adapt or mitigate impacts. There is a need for GI to handle flashier and more intense storms better using performance-enhanced devices (Hirschman D. et al., 2019) to improve soil infiltration, water-holding capacity, and nutrient transformation in engineered media.

Biochar amendments offer urban communities a versatile tool to meet today's challenges and beyond 2025:

- To enhance the function of existing BMPs or to revive the function of poorly or non-functioning existing BMPs,
- To enhance the function of new structural and non-structural BMPs installed for new or redevelopment activities and
- As a stand-alone landscape-scale BMP (e.g., urban soil amendments).

The overall trend in peer-reviewed journal publications involving biochar, as shown in previous sections of the scientific literature on biochar applications to urban stormwater BMPs, has increased, as shown in Figure 20. The number of scientific publications on biochar applications in stormwater is approximately 0.5% of the total number of scientific biochar publications over the same time see previous sections. This observation is consistent with the historical focus of applying biochar to agricultural soil to improve crop productivity or sequester carbon (Schmidt et al., 2021).

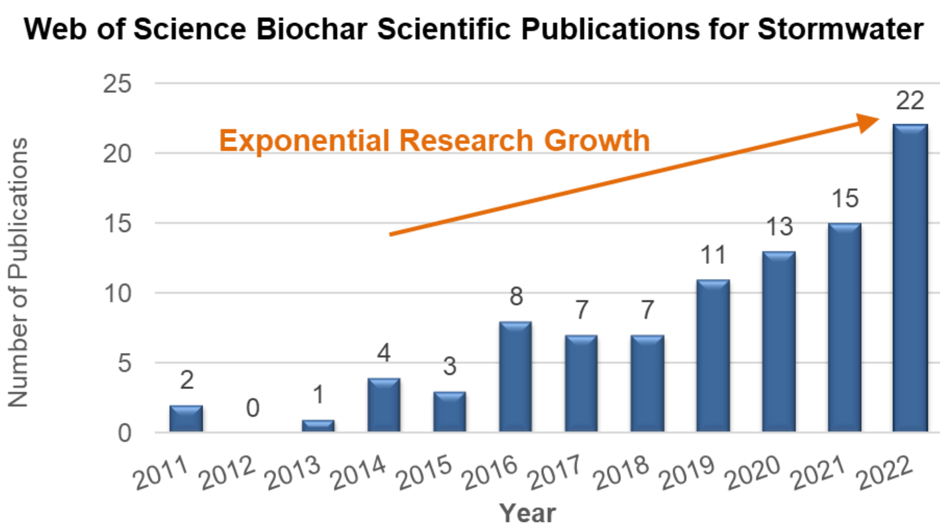


Figure 18. Growth in the number of scientific publications on biochar applications for stormwater management.

Fortunately, although the number of scientific studies of biochar applications to stormwater BMPs is not large, many of the findings of biochar's impact on agricultural soil are transferable to stormwater BMPs. Figure 21 shows scientific studies where biochar was applied to stormwater BMPs. All applications are additive to an engineered medium, except for infiltration trench/basins. All include plants that are an integral part of the BMP for stormwater treatment and an essential component of applications in agricultural soil. Notably, biochar application to bioretention and sand filters are the dominant applications studied.

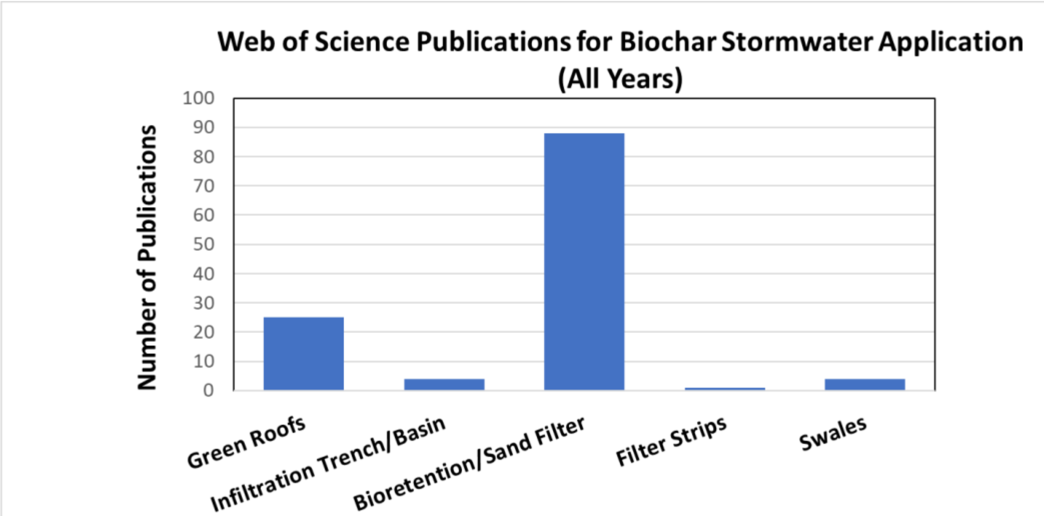


Figure 19. Number of biochar applications in different stormwater BMPs as described in scientific publications (2011-2022).

In each type of application, biochar improves soil infiltration capacity, reducing runoff and pollutant loads. The additional water-holding capacity (25-27%) provided by biochar amendments helps to address outcomes identified by the CBP's Climate Resiliency Workgroup (e.g., "pursue, design, and construct restoration and protection projects to enhance the resiliency of Bay and aquatic ecosystems from the impacts of coastal erosion, coastal flooding, more intense and more frequent storms, and sea level rise"). Biochar increases soil micro and macropores and soil aggregation via microbial processes. Biochar amendment also mitigates the heat island effect by metering soil temperatures, causing warmer soil temperatures at night and cooler temperatures during the day, which allow microbes to work longer, which is critical for nitrogen conversion and reduction of nitrous oxide and other greenhouse gas emissions (Lyu et al., 2022). Likewise, based on the study conducted along US-896 in Delaware during 2016/2017, the biochar provided significant thermal seasonality benefits with soils cooler in the summer, warmer in the winter, and metered extreme temperature shifts year-round over the control unamended soils (Figure 22 and Figure 23).

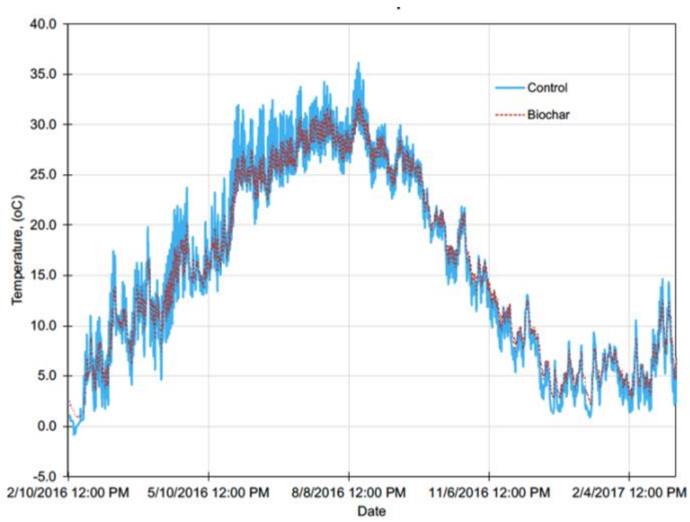


Figure 20. Seasonal continuous temperature soil monitoring of biochar amended and unamended soils along US-896, Delaware. University of Delaware (2016/2017).

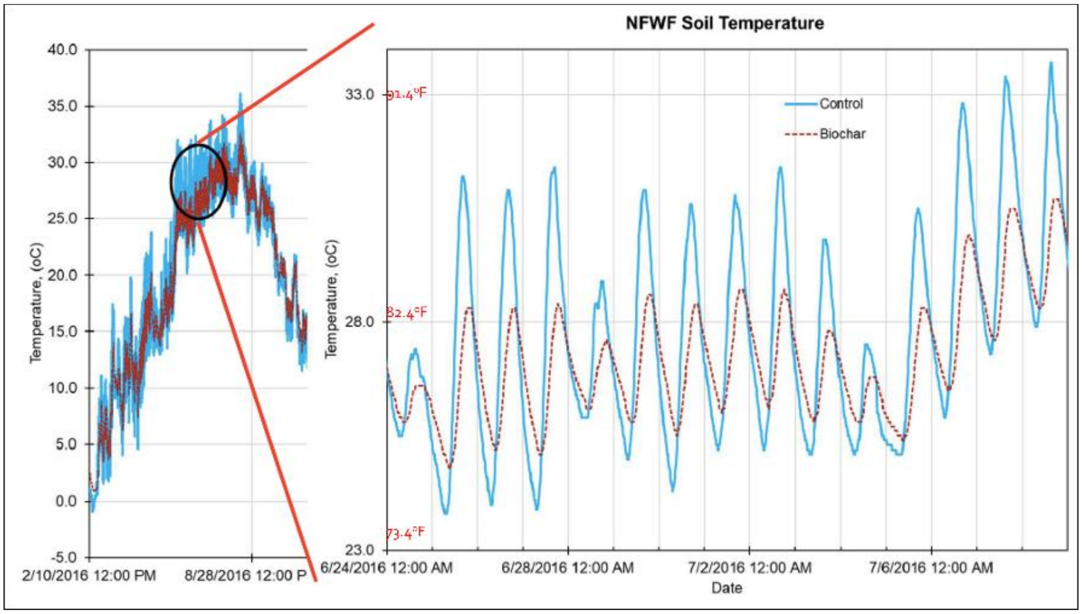


Figure 21. Daily continuous temperature soil monitoring of biochar amended and unamended soils along US-896, Delaware. University of Delaware (2016/2017).

The production and use of biochar provide use for what was previously considered waste and can create jobs and energy. As green carbon, biochar is the only carbon-negative stormwater treatment technology with the potential to combat climate change. Based on the amount of fixed carbon of a feedstock (wood is higher, manures lower) and the Life Cycle Analysis for the production facility, which is typically between 2.0-2.5 tons of CO_2e for every ton of fixed carbon contained in biochar when you subtract out the energy inputs from 3.67 tons of CO_2.

Biochar amendment in new or existing BMPs represents a relatively small incremental cost that can significantly improve runoff reduction and enhance removal rates for nutrients, toxics, and bacteria in those BMPs and make better use of underutilized urban green spaces that were previously off-limits for many green infrastructure practices.

Research by the University of Delaware has documented the runoff reduction capabilities of biochar amendments at seven different field sites. In all seven applications of biochar amendment to compacted soils, biochar amendments significantly increased stormwater infiltration by 50% over identical treatments without biochar and, in some cases, by over 100%.

Some specific examples from these studies and similar investigations of biochar amendment to bioretention media include:

- Biochar was amended at 4% to a sandy loam in a roadway filter strip along a four-lane divided highway in Delaware (Figure 24). Over 84 storm events in 2016/2017, biochar amendment resulted in an average reduction of stormwater runoff volume and peak flow rate by 88 and 83%, respectively (Figure 25). These results were explained by the approximately 47-50% increase in saturated hydraulic conductivity with biochar amendment and increased natural soil aggregation (Imhoff et al., 2017).

- Using published models for the effect of biochar on soil saturated hydraulic conductivity and USDA soil maps, biochar at 4% by mass was predicted to cause a similar 47-50% increase in saturated hydraulic conductivity in all roadway soils in New Castle County, Delaware (Imhoff et al., 2019).
- When biochar was used as an amendment to bioretention media, on average, biochar increased nitrate removal by a factor of 5 (i.e., 500%) while increasing infiltration four-fold for a typical storm event, with no diminished performance from media compaction (Tian et al., 2018).
- Using data collected from a Delaware field site (Imhoff et al., 2018) and two application sites in the Tiber Hudson (Maryland) watershed (Imhoff et al., 2020), biochar amendment to soils at the impervious/pervious disconnect zone was predicted to reduce stormwater runoff by 80% on average, with the actual runoff reduction determined by the impervious/pervious ratio that will differ for application area (Imhoff et al., 2018) (Figure 26).

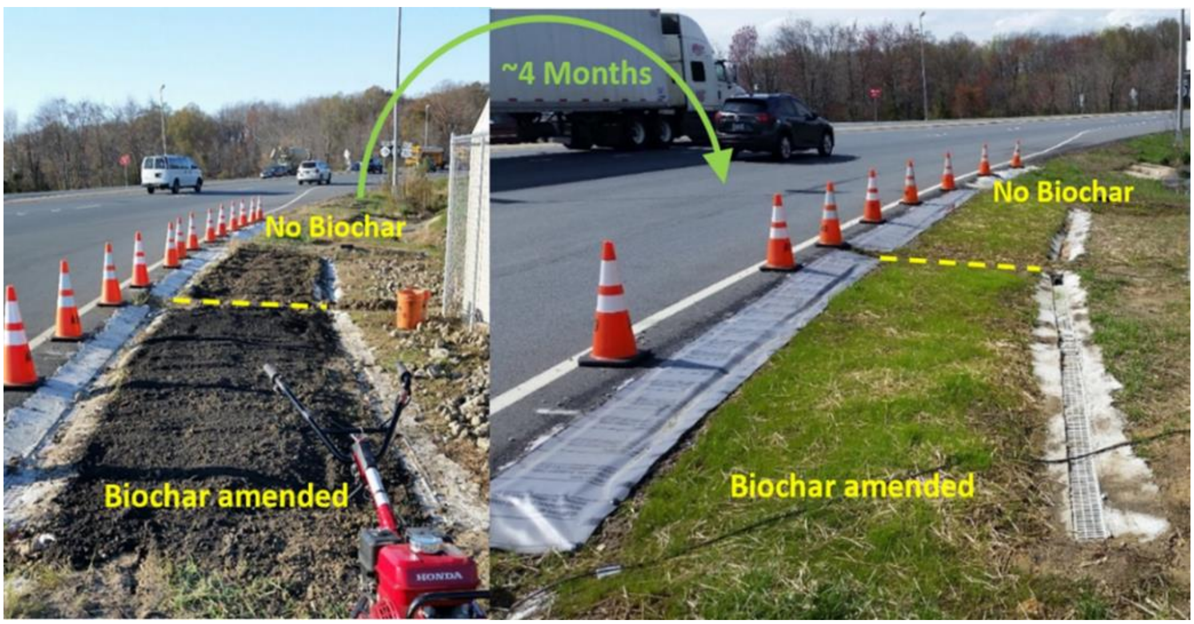


Figure 22. Installation of biochar and control section (Left) and trench drains in white concrete to document reductions in stormwater runoff for over 100 storm events (Right).

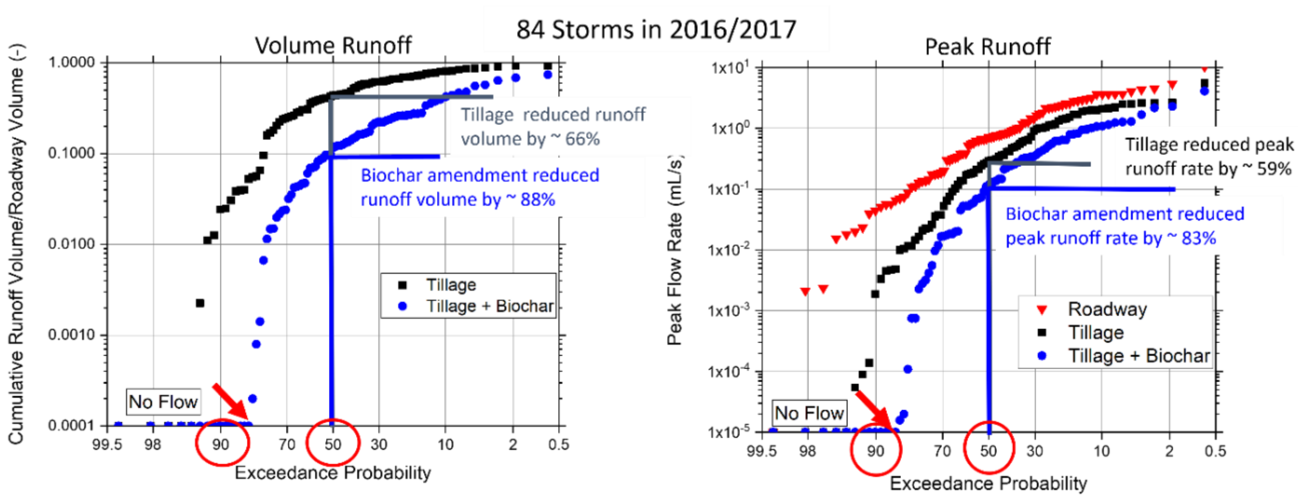


Figure 23. Reduction in peak runoff (Left) and reduction in runoff volume from tillage (black) and tillage + biochar (blue) for 4% by mass biochar amendment to the site (Right) in Figure 24.

While similar improvements have been seen with compost amendment in other studies, biochar as a recalcitrant carbon continued to reduce stormwater runoff over the study period. Compost amendments' improvements diminish over time since compost is readily decomposed, whereas biochar persists in the soil for many years. Measurements from biochar applications indicated that soils often improved with time through natural soil aggregation, resulting in increased hydraulic conductivity and stormwater infiltration.

Figure 24. Biochar Amended Highway Greenway – 4% by mass. Similar benefits are at 2-3% by mass based on in-situ soil characteristics, as in Delaware and Maryland.

One reason biochar amendment to bioretention may be particularly advantageous is that it overcomes drawbacks associated with nutrient leaching from compost (Owen et al., 2023), which is a required organic amendment for bioretention in all states within the Chesapeake Bay watershed (Akipinar et al., 2023a). Biochar amendment provides many of the benefits of compost addition, e.g., increased water retention (Akpinar et al., 2023a) and improved plant growth (Akpinar et al., 2023b), attributes that resulted in compost inclusion as a required component of bioretention media (Owen et al., 2023; Akipinar et al., 2023a). If properly selected, biochar will not leach significant nutrients (Akipinar et al., 2023 and Figure 27). Thus, biochar is a promising amendment for bioretention where nutrient removal is essential, such as in the Chesapeake Bay watershed.

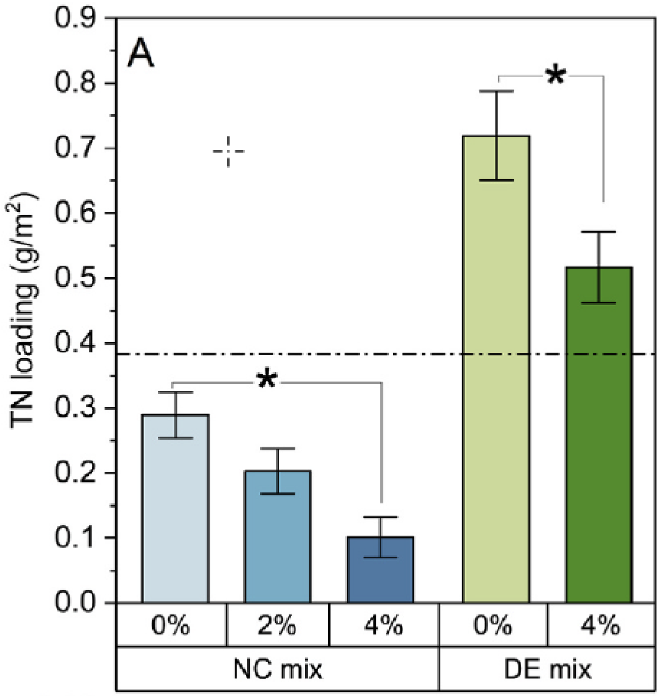


Figure 25. Figure 27 – Effect of biochar amendment (0, 2, and 4% by mass) on total nitrogen (TN) loading from two bioretention media – NC mix (without compost) and DE mix (with compost). Influent TN loading is horizontal dashed line. Biochar amendment decreased TN loading from both media, although TN in DE mix exceeded influent when compost present. Taken with permission from Akpinar et al. (2023b).

While biochars produced from a wide variety of organic feedstocks have been studied in stormwater BMPs, wood biochars were used in 84% of investigations in bioretention (Biswal et al., 2022), the most frequently studied BMP. For example, in the bioretention studies of Akpinar et al. (2023a and 2023b), where biochar was proposed to replace or reduce the amount of compost, a wood biochar was used. When biochar is amended to bioretention, it has resulted in pollutant reductions. Approximately 40% of the bioretention studies quantified pollutant removal, and removal percentages are reported in Table 7 (Biswal et al., 2022). The reduction of pollutants varies between studies for the same compound. For example, removal ranges between 32% and 64% for total nitrogen (TN). The variation in pollutant removal efficiency is due to the variety of biochars employed and differences in experimental conditions.

Table 7. The percentage of pollutants in bioretention was reduced when amended with biochar (Biswal et al., 2022).

Pollutant	Reduction Range with Biochar
Heavy Metals	27 – 100%
Total Nitrogen	32 – 64%
Total Phosphorus	45 – 94%
Microorganisms	Log10 = 0.78 – 4.23
Organics (PAHs, etc.)	54 – 100%

Biswal et al. (2022) noted in their review that biochar amendment demonstrates promising performance with nitrogen removal enhanced in > 90% of the studies for nitrogen and phosphorus, which are key pollutants for the Chesapeake Bay. The primary limitation of biochar applications in bioretention is that 88% of the published studies were conducted in the laboratory. Laboratory experiments are generally short-term and do not assess seasonal effects or long-term performance, which might only be observed in field studies. To move beyond the laboratory, the NFWF Scaling Up Biochar grant promotes shovel-ready infiltration BMPs to collect field-scale performance and operational aspects of biochar (Figure 28).

Figure 26. Infiltration basin retrofit and amended with biochar DelDOT US301, Delaware.

While bioretention is the most studied BMP for biochar amendment, a recent critical review of the scientific literature concluded that biochar might improve the performance of green roofs, infiltration trenches/basins, bioretention/sand filters, constructed wetlands, filter strips, and bioswales (Mohanty et al., 2018). Consistent with these findings, Liao et al. (2023) conducted a global meta-analysis and synthesis of biochar amendment to green infrastructure in urban settings and found that biochar resulted in moderate decreases in the discharge of most pollutants. For example, across all BMPs examined, a qualitative assessment of published data found that biochar resulted in a 38% and 27% reduction in the load of total nitrogen (TN) and total phosphorus (TP) delivered out of the BMPs. Biochar application also resulted in moderate decreases in stormwater discharge volume (15%) and emissions of all greenhouse gases (N_2O, CH_4, and CO_2).

The number of published studies on biochar amendment in stormwater in urban landscapes is increasing exponentially. There are far fewer than in the agriculture and environmental contaminants sectors, but they can be valuable studies for comparative research. Nevertheless, these published studies indicate that biochar amendment significantly reduces pollutant load, particularly nutrients, as well as the volume of stormwater discharged. These studies' limitations are that most are in the laboratory and of short duration. For example, in the Liao et al. (2023) meta-analysis, the mean experimental duration across all studies was < 15 months. For this reason, monitoring of field biochar applications is recommended to establish the longevity of the benefits found from biochar applications.

Finally, despite these documented benefits, the widespread use of biochar amendments by the stormwater sector in the Chesapeake Bay is currently limited by 1) a general lack of education and awareness about biochar and its use to help meet stormwater and climate resiliency goals; 2) the absence of accepted technical specifications for the integration of biochar in various urban stormwater applications, including documented methods for selecting the amount/type of biochar for particular soils or bioretention media and calculating water quality benefits; 3) limited regional sources of certified, quality biochar and 4) a Bay-wide crediting pathway for biochar that integrates testing and validation with modeling in coordination with regulatory agencies. Addressing these limitations and issues is the intention of this report, as well as the work being completed by the NFWF Scaling Up Biochar grant efforts.

5.3 Emerging Toxic Contaminants (ETC) Workshop Group

Dominique Lueckenhoff, Sr. Vice President, Hugo Neu, Inc.
Isabel Lima, Ph.D., USDA ARS
Mark Johnson, Ph.D., US EPA

5.3.1 Emerging Toxic Contaminants (ETC) in the Watershed

Several reports detail the recent advancements in understanding the complexities of water quality in the Chesapeake Bay. The 2015 report by Schueler and Youngk by the Chesapeake Stormwater Network, titled "Potential Benefits of Nutrient and Sediment Practices to Reduce Toxic Contaminants in the Chesapeake Bay Watershed Part 1: Removal of Urban Toxic Contaminants," focuses on the effectiveness of urban Best Management Practices in removing contaminants like Polychlorinated Biphenyls (PCBs), Polycyclic Aromatic Hydrocarbons (PAHs), mercury, and metals in stormwater. It emphasizes BMP's ability to capture suspended sediments but notes the lack of coverage for contaminants, such as pesticides and emerging substances like Per- and Polyfluoroalkyl Substances (PFAS) (Schueler & Youngk, 2015).

The 2023 report by the Scientific and Technical Advisory Committee, "Achieving Water Quality Goals in the Chesapeake Bay: A Comprehensive Evaluation of System Response," calls for revising and broadening water quality criteria. It suggests incorporating factors like water temperature and concentrating on toxic and emerging contaminants. The report proposes a tiered approach to managing Total Maximum Daily Loads, focusing on reducing pollutants in specific areas. It also emphasizes addressing the impact of emerging chemicals on the ecosystem, advocating for a more holistic water quality management strategy (STAC, 2023).

Testa et al.'s 2023 study, "Knowledge Gaps, Uncertainties, and Opportunities Regarding the Response of the Chesapeake Bay Estuary to Restoration Efforts," emphasizes the need for integrating estuarine biogeochemistry with watershed and living resources science. It identifies critical issues like excess carbon, altered water patterns, and ongoing chemical discharges. It advocates for a comprehensive approach to understanding the cumulative effects of various loads on the estuary's ecosystem.

The reports underscore the evolving and complex nature of water quality management beyond the targeted TMDL requirements of nutrient and sediment reductions in the Chesapeake Bay watershed. They highlight the necessity for ongoing research and adaptation of management strategies to effectively tackle the challenges posed by both emerging and toxic contaminants, emphasizing an integrated and comprehensive approach to preserving the health of this vital ecosystem. The broad-scale use of biochar in the watershed could aid in controlling emerging and toxic contaminants.

5.3.2 The Summary of Biochar Science in Emerging Toxic Contaminants

The growing global water and soil contamination problems necessitate innovative and efficient methods to eliminate various pollutants, including heavy metal ions, dyes, antibiotics, pesticides, and increasingly, Per- and Polyfluoroalkyl Substances (PFAS). Studies demonstrate that biochar is a practical, cost-effective green solution for this environmental challenge. Research by Qiu et al. (2022) supports biochar's role in improving soil and water quality by removing contaminants. Moreover, numerous studies have demonstrated that biochar not only helps detoxify soil but also enhances its physical, chemical, and biological properties, thereby increasing crop productivity (Chan et al., 2007; Park et al., 2011; Novak et al., 2016; Ghorbani et al., 2019).

Biochar, as a sustainable and cost-effective solution for environmental remediation, has garnered significant research attention, as indicated by a recent bibliometric analysis by Kumar et al. (2023). As of October 2022, a substantial number of studies (approximately 2500) have focused on biochar's effectiveness in contaminant removal, with the majority addressing water purification (1549 publications), followed by soil (887 publications) and air (101 publications). This surge in research highlights biochar's versatile utility in reducing the mobility and bioavailability of organic and inorganic pollutants. The mechanisms underlying its effectiveness encompass physisorption (e.g., hydrogen bonding, electrostatic interaction, and surface sorption), chemisorption (including ion exchange and complexation), chemical transformations, and biodegradation processes. This trend signifies biochar's evolution from a traditional soil enhancer to a crucial component in environmental management across diverse ecosystems.

The efficacy of biochar in immobilizing heavy metals and persistent organic pollutants (POPs) in soils is influenced by various factors, including its source, application rate, soil type, and the nature of the pollutant (Ahmad et al., 2014; O’Connor et al., 2018; Zama et al., 2018; Kumpiene et al., 2019; Yuan et al., 2019). Guo et al. (2020) observe that the quality of biochar, derived from diverse feedstocks such as forest debris, crop residue, food processing waste, and manures including sewage sludge and biosolids, varies with its production conditions, impacting its ability to stabilize contaminants. Ji et al. (2022) highlight a gap in the current understanding of biochar application, noting the absence of comprehensive guidelines for selecting suitable biochar types for different soil pollution scenarios, emphasizing the necessity for further research in this field.

5.3.3 Contaminated Soil Heavy Metals and Organic Compounds Remediation

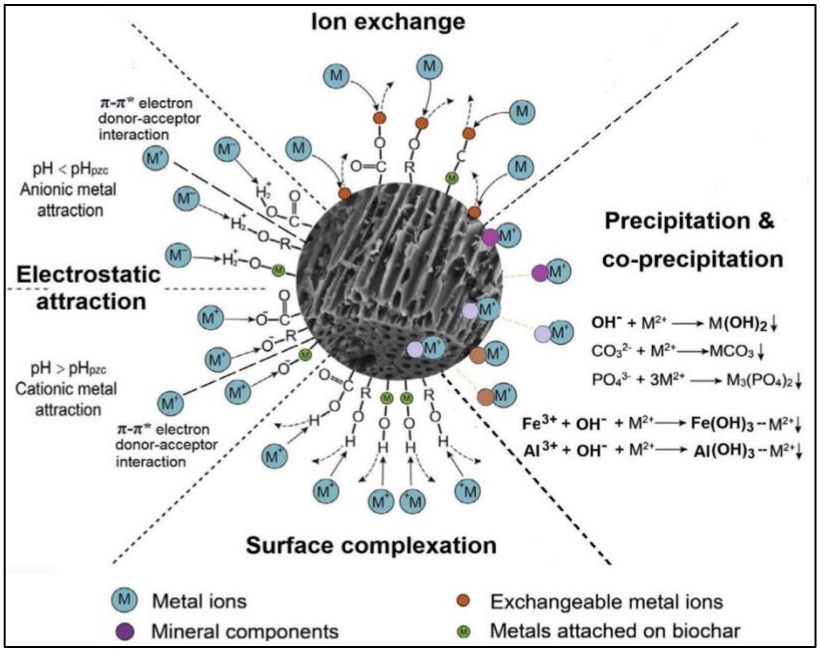


Figure 27. Major mechanisms through which biochar stabilizes heavy metals in contaminated soils. Guo, et. Al., 2020. Graph modified from Tian et al., 2015).

Research interest in contaminated soil remediation has significantly increased, with publications growing from 2 in 2010 to 157 in 2022 (Kumar et al., 2023). Studies have demonstrated that biochar effectively remediates heavy-metal-contaminated soils by absorbing heavy metal cations from water and immobilizing heavy metal elements in the soil. This process reduces the ecotoxicity of heavy-metal-contaminated soils (Guo et al., 2010; Ahmad et al., 2014; Tan et al., 2015; O'Connor et al., 2018). Rather than eliminating heavy metals from the soil, biochar stabilizes them, transforming toxic elements into less soluble and bio-accessible forms. Biochar amendment facilitates the stabilization of heavy metals in contaminated soils through surface interactions (electrostatic attraction, ion exchange, and surface complexation) and co-precipitation (Guo et al., 2020, Figure 29), thus reducing the bioavailability and ecotoxicity of heavy metals in the treated soils, making them suitable for safe crop cultivation (Guo et al., 2020) or public use.

In biochar-facilitated soil remediation, specific biochar products are applied appropriately to polluted sites and thoroughly mixed with the contaminated soil. Soil amendment with biochar at concentrations exceeding 2.0 wt% generally stabilizes cationic heavy metals, reducing their bio-accessible portion and bioaccumulation in soil (Guo et al., 2020). The applied biochar interacts with heavy metals in the soil, adsorbing heavy metal ions on the pore surfaces and potentially transforming them into hydroxide, carbonate, and phosphate precipitates. Consequently, the soil's water-soluble, bioactive fraction decreases, minimizing the potential uptake and bioaccumulation of heavy metals by soil organisms, including plant roots (Ahmad et al., 2014). Manure-derived biochars, with higher mineral ash content, tend to be more efficient than wood-derived biochars in stabilizing soil heavy metals (Figure 30 – Guo, 2020). It is essential to incorporate biochar into contaminated soil to achieve effective remediation uniformly, typically using biochar particles smaller than 2mm, often less than 1mm in size (Guo et al., 2020).

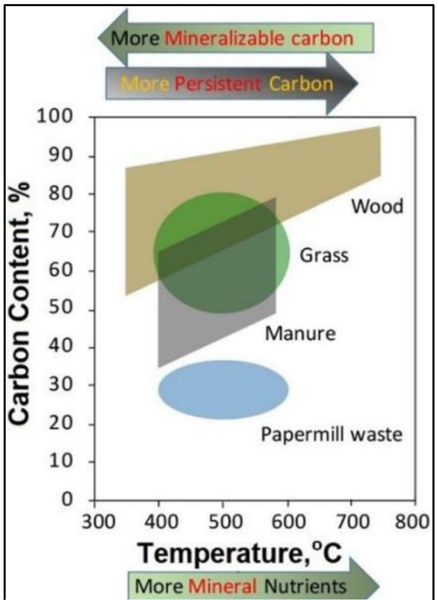


Figure 28. General change trends of biochar's (Guo, et al. 2020, as modified from Joseph et al., 2019).

<u>Organic Compounds Treatment</u>

Biochar plays a crucial role in remediating soils contaminated with organic compounds, effectively mitigating pollution from a variety of contaminants such as pesticides, herbicides, antibiotics, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), petroleum hydrocarbons, and various persistent organic pollutants (POPs) (Ahmad et al., 2014; Tan et al., 2015; Zama et al., 2018).

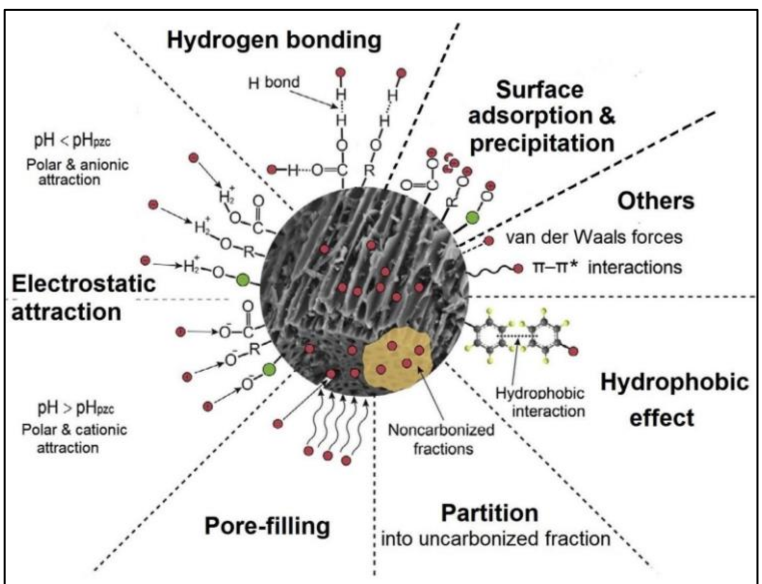


Figure 29. Major mechanisms through which biochar stabilizes organic contaminants in soil (Guo et al., 2020, Graph modified from Tian et al. 2015).

Biochar not only retains organic contaminants but also promotes their decomposition. Its porous structure, rich in functional groups and aromatic carbon, enables it to adsorb various organic compounds, reducing their concentration and bioavailability in soil. Due to this adsorption, the concentrations of organic pollutants in soil water are significantly reduced, limiting their bioavailability to soil organisms, including plant roots. This improves soil health, enhancing physical, chemical, and biological properties (Guo, 2020).

Amended soils with biochar show improved microbial community structure and increased microbial activity, leading to faster mineralization of organic pollutants. Biochar stabilizes these contaminants through various physical and chemical sorption mechanisms (Figure 31, Guo et al., 2020; Liao et al., 2016; Irfan et al., 2019).

Different biochar types have distinct sorption capacities and mechanisms. Non-polar and hydrophobic contaminants like PAHs and petroleum hydrocarbons are adsorbed through pore filling and hydrophobic effects, while polar and ionized pollutants like pesticides are adsorbed via hydrogen bonding and electrostatic attraction (Guo et al., 2020).

Biochar's physicochemical properties also affect soil characteristics, impacting pH, nutrient retention, and water-holding capacity. These changes influence microbial species, leading to shifts in microbial community structure and soil element cycling (Zhu, 2017; Biederman and Harpole, 2013; Lauber et al., 2009; Rousk et al., 2009, 2010; Paz-Ferreiro et al., 2014).

Biochar is an effective soil remediation agent recognized for its positive impact on soil properties and microbial dynamics. Biochar significantly influences soil microbial activity, biomass, bacteria-to-fungi ratio, soil enzyme activity, and microbial community structure (Zhu, 2017; Ahmad et al., 2016; George et al., 2012; Mackie et al., 2015; Nielsen et al., 2014; Rutigliano et al., 2014).

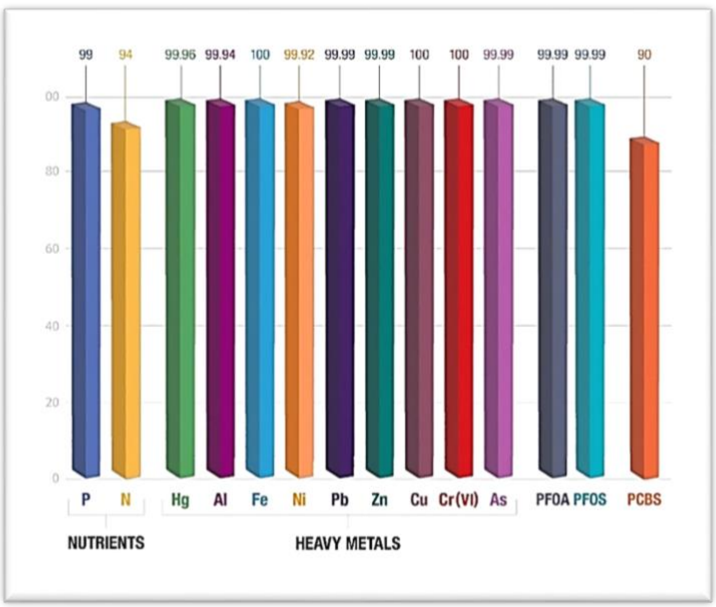


Figure 30. Activated manure derived biochar pollutant removal efficiencies for various nutrients, heavy metals, PCBs & PFAS (Credit - Ecochar Environmental Solutions, LLC.).

In real-world applications, biochars made from wood and plant residues, especially those processed at high pyrolysis temperatures and activated with steam, are preferred for stabilizing organic contaminants through sorption. Such biochar treatments enhance soil microbial activities, which can lead to the breakdown and removal of organic contaminants from the soil over time. The specific processes by which biochar improves soil health and microbial functions are detailed in studies by Paz-Ferreiro et al. (2016) and Guo (2020). Biochars derived from crop residues and woody biomass are particularly effective for remediating organic pollution and reducing greenhouse gases.

In contrast, biochars with a higher ash content are more adept at tackling cationic organic pollutants and heavy metals, typically found in manure and sludge (Ji et al., 2022). As scientific research continues to grow related to toxic contaminants, several commercial biochar companies are developing fit-to-purpose activated “green carbon” from complex waste streams (i.e., manures and biosolids) to address the growing list of emerging toxic contaminants offering an alternative to activated carbon (Figure 32).

In summary, biochar amendment represents a promising approach for stabilizing soil heavy metals and organic contaminants, offering a valuable means to mitigate the adverse effects of soil pollution. While it may not achieve the same level of stabilization efficiency as other agents like lime, phosphate salts, and activated carbon, biochar presents distinct advantages in terms of cost-effectiveness and additional environmental benefits. When applied judiciously, biochar has the potential to sequester carbon and enhance soil health, contributing to its appeal as a versatile remediation tool.

Biochar amendment can find application in a range of scenarios, including slightly polluted cropland to ensure safe food production, mine land restoration initiatives aimed at promoting vegetation growth, and soil bioremediation and phytoextraction projects designed to facilitate the remediation process (Guo et al., 2020). Its versatility and multifaceted benefits make biochar a valuable option in the toolkit for addressing soil pollution and promoting sustainable land management.

5.3.4 Water Emerging Contaminant Remediation

The enforcement of stringent water quality standards for residential and industrial wastewater and the increasing awareness of the negative impacts of untreated urban stormwater runoff have amplified the demand for efficient and cost-effective adsorbents. Unprocessed stormwaters, often directly discharged into the environment or overwhelming municipal wastewater treatment facilities, especially in areas with combined sewers, challenge the efficacy of existing wastewater treatment infrastructure and impede efficient resource recovery. The surge in research on emerging water contaminants is evident, with a significant increase in publications from 62 in 2016 to 371 in 2021 and over 290 documents already in 2022, demonstrating a growing academic focus in this area (Kumar et al., 2023). These emerging pollutants, such as endocrine-disrupting chemicals (EDCs), microplastics (MPs), pesticides, flame retardants, nanomaterials, and pharmaceutical and personal care products (PPCPs), often originate from varied sources, including hospital and factory wastewater, residential sewage, urban and agricultural runoff

(Figure 33). Many of these are persistent organic pollutants, leading to long-term environmental consequences due to their pseudo-persistent presence (Wu et al., 2021).

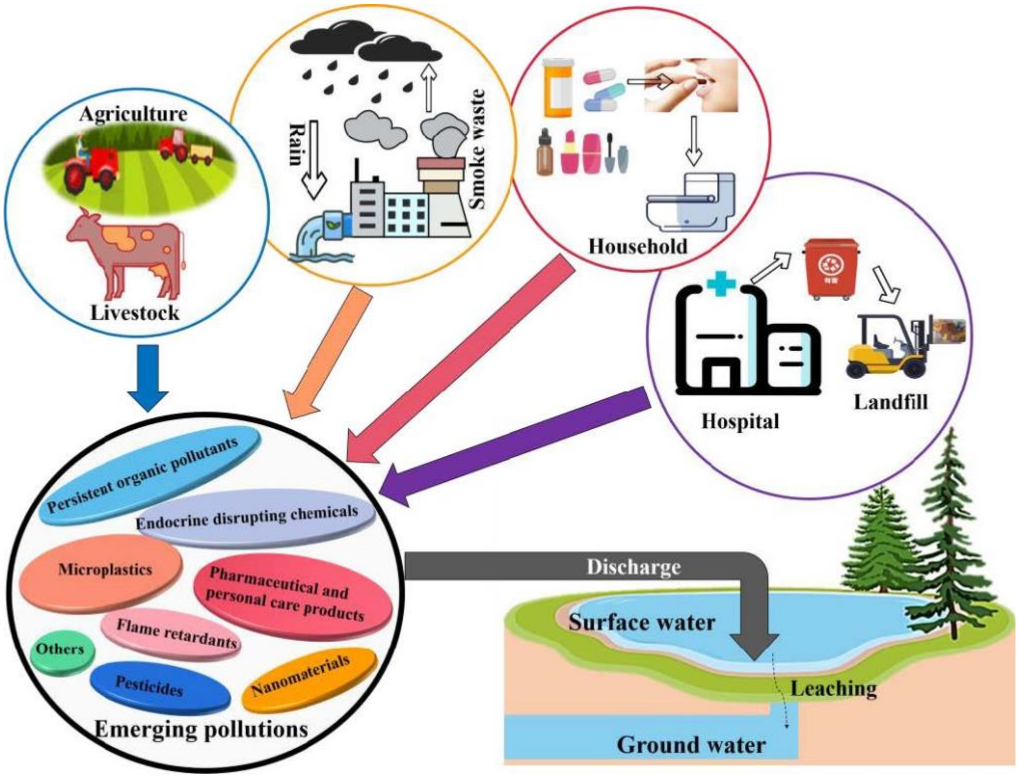


Figure 31. Resources of emerging pollutants and routes to aquatic systems (Dong et al., 2023).

Biochar, recognized for its cost-effectiveness and versatility, has emerged as a promising alternative to activated carbon in water treatment, demonstrating efficacy in various domains due to its ability to remove diverse contaminants. Its success in treating stormwater and municipal wastewater is contingent upon specific biochar properties, the nature of pollutants, and operational conditions. Biochar effectively absorbs various pollutants, including furans, phenolic compounds, pharmaceuticals, dyes, persistent organic pollutants, agrochemicals, volatile organic compounds, microplastics, endocrine disruptors, and inorganic pollutants like cations and anions. This broad application spectrum and its capacity to absorb crude oil from spills highlight biochar's increasing relevance in environmental remediation (Dong et al., 2023).

The performance of biochar in removing contaminants is impacted by its source material, production processes, and specific contaminants it targets. However, natural pristine biochar often faces suboptimal adsorption capacity, narrow adsorption range, and other shortcomings. To overcome these low surface areas (200–600 m2/g), biochar is often modified to improve its performance in water treatment. Currently, there are many reports on the removal of ECs from water by modified biochar. Different modification methods to functionalize biochar with various physicochemical properties have been developed, resulting in distinct adsorption effects, behaviors, and mechanisms of modified biochar on different ECs (Cheng et al., 2021).

Techniques like amination, acid treatment, and magnetic modification have enhanced biochar's properties, improving surface area and more effective contaminant removal. Such advancements demonstrate the adaptability and cost-effectiveness of biochar, underscoring that ultra-high porosities are not crucial for effective water purification. This progress in biochar technology points to its increasing value in wastewater treatment and other applications (Cheng et al., 2021; Arif et al., 2021; Li et al., 2021b; Qiu et al., 2022; Siipola et al., 2020).

5.3.5 Addressing the PFAS "Forever Chemicals" Challenge

Per- and polyfluoroalkyl substances (PFAS), also known as "forever chemicals," pose significant health and environmental risks even at undetectable levels. There are estimated to be over 15,000 types of PFAS, according to the National Institute of Health. While the scale of the problem is unknown globally, in the United States, these compounds are commonplace in our environment. Of these many PFAS compounds, most are used extensively in consumer products and various industries. These chemicals are highly durable, with some compounds taking centuries to degrade. PFAS have been linked to severe health issues like cancer and infertility (ITRC, 2020) and are found in a large portion of the U.S. drinking water supply (Andrews et al., 2020), in our soils, which can transfer to plants and human food chain (Piva, 2023), the air we breathe (De Silva et al., 2020) and in the blood of most Americans (ITRC, 2020).

Adding to the previously mentioned concerns, a recently completed investigation and study by Saha et al. (2023) on PFAS in yard waste compost uncovers significant contamination issues, emphasizing the co-presence of PFAS with plastics such as LDPE and PET. The research found certain PFAS compounds especially prone to volatilization, migration, and transformation within compost piles, raising concerns over groundwater safety and highlighting the necessity for innovative management strategies. With total PFAS concentrations detected at 18.53 ± 1.5 mg/kg, the study highlights a level of contamination comparable to that found in biosolids-derived composts. The finding underscores an urgent need for enhanced testing and regulatory frameworks for compost, a widely used soil amendment, to mitigate risks associated with land application and safeguard environmental health.

Despite their widespread usage and recognized health concerns dating back to the 1970s, environmental documentation of PFAS only began in the early 2000s, coinciding with the development of more sensitive testing methods (Figure 33). Recent increases in international production of PFAS may counteract the reduction expected from the U.S. phaseout, and the import of PFAS-containing materials remains unregulated (ITRC, 2020).

The 2023 report by the Scientific and Technical Advisory Committee on PFAS in the Chesapeake Bay Watershed emphasizes these substances' complex challenges. The report calls for enhanced research and monitoring efforts to understand the full impact of PFAS, underscoring the importance of such initiatives in informing effective management and policy decisions. The Toxic Contaminants Workgroup's active implementation of these recommendations highlights the concerted effort to address the PFAS challenge in the Chesapeake Bay region, reflecting a broader commitment to environmental health and safety (Smalling, K et al., 2023).

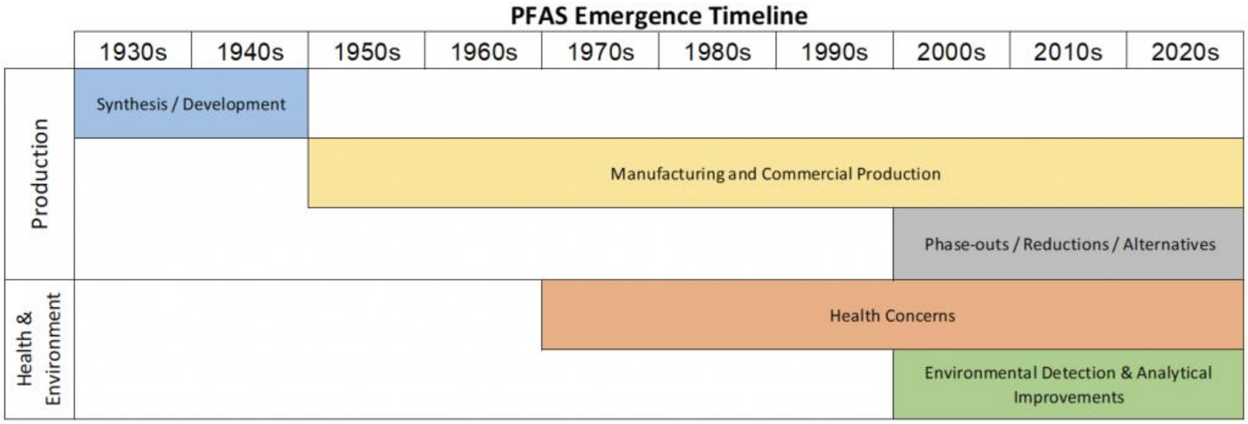


Figure 32. General Timeline of PFAS Emergence & Awareness (ITRC, 2020).

The intensification of PFAS-related concerns has catalyzed the development of economically feasible remediation methods. Gasification globally has become a promising approach for destroying PFAS in biosolids, with a ground-breaking, pioneering facility expected to commence operations in the Chesapeake Bay watershed in early 2024. In parallel, leveraging sewage sludge to fabricate biochar-based sorbents is emerging as an eco-friendly strategy for PFAS extraction from water and soil, as documented by Beesley et al. (2011), Hale et al. (2011), Khan et al. (2013), Krahn et al. (2022), Regkouzas and Diamadopoulos (2019), and Tang et al. (2018). This innovative method trumps activated carbon in sustainability, propelled by its carbon sequestration capacity (Smith, 2016) and diminished environmental impact (Zheng et al., 2019). However, the high mineral biochar efficacy without post-treatment, such as activation, as a PFAS sorbent is impeded by its inferior carbon content, porosity, and surface area (Leng et al., 2021), notwithstanding the circular economy benefits and the prohibitive costs and ecological dilemmas of sewage sludge landfilling (Propp et al., 2021; Raheem et al., 2018) and land application. The pyrolysis process obliterates pathogenic bacteria, enriching the resulting biochar with nutrients such as K, P, Ca, and Mg, offering multiple benefits, including climate change mitigation and the environmentally benign disposal of sludge (Singh et al., 2020).

The nature of the feedstock and the type of PFAS present in the samples should be considered, as removal efficiencies vary depending on the feedstock being pyrolyzed (Sørmo, 2023). For optimal PFAS removal, it is essential to employ adequately high pyrolysis temperatures and sufficient residence times (Sørmo, 2023). As the destruction of PFAS substances is challenging because they are highly durable and resistant to breakdown at low treatment temperatures (<1000°C), making common treatment technologies like composting and anaerobic digestion ineffective. High-heat pyrolysis or gasification (>1000°C) can convert PFAS into innocuous substances (Longendyke et al., 2022), yet completely disintegrating PFAS in real-life scenarios is difficult (Xiao et al., 2020; Kim et al., 2015). Some PFAS compounds are stubbornly resistant and might require even higher temperatures (Bamdad et al., 2022), which can be impractical or not cost-effective (Jouhara et al., 2018).

The fraction of PFAS in the original organic wastes that ends up being released with the flue gas is relatively low (<3%). However, despite this small fraction, the total emissions from large-scale operations could be significant. To mitigate this risk, flue gas cleaning methods including oxidizers, scrubbers, and biofilters should be considered to prevent any potential PFAS compounds from being cycled back into the environment (Sørmo, 2023). While there is a pressing need for research to enhance biochar technology for PFAS remediation, biochar and advanced pyrolysis processes are already being applied effectively in various settings.

The treatment approaches of PFAS in the environment remain a challenge, with considerable research being conducted to evaluate several possible solutions, including granular and powdered activated carbon (GAC/PAC) and various biochar materials to reduce mobility of PFAS in soil and water (Askeland et al., 2020; Hale et al., 2017; Kupryianchyk et al., 2016; Silvani et al., 2019; Sörengård et al., 2019). A recent review of remediation alternatives for PFAS contaminated soils (Mahinroosta and Senevirathna, 2020) concluded that immobilization with carbonaceous sorbents is among the most promising options. The persistence of PFAS in the environment and within living organisms (Muir et al., 2019) raises critical awareness of the environmental and health crisis, prompting the need for market-ready and scalable shovel-ready solutions.

Research related to the destruction of PFAS through pyrolysis and gasification, along with its immobilization via fit-to-purpose biochar, has gained considerable momentum over the last few years. However, in the process of capturing PFAS using biochar, there is no one-size-fits-all, and the biochar should be targeted for the size of its contaminant-trapping pores, and other properties should be the target toward the specific pollutant and context (IBI, 2024). Current research has demonstrated that biochar can effectively immobilize PFAS due to its adsorptive properties and can capture the harmful compounds in both contaminated water and soils (Ahmad et al., 2014) but must be post-treated or activated to achieve useful sorption capacity (Sørmo et al., 2021).

Considering the Scientific and Technical Advisory Committee's 2023 report on PFAS in the Chesapeake Bay watershed, the path ahead is paved with challenges and opportunities. The report's call to action for more profound research and comprehensive monitoring is a testament to the complexity of PFAS contamination and its pervasive impact on the watershed. The Toxic Contaminants Workgroup's engagement in these recommendations is a beacon of the region's resolve to safeguard the bay's ecological balance.

As biochar rises as a critical player in the arsenal against PFAS, its versatility shines in confronting these pollutants and offering a broader spectrum of environmental remedies. The impetus now falls on policymakers to champion initiatives that leverage biochar's full potential. Support is instrumental in steering us towards a future where PFAS unburdens the waters and soils of the Chesapeake Bay.

The commitment to innovative and scientifically backed solutions like biochar is not just about addressing today's pollution problems—it is an investment in the watershed's health for future generations. By directing resources towards research, shaping robust policies, and encouraging the uptake of sustainable technologies, we edge closer to a vision of a PFAS-free watershed.

Funders also hold a critical role in this journey, as their investments in biochar research, pilot schemes, and real-world applications are vital cogs in pollution control and environmental stewardship. With continued research and financial backing, biochar's efficacy can be honed, ensuring it stands as a bastion for Chesapeake Bay's environmental future.

In conclusion, the collective research, policy, and funding endeavors set the Chesapeake Bay on a course toward restoration and resilience. This shared mission resonates with the universal pursuit of a cleaner, safer, and sustainable environment.

5.3.6 A Solution for the Bay

Exploring biochar as a sustainable solution for managing ETCs in the Chesapeake Bay watershed represents a proactive and promising strategy. This approach involves converting biomass waste, such as manure and forestry residues, into biochar products suited for the Urban Landscape within the Bay watershed. While there is a lack of specific guidance for ETCs in the CBP, the need to develop criteria addressing the impact of emerging contaminants is recognized. Implementing biochar production and usage in this watershed necessitates a comprehensive evaluation of its effectiveness in mitigating the effects of ETCs, underlining its importance for the health and preservation of the watershed.

Biochar production from agricultural waste and manure offers a sustainable solution for addressing legacy toxics and persistent pollutants and provides multiple additional benefits. These include reducing nutrient runoff from manure, decreasing greenhouse gas emissions, and supplying affordable, eco-friendly, low-cost “Green” carbon for remediating soil and water pollutants. Developing a biochar market in the Chesapeake Bay area could also create economic opportunities for farmers and communities, aligning with goals to improve environmental health and climate resilience. Hence, prioritizing the exploration and promotion of biochar is imperative in the continued efforts to preserve and enhance the environmental quality and sustainability of the Chesapeake Bay watershed.

6. Considerations and Recommendations for Biochar Implementation in the Chesapeake Bay

Workshop discussions and deliberations related to the broad-scale use of biochar and its inclusion into approved watershed protocols were a productive part of the workshop. Some considerations and recommendations that arose from workshop discussions are summarized below.

6.1 Considerations

Several critical gaps remain but are not barriers to implementing biochar. The scientific, technical, and regulatory guidance questions that remain can be addressed in future research and project efforts. The few considerations that arose during the workshop and workshop group discussions are listed below.

What are key gaps in the current science that is informing best practices?

- Conduct a cost-effectiveness analysis of biochar amendments in stormwater BMPs to show the relatively small incremental cost with significant benefits for runoff reduction and water quality improvement. (e.g., expand on Price, E., Flemming, T. H., & Wainger, L. (2021). Cost analysis of stormwater and agricultural practices for reducing nitrogen and phosphorus runoff in Maryland. University of Maryland Center for Environmental Science Technical Report #TS-772-21.https://doi.org/10.13140/RG.2.2.28896.74246/1

- Continue field monitoring to establish the long-term benefits of biochar applications in urban landscapes through opportunities such as the NFWF Scaling Up Biochar grant and others in corporations with stakeholders, including state and local municipalities, non-profits, universities, and private industry.

- Develop a clear summary of factors influencing efficacy, including biochar source, application rate, and soil type, leading to standardization for use and application. (e.g., build on Hirschman Water & Environment, LLC., 2018. Performance Enhancing Devices for Stormwater BMPs. – Biochar. https://cbtrust.org/wp-content/uploads/15781_PED_and_RDM_Practices.pdf

What are the critical gaps in the current regulatory process or guidance?

- Expand the reimbursement structure for biochar practices to include additional ecosystem service co-benefits and incentivize broader adoption.
- Provide several business case studies for the circular economy (can create jobs, energy, and combat climate change).
- Develop guidance and specifications for wastewater treatment use.

What are the opportunities for better sharing knowledge/insights/approaches to achieve the best outcome for all?

- Educate farmers and potential users on the current specifications, application, and purchase of biochar.
- All the Chesapeake Bay watershed states have adopted CPS 336 and work with state NRCS and state agriculture departments to ensure that use and crediting are accounted for.
- Demonstration of how the scientific literature on biochar applications in stormwater management has grown, indicating transferable benefits from agricultural soil applications.

6.2 Recommendations

Four high-level recommendations for the CBP partnership arose from the STAC Workshop held in May 2023, including the use of biochar:

- Support pursuing biochar enhancement credit in approved BMP protocols.
- Recommend and support expanded applied research and knowledge filling.
- Support scaling up scientifically practical application of biochar use.
- Provide letters of support to expand collaborative partnerships.

1. **Support pursuing biochar enhancement credit for approved BMP Protocols:** One of the key recommendations is the integration of biochar into the Chesapeake Bay model for nutrients. This would involve incorporating biochar's impact on nutrient management into the modeling tools used to assess the health of the Bay and develop strategies to improve water quality. By including biochar in these models, policymakers and stakeholders can better understand its role in achieving water quality and climate resiliency objectives. To encourage the adoption of biochar in a BMP, follow the CBP's Urban Stormwater workgroup process for BMPs based on the Process for Handling Urban BMP Decision Requests.

2. **Recommend and expand applied research and knowledge filling:** While biochar is promising, continued research and data collection efforts are essential. There should be a commitment to ongoing scientific research to fill knowledge gaps and applications. It is crucial to support ongoing research efforts to fill these gaps and enhance our understanding of biochar's effectiveness in specific contexts within the Chesapeake Bay watershed. This data will be essential for refining protocols and optimizing the use of **biochar.**

3. **Support scaling up scientifically practical application of biochar use:** To accelerate the adoption of biochar, it is important to scale up its use across various sectors in the Chesapeake Bay watershed. This includes agriculture, forestry, urban landscapes, and addressing emerging and toxic contaminants. Developing guidelines, standards, and accreditation for biochar applications can help ensure effective and safe use in these diverse settings.

4. **Provide letters of support to expand collaborative partnerships (NFWF, Forestry)**
   Foster collaboration among government agencies, research institutions, non-profit organizations, and private sector stakeholders to facilitate the widespread adoption of biochar. Joint efforts can help streamline research, share best practices, disseminate information, accelerate the implementation of biochar projects, and build a community of practice for biochar adoption.

If accepted by the CBP partnership and implemented, these recommendations could contribute significantly to achieving water quality goals and enhancing climate resilience in the Chesapeake Bay watershed. Integrating biochar into models and protocols, crediting, incentives, ongoing research, and stakeholder collaboration can contribute significantly to the long-term vision of a healthy and sustainable Chesapeake Bay today and beyond 2025.

References

Abeysinghe, S. and K. Baek. 2022. Fluoride-contaminated water remediation using biochar derived from dairy processing sludge. Chemical Engineering Journal 446:136955.

Ahmad, H. A., S. Ahmad, Q. Cui, Z. Wang, H. Wei, X. Chen, S. Ni, Q.S. Ismail, H.M. Awad, and A. Tawfik. 2022. The environmental distribution and removal of emerging pollutants, highlighting the importance of using microbes as a potential degrader: A review. Science of The Total Environment 809: 151926.

Ahmad, M., A.R. Usman, I.R. Muhammad, and M.I. Al-Wabel. 2019. Engineered biochar composites with zeolite, silica, and nano-zerovalent iron for the efficient scavenging of chlortetracycline from aqueous solutions. Environmental Science and Pollution Research 26: 15136-15152.

Ahmad, M., A.R. Usman, I.R. Muhammad, and M.I. Al-Wabel. 2019. Engineered biochar composites with zeolite, silica, and nano-zerovalent iron for the efficient scavenging of chlortetracycline from aqueous solutions. Environmental Science and Pollution Research 26: 15136-15152.

Ahmad, M., A.U. Rajapaksha, J.E. Lim, M. Zhang, N. Bolan, D. Mohan, M. Vithanage, S.S. Lee, and Y.S. Ok. 2014. Biochar as a sorbent for contaminant management in soil and water: a review. Chemosphere 99: 19-33. https://doi.org/10.1016/j.chemosphere.2013.10.071

Ahmad, M., Y.S. Ok, B.-Y. Kim, J.-H. Ahn, Y.H. Lee, M. Zhang, D.H. Moon, M.I. Al-Wabel, S. S. Lee. 2016. Impact of soybean stover- and pine needle-derived biochars on Pb and as mobility, microbial community, and carbon stability in a contaminated agricultural soil. Journal of Environmental Management 166: 131-139.

Akpinar, D., J. Tian, E. Shepherd, and P.T. Imhoff. 2023a. Impact of wood-derived biochar on the hydrologic performance of bioretention media: Effects on aggregation, root growth, and water retention. Journal of Environmental Management 339: 117864. https://doi.org/10.1016/j.jenvman.2023.117864

Akpinar, D., S. Chowdhury, J. Tian, M. Guo, S. Barton, and P.T. Imhoff. 2023b. Understanding a wood-derived biochar's impact on stormwater quality, plant growth, and survivability in bioretention soil mixtures. Journal of Environmental Management 348: 119359. https://doi.org/10.1016/j.jenvman.2023.119359.

Aller, D., K. Trippe, B. Smith, R. Seman-Varner, , M. Delaney, and T. Miles. 2023. Biochar Guidelines for Agricultural Applications: Practical insights for applying biochar to annual and perennial crops. United States Biochar Initiative.

Andrady, A.L. 2011. Microplastics in the marine environment. Marine Pollution Bulletin 62: 1596-1605.

Andrews, D.Q and O.V. Naidenko. 2020, Population-wide exposure to per- and polyfluoroalkyl substances from drinking water in the United States. Ecotoxicology and Public Health 7(12): 931-936. https://doi.org/10.1021/acs.estlett.0c00713

Antonangelo, J.A., X. Sun, and H. Zhang. 2021. The roles of co-composted biochar COMBI in improving soil quality, crop productivity, and toxic metal amelioration. Journal of Environmental Management 277: 111443. https://doi.org/10.1016/j.jenvman.2020.111443.

Arif, M., G. Liu, B. Yousaf, R. Ahmed, S. Irshad, A. Ashraf, M. Zia-ur-Rehman, and M.S. Rashid. 2021. Synthesis, characteristics and mechanistic insight into the clays and clay minerals-biochar surface interactions for contaminants removal-a review. Journal of Cleaner Production 310: 127548.

Askeland, M., B.O. Clarke, S.A. Cheema, A. Mendez, G. Gasco, and J. Paz-Ferreiro, J. 2020. Biochar sorption of PFOS, PFOA, PFHxS and PFHxA in two soils with contrasting texture. Chemosphere 249: 126072.

Bai, X., Y. Huang, W. Ren, M. Coyne, P. Jacinthe, B. Tao, D. Hui, J. Yang, and C. Matocha. 2019. Responses of soil carbon sequestration to climate-smart agriculture practices: A meta-analysis. Global Change Biology 258: 2591–2606. https://doi.org/10.1111/gcb.14658.

Bamdad, H., S. Papari, E. Moreside, and F. Berruti. 2022. High-temperature pyrolysis for elimination of per- and polyfluoroalkyl substances PFAS from biosolids. Processes 10(11): 2187. https://doi.org/10.3390/pr10112187.

Beesley, L., E. Moreno-Jiménez, J.L. Gomez-Eyles, E. Harris, B. Robinson, and T. Sizmur. 2011. A review of biochars' potential role in the remediation, revegetation and restoration of contaminated soils. Environmental Pollution 15912: 3269–3282.

Bekchanova, M., L. Campion, S. Bruns, T. Kuppens, J. Lehmann, M. Jozefczak, A. Cuypers, and R. Malina. 2024. Biochar improves the nutrient cycle in sandy-textured soils and increases crop yield: A systematic review. Environmental Evidence 13. https://doi.org/10.1186/s13750-024-00326-5.

Berger, A.W. 2018. Nitrate removal by Biochar-Amended Woodchip Biofilters. Masters Theses, UCLA. 55 pp.

Biederman, L.A., and W.S. Harpole. 2013. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. Global Change Biology Bioenergy 5: 202-214.

Bisom, K., S. Campbell, S. Donner, B. Elliot, A. Hartman, T. Haid, A. Henry, T. Koon, D. Lillard, M. Monre, D. Montali, G. Neil, M. Neil, J. Pauer, H. Peddicord, M. Pennington, F. Rogers, P. Russell, C. Shreve, and J. Skaggs. 2019. West Virginia's Phase 3 Watershed Implementation Plan for the Chesapeake Bay Total Maximum Daily Load. <https://wvca.us/bay/files/bay_documents/1298_WV_WIP3_final_082319.pdf>

Boehm, A. B., C.D. Bell, N.J.M. Fitzgerald, E. Gallo, C.P. Higgins, T.S. Hogue, R.G. Luthy, A.C. Portmann, B. Ulrich, and J.M. Wolfard. 2020. Biochar-augmented biofilters to improve pollutant removal from stormwater − can they improve receiving water quality? Environmental Science: Water Research and Technology 66: 1520–1537.

Borchard, N., M. Schirrmann, M.L. Cayuela, C. Kammann, N. Wrage-Mönnig, J. M. Estavillo, T. Fuertes-Mendizábal, G. Sigua, K. Spokas, J. A. Ippolito, and J. Novak. 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.

Cayuela, M.L., L. van Zwieten, B.P. Singh, S. Jeffery, A. Roig, and M.A. Sánchez-Monedero. 2014. Biochar's role in mitigating soil nitrous oxide emissions: A review and meta-analysis. Agriculture, Ecosystems and Environment 191: 5–16. https://doi.org/10.1016/J.AGEE.2013.10.009.

Chan, K.Y., E.L. van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2007. Agronomic values of greenwaste biochar as a soil amendment. Australian Journal of Soil Research 45(8): 629–634. https://doi.org/10.1071/SR07109.

Cheng, N., B. Wang, P. Wu, X. Lee, Y. Xing, M. Chen, and B. Gao. 2021. Adsorption of emerging contaminants from water and wastewater by modified biochar: a review. Environmental Pollution 273: 116448. https://doi.org/10.1016/j.envpol.2021.116448.

Cheng, N., B. Wang, P. Wu, X. Lee, Y. Xing, M. Chen, and B. Gao. 2021b. Adsorption of emerging contaminants from water and wastewater by modified biochar: a review. Environmental Pollution 273: 116448.

Covell, P., G. Gammie, S. Hunt, L. Brunjes L, and Ng F Nees. 2011. Advancing biochar in the Chesapeake: a strategy to reduce pollution from poultry litter. 47 pp. https://api.semanticscholar.org/CorpusID:130699025.

Choudhary, V., and L. Philip. 2022. Sustainability assessment of acid-modified biochar as adsorbent for the removal of pharmaceuticals and personal care products from secondary treated wastewater. Journal of Environmental Chemical Engineering 10(3): 107592.

Covell, P., G. Gammie, S. Hunt, L. Brunjes L, Ng F, Nees. 2011. Advancing biochar in the Chesapeake: a strategy to reduce pollution from poultry litter. 47 pp. https://api.semanticscholar.org/CorpusID:130699025.

De Silva, A.O., J.M. Armitage, T.A. Bruton, C. Dassuncao, W. Heiger-Bernays, X.C. Hu, A. Kärrman, B. Kelly, C. Ng, A. Robuck, M. Sun, T. Webster, and E.M. Sunderland. 2021. PFAS exposure pathways for humans and wildlife: A synthesis of current knowledge and key gaps in understanding. Environmental Toxicology and Chemistry 40(3): 631–657. https://doi.org/10.1002/etc.4935

Deng, S., J. Chen, and J. Chang. 2021. Application of biochar as an innovative substrate in constructed wetlands/biofilters for wastewater treatment: Performance and ecological benefits. Journal of Cleaner Production 293: 126156. https://doi.org/10.1016/j.jclepro.2021.126156.

Ding, F., L. Van Zwieten, W. Zhang, Z. Weng, S. Shi, J. Wang, and J. Meng. 2018. A meta-analysis and critical evaluation of influencing factors on soil carbon priming following biochar amendment. Journal of Soils and Sediments 184: 1507–1517. https://doi.org/10.1007/s11368-017-1899-6.

Dong, M., L. He, M. Jiang, Y. Zhu, J. Wang , W. Gustave, S. Wang , Y. Deng , X. Zhang, and Z. Wang. 2023. Biochar for the removal of emerging pollutants from aquatic systems: A review. International Journal of Environmental Research and Public Health 20(3): 1679. https://doi.org/10.3390/ijerph20031679.

Downie, A.E., L. Van Zwieten, R. J. Smernik, S. Morris, and P.R. Munroe. 2011. Terra Preta Australis: Reassessing the carbon storage capacity of temperate soils. Agriculture, Ecosystems and Environment 140(1-2): 137–147. https://doi.org/10.1016/J.AGEE.2010.11.020.

Easton, Z., K. Stephenson, B. Benham, J.K. Böhlke, A. Buda, A. Collick, L. Fowler, E. Gilinsky, C. Hershner, A. Miller, G. Noe, L. Palm-Forster, and T. Thompson. 2023. Evaluation of management efforts to reduce nutrient and sediment contributions to the Chesapeake Bay estuary. STAC Publication Number 23-003, Chesapeake Bay Program Scientific and Technical Advisory Committee (STAC), Edgewater, MD. 55 pp.

El-Naggar, A., N. Ahmed, A. Mosa, N.K. Niazi, B. Yousaf, A. Sharma, B. Sarkar, Y. Cai, and S.X. Chang. 2021. Nickel in soil and water: sources, biogeochemistry, and remediation using biochar. Journal of Hazardous Materials 419: 126421.

European Biochar Industry Consortium. 2023. European Biochar Market Report 2022, 2023. Retrieved from https://www.biochar-industry.com/2023/european-biochar-market-report-2021-2022-available-now-2/

Frausin, V., J. A. Fraser, W. Narmah, M.K. Lahai, T.R.A. Winnebah, J. Fairhead, and M. Leach. 2014. “God made the soil, but we made it fertile”: Gender, knowledge, and practice in the formation and use of African dark earths in Liberia and Sierra Leone. Human Ecology 42: 695–710. https://doi.org/10.1007/s10745-014-9686-0.

Gao, S., T.H. DeLuca, and C.C. Cleveland. 2019. Biochar additions alter phosphorus and nitrogen availability in agricultural ecosystems: A meta-analysis. Science of the Total Environment 654: 463–472. https://doi.org/10.1016/J.SCITOTENV.2018.11.124.

Gelardi, D.L., and S.J. Parikh. 2021. Soils and beyond: Optimizing sustainability opportunities for biochar. Sustainability 13(18): 10079. https://doi.org/10.3390/su131810079.

George, C., M. Wagner, M. Kuecke, and M.C. Rillig. 2012. Divergent consequences of hydrochar in the plant-soil system: arbuscular mycorrhiza, nodulation, plant growth and soil aggregation effects. Applied Soil Ecology 59: 68-72.

Ghorbani, M., H. Asadi, and S. Abrishamkesh. 2019. Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. International Soil and Water Conservation Research 7(3): 258–265. https://doi.org/10.1016/j.iswcr.2019.05.005.

Glaser, B. 2007. Prehistorically modified soils of central Amazonia: A model for sustainable agriculture in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences 362(1478): 187–196. https://doi.org/10.1098/Rstb.2006.1978.

Guo, M., W. Song, and J. Tian. 2020. Biochar-facilitated soil remediation: mechanisms and efficacy variations. Frontiers in Environmental Science 8: 521512. doi: 10.3389/fenvs.2020.521512.

Guo, W., S. Lu, J. Shi, and X. Zhao.. 2019. Effect of corn straw biochar application to sediments on the adsorption of 17-ethinyl estradiol and perfluorooctane sulfonate at the sediment-water interface. Ecotoxicology and Environmental Safety 174: 363-369.

Haddaoui, I., and J. Mateo-Sagasta. 2021. A review on occurrence of emerging pollutants in waters of the MENA region. Environmental Science and Pollution Research 28: 68090-68110.

Hale, S., K. Hanley, J. Lehmann, A. Zimmerman, and G. Cornelissen. 2011. Effects of chemical, biological, and physical aging as well as soil addition on the sorption of pyrene to activated carbon and biochar. Environmental Science and Technology 45(24): 10445–10453. https://doi.org/10.1021/es202970x.

Hale, S.E., H.P.H. Arp, G.A. Slinde, E.J. Wade, K. Bjørseth, G.D. Breedveld, B.F. Straith, K. G. Moe, M. Jartun, and Å. Høisæter. 2017. Sorbent amendment as a remediation strategy to reduce PFAS mobility and leaching in a contaminated sandy soil from a Norwegian firefighting training facility. Chemosphere 171: 9–18.

Herbort, A. F., M. T. Sturm, and K. Schuhen. 2018. A new approach for the agglomeration and subsequent removal of polyethylene, polypropylene, and mixtures of both from freshwater systems—A case study. Environmental Science and Pollution Research 25(15): 15226-15234. doi: 10.1007/s11356-018-1981-7.

Hirschman, D. 2018. Performance enhancing devises for stormwater best management practices – biochar for roadside ditch management and PEDs. Hirschman Water and Environment, LLC. and Center for Watershed Protection, Inc. 7 pp. https://hirschmanwater.com/wp-content/uploads/2019/04/Biochar_122418.pdf

Hirschman, D., B. Seipp, and T. Schueler. 2017. Performance enhancing devises for stormwater best management practices. 38 pp. https://chesapeakestormwater.net/wp-content/uploads/2022/07/7714-1.pdf

Imhoff, P., and S.A.A. Nakhli. 2017. Reducing stormwater runoff and pollutant loading with biochar addition to highway greenways. 51 pp. <https://onlinepubs.trb.org/onlinepubs/IDEA/FinalReports/Highway/NCHRP182_Final_Report.pdf>

International Biochar Initiative 2024, Containing Contaminants: Harnessing Biochar for Effective Pollution Control, https://biochar-international.org.

International Biochar Initiative. 2015. Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used in Soil Version 2.1 [IBI-STD-2.1]. Retrieved from https://biochar-international.org/standard-certification-training/biochar-standards/.

Interstate Technology and Regulatory Council ITRC. 2020. History and Use of Per- and Polyfluoroalkyl Substances PFAS found in the Environment. 4 pp. http://tinyurl.com/3szha2bk

IPCC. 2018. Global warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.) Cambridge University Press.

Irfan, M., Q. Hussain, K.S. Khan, M. Akmal, S.S. Ijaz, R. Hayat, A. Khalid, M. Azeem, and M Rashid. 2019. Response of soil microbial biomass and enzymatic activity to biochar amendment in the organic carbon deficient arid soil: a 2-year field study. Arabian Journal of Geosciences 12(95). https://doi.org/10.1007/s12517-019-4239-x.

Ivar do Sul, J.A., and M.F. Costa. 2014. The present and future of microplastic pollution in the marine environment. Environmental Pollution 185: 352-364.

Jari, Y., N. Roche, M.C. Necibi, S. El Hajjaji, D. Dhiba, and A. Chehbouni. 2022. Emerging pollutants in Moroccan wastewater: Occurrence, impact, and removal technologies. Journal of Chemistry: 9727857.

Ji, M., X. Wang, M. Usman, F. Liu, Y. Dan, L. Zhou, S. Campanaro, G. Luo, and W. Sang. 2022. Effects of different feedstocks-based biochar on soil remediation: A review. Environmental Pollution 294: 118655. https://doi.org/10.1016/j.envpol.2021.118655.

Joseph, S., A.L. Cowie, L. Van Zwieten, N. Bolan, A. Budai, W. Buss, M.L. Cayuela, E.R. Graber, J.A. Ippolito, Y. Kuzyakov, Y. Luo, Y.S. Ok, K.N. Palansooriya, J. Shepherd, S. Stephens, Z. Weng, and J. Lehmann. 2021. How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. Global Change Biology Bioenergy 1311: 1731-1764. https://doi.org/10.1111/gcbb.12885.

Jouhara, H., D. Ahmad, I. van den Boogaert, E. Katsou, S. Simons, and N. Spencer. (2018). Pyrolysis of domestic based feedstock at temperatures up to 300 °C. Thermal Science and Engineering Progress 5: 117-143. https://doi.org/10.1016/j.tsep.2017.11.007.

Kern, J., L. Giani, W. Teixeira, G. Lanza, G., and B. Glaser. 2019. What can we learn from ancient fertile anthropic soil (Amazonian Dark Earths, shell mounds, Plaggen soil) for soil carbon sequestration? Catena 172: 104–112. https://doi.org/10.1016/J.CATENA.2018.08.008

Khan, S., C. Chao, M. Waqas, H.P.H. Arp, and Y.-G. Zhu. 2013. Sewage sludge biochar influence upon rice Oryza sativa L yield, metal bioaccumulation and greenhouse gas emissions from acidic paddy soil. Environmental Science and Technology 47(15): 8624–8632. doi: 10.1021/es400554x.

Krahn, K.M., G. Cornelissen, G. Castro, H.P.H. Arp, A.G. Asimakopoulos, R. Wolf, R. Holmstad, A.R. Zimmerman, and E. Sørmo. 2023. Sewage sludge biochars as effective PFAS sorbents. Journal of Hazardous Materials 445: 130449. doi: 10.1016/j.jhazmat.2022.130449.

Kumar, A., T. Bhattacharya, W.A. Shaikh, A. Roy, S. Chakraborty, M. Vithanage, and J.K. Biswas. 2023. Multifaceted applications of biochar in environmental management: A bibliometric profile. Biochar 5(11). https://doi.org/10.1007/s42773-023-00207-z.

Kumpiene, J., J. Antelo, E. Brännvall, I. Carabante, K. Ek, M. Komárek, C. Söderberg, and L. Wårell. 2019. In situ chemical stabilization of trace element-contaminated soil – field demonstrations and barriers to transition from laboratory to the field – a review. Applied Geochemistry 100: 335–351. https://doi.org/10.1016/j.apgeochem.2018.12.003.

Kupryianchyk, D., S.E. Hale, G.D. Breedveld, and G. Cornelissen. 2016. Treatment of sites contaminated with perfluorinated compounds using biochar amendment. Chemosphere 142: 35–40. doi: 10.1016/j.chemosphere.2015.04.085.

Kuzyakov, Y., J. Friedel, and K. Stahr. 2000. Review of mechanisms and quantification of priming effects. Soil biology and biochemistry 32(11-12): 1485–1498. https://doi.org/10.1016/S0038-0717(00)00084-5.

Lares, M., M.C. Ncibi, M. Sillanpää, and M. Sillanpää. 2018. Occurrence, identification and removal of microplastic particles and fibers in conventional activated sludge process and advanced MBR technology. Water research 133, 236-246. https://doi.org/10.1016/j.watres.2018.01.049.

Lauber, C. L., M. Hamady, R. Knight, and N. Fierer. 2009. Pyrosequencing-based assessment of soil pH as a predictor of soil bacterial community structure at the continental scale. Applied and environmental microbiology 75: 5111-5120. https://doi.org/10.1128/AEM.00335-09.

Lehmann, J., D. Kern, B. Glaser, and W. Wodos (eds.). 2004. Amazonian Dark Earths. Springer, Dordrecht. 510 pp. https://doi.org/10.1007/1-4020-2597-1.

Lehmann, J., J. Gaunt, and M. Rondon. 2006. Bio-char sequestration in terrestrial ecosystems –a review. Mitigation and Adaptation Strategies for Global Change 11: 395–419. https://doi.org/10.1007/s11027-005-9006-5.

Leng, L., Q. Xiong, L. Yang, H. Li, Y. Zhou, W. Zhang, S. Jiang, H. Li, and H. Huang. 2021. An overview on engineering the surface area and porosity of biochar. Science of the total environment 763: 144204. https://doi.org/10.1016/j.scitotenv.2020.144204

Li, J., H. Liu, and J. Paul Chen. 2018. Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. Water Research 137: 362-374.

Li, Y., H. Yu, L. Liu, and H. Yu. 2021b. Application of co-pyrolysis biochar for the adsorption and immobilization of heavy metals in contaminated environmental substrates. Journal of Hazardous Materials 420: 126655.

Liao, N., Q. Li, W. Zhang, G. Zhou, L. Ma, W. Min, J. Ye, and Z. Hou. 2016. Effects of biochar on soil microbial community composition and activity in drip-irrigated desert soil. European Journal of Soil Biology 72: 27–34. https://doi.org/10.1016/j.ejsobi.2015.12.008

Liao, W., M.A. Halim, I. Kayes, J.A.P. Drake, and S.C. Thomas. 2023. Biochar benefits green infrastructure: Global meta-analysis and synthesis. Environmental Science and Technology 57(41): 15475-15486. https://doi.org/10.1021/acs.est.3c04185.

Longendyke, G., S. Katel, and Y. Wang. 2022. PFAS fate and destruction mechanisms during thermal treatment: A comprehensive review. Environmental Science: Processes and Impacts 24: 196-208. https://doi.org/10.1039/D1EM00465D.

Lucaccioni, L., V. Trevisani, L. Marrozzini, N. Bertoncelli, B. Predieri, L. Lugli, A. Berardi, and L. Iughetti. 2020. Endocrine-disrupting chemicals and their effects during female puberty: A review of current evidence. International Journal of Molecular Sciences, 2(16): 2078. doi: 10.3390/ijms21062078.

Lyu, H., Zhang, H., Chu, M., Zhang, C., Tang, J., Chang, S.X., Maˇsek, O., and Y.S. Ok, 2022, Biochar affects greenhouse gas emissions in various environments: A critical review. Land Degradation & Development 33(17):3327–3342. https://doi.org/10.1002/ldr.4405.

Mackie, K. A., S. Marhan, F. Ditterich, H. P. Schmidt, and E. Kandeler. 2015. The effects of biochar and compost amendments on copper immobilization and soil microorganisms in a temperate vineyard. Agriculture, Ecosystems, & Environment 201: 58-69. https://doi.org/10.1016/j.agee.2014.12.001.

Maestrini, B., P. Nannipieri, and S. Abiven. 2014. A meta-analysis on pyrogenic organic matter induced priming effect. Global Change Biology Bioenergy 7,: 577-590. https://doi.org/10.1111/gcbb.12194.

Magid, A.S.I.A., M.S. Islam, Y. Chen, L. Weng, J. Li, J. Ma, and Y. Li. 2021. Enhanced adsorption of polystyrene nanoplastics onto oxidized corncob biochar with high pyrolysis temperature. Science of the Total Environment 784: 147115.

Mahinroosta, R., and L. Senevirathna. 2020. A review of the emerging treatment technologies for PFAS contaminated soils. Journal of Environmental Management, 255: 109896.
Maryland Department of Natural Resources. 2020. 2020 Forest Action Plan Part I: Forest Resource Assessment. 94 pp.

Mohan, D., A. Sarswat, Y.S. Ok, and C.U. Pittman. 2014. Organic and inorganic contaminants removal from water with biochar, a renewable, low-cost and sustainable adsorbent—a critical review. Bioresource Technology 160: 191-202. https://doi.org/10.1016/j.biortech.2014.01.120.
Montgomery County Climate Action Plan. 2021. Montgomery County, Maryland. AECOM, InspireGreen. 168 pp.
https://www.montgomerycountymd.gov/climate/Resources/Files/climate/climate-action-plan.pdf

Muir, D., R. Bossi, P. Carlsson, M. Evans, A. De Silva, C. Halsall, C. Rauert, D. Herzke, H. Hung, R. Letcher, F. Rigét, and A. Roos. 2019. Levels and trends of poly- and perfluoroalkyl substances in the Arctic environment – An update. Emerging Contaminants 5: 240-271. https://doi.org/10.1016/j.emcon.2019.06.002

National Center for Resource Development (NCRD), Institute for Rural Entrepreneurship and Economic Development IREED, Infinite Solutions. 2019. Manure de Force Report. December 31, 2019.

Navarathna, C.M., N.B. Dewage, C. Keeton, J. Pennisson, R. Henderson, B. Lashley, X. Zhang, E.B. Hassan, F. Perez, D. Mohan, C.U. Pittman Jr., and T. Misna. 2020. Biochar adsorbents with enhanced hydrophobicity for oil spill removal. ACS Applied Materials & Interfaces 12(18): 9248-9260. https://doi.org/10.1021/acsami.9b20924.

Nguyen, M.K., C. Lin, H.G. Hoang, X.T. Bui, H.H. Ngo, V.G. Le, and H.T. Tran. 2023. Investigation of biochar amendments on odor reduction and their characteristics during food waste co-composting. Science of the Total Environment 865: 161128. http://dx.doi.org/10.1016/j.scitotenv.2022.161128.

Ni, N., D. Kong, W. Wu, J. He, Z. Shan, J. Li, Y. Dou, Y. Zhang, Y. Song, and X. Jiang. 2020. The role of biochar in reducing the bioavailability and migration of persistent organic pollutants in soil–plant systems: A review. Bulletin of Environmental Contamination and Toxicology 104(2):157-165.

Nielsen, S., T. Minchin, S. Kimber, L. van Zwieten, J. Gilbert, P. Munroe, S. Joseph, and T. Thomas. 2014. Comparative analysis of the microbial communities in agricultural soil amended with enhanced biochars or traditional fertilisers. Agriculture, Ecosystems & Environment 191: 73-82. https://doi.org/10.1016/j.agee.2014.04.006.

Nikolaou, S., J. Vakros, E. Diamadopoulos, and D. Mantzavinos. 2020. Sonochemical degradation of propylparaben in the presence of agro-industrial biochar. Journal of Environmental Chemical Engineering 8(4): 104010. https://doi.org/10.1016/j.jece.2020.104010.

Novak, J. M., Ippolito, J. A., Lentz, R. D., Spokas, K. A., Bolster, C. H., Trippe, K. M., C.L. Phillips, and M.G. Johnson. 2016. Soil health, crop productivity, microbial transport, and mine spoil response to biochars. Bioenergy Research 9: 454–464. https://doi.org/10.1007/s12155-016-9720-8.

O'Connor, D., T. Peng, J. Zhang, D.C.W. Tsang, D.S. Alessi, Z. Shen, N.S. Bolan, D. Hou. 2018. Biochar application for the remediation of heavy metal polluted land: A review of in situ field trials. Science of the Total Environment 619–620: 815–826. https://815–826. https://doi.org/10.1016/j.scitotenv.2017.11.132

Omondi, M.O., X. Xia, A. Nahayo, X. Liu, P.K. Korai., and G. Pan. 2016. Quantification of biochar effects on soil hydrological properties using meta-analysis of literature data. Geoderma 274: 28–34. https://doi.org/10.1016/J.GEODERMA.2016.03.029

Ortiz, L. R., E. Torres, D. Zalazar, H. Zhang, R. Rodriguez, and G. Mazza. 2020. Influence of pyrolysis temperature and bio-waste composition on biochar characteristics. Renewable Energy 155: 837-847.

Park, J. H., G.K. Choppala, N.S. Bolan, J.W.T. Chung, and Cuasavathi. 2011. Biochar reduces the bioavailability and phytotoxicity of heavy metals. Plant and Soil 348: 439–451. https://doi.org/10.1007/s11104-011-0948-y.

Paz-Ferreiro, J., S.L. Fu, A. Mendez, and G. Gasco. 2014. Interactive effects of biochar and the earthworm Pontoscolex corethrurus on plant productivity and soil enzyme activities. Journal of Soils and Sediments 14(3): 483-494. DOI:10.1007/s11368-013-0806-z.

Petersen, H.I., L. Lassen, A. Rudra, L.X. Nguyen, P.T.M. Do, and H. Sanei. 2023. Carbon stability and morphotype composition of biochars from feedstocks in the Mekong Delta, Vietnam. International Journal of Coal Geology 271: 104233. https://doi.org/10.1016/j.coal.2023.104233.

Piva, E., P. Fais, P. Ioime, M. Forcato, G. Viel, G. Cecchetto, G., and J.P. Pascali,. 2023. Per- and polyfluoroalkyl substances PFAS presence in food: Comparison among fresh frozen and ready-to-eat vegetables. Food Chemistry 410: 135415. https://doi.org/10.1016/j.foodchem.2023.135415.

Propp, V. R., A.O. de Silva, C. Spencer, S.J. Brown, S.D. Catingan, J.E. Smith, and J.W. Roy. 2021. Organic contaminants of emerging concern in leachate of historic municipal landfills. Environmental Pollution 276: 116474. DOI: 10.1016/j.envpol.2021.116474.

Qiu, M., L. Liu, Q. Ling, Y. Cai, S. Yu, S. Wang, D. Fu, B. Hu, B., and X. Wang. 2022. Biochar for the removal of contaminants from soil and water: A review. Biochar 4(19). https://doi.org/10.1007/s42773-022-00146-1.

Raheem, A., V.S. Sikarwar, J. He, W. Dastyar, D.D. Dionysiou, W. Wang, and M. Zhao. 2018. Opportunities and challenges in sustainable treatment and resource reuse of sewage sludge: A review. Chemical Engineering Journal 337: 616–641. https://doi.org/10.1016/j.cej.2017.12.149.

Razzaghi, F., P.B. Obour, and E. Arthur. 2020. Does biochar improve soil water retention? A systematic review and meta-analysis. Geoderma 361: 114055. https://doi.org/10.1016/J.GEODERMA.2019.114055.

Regkouzas, P., and E. Diamadopoulos. 2019. Adsorption of selected organic micro-pollutants on sewage sludge biochar. Chemosphere 224: 840–851. https://doi.org/10.1016/j.chemosphere.2019.02.165.

Rizwan, M., Murtaza, G., Zulfiqar, F., Moosa, A., Iqbal, R., Ahmed, Z., Irshad, S., Khan, I., Li, T., Chen, J., Zhang, M., Siddique, K. H. M., Leng, L., & Li, H. 2023. Sustainable manufacture and application of biochar to improve soil properties and remediate soil contaminated with organic impurities: A systematic review. *Frontiers in Environmental Science, 11*, 1277240. https://doi.org/10.3389/fenvs.2023.1277240

Rousk, J., E. Baath, P.C. Brookes, C.L. Lauber, C. Lozupone, J.G. Caporaso, R. Knight, and N. Fierer. 2010. Soil bacterial and fungal communities across a pH gradient in an arable soil. ISME Journal 4(10): 1340-1351.

Rousk, J., P.C. Brookes, and E. Baath. 2009. Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization. Applied and Environmental Microbiology 75(6): 1589-1596.

Rutigliano, F. A., M. Romano, R. Marzaioli, I. Baglivo, S. Baronti, F. Miglietta, and S. Castaldi. 2014. Effect of biochar addition on soil microbial community in a wheat crop. European Journal of Soil Biology 60: 9-15. https://doi.org/10.1016/j.ejsobi.2013.10.007.

Saha, B., M. Ateia, S. Fernando, J. Xu, T. DeSutter, and S.M. Iskander. 2024. PFAS occurrence and distribution in yard waste compost indicate potential volatile loss, downward migration and transformation. Environmental Science: Processes & Impacts 26: 657-666. https://doi.org/10.1039/d3em00538k

Sanei, H., A. Rudra, Z.M. Moltesen Przyswitt, S. Kousted, M. Benkhettab Sindlev, X. Zheng, S.B. Nielsen, and H.I. Petersen. 2024. Assessing biochar's permanence: An inertinite benchmark. International Journal of Coal Geology 281: 104409. https://doi.org/10.1016/j.coal.2023.104409

Schmidt, H. P., C. Kammann, N. Hagemann, J. Leifeld, T.D. Bucheli, M.A. Sánchez Monedero, and M. Luz Cayuela. 2021. Biochar in agriculture – A systematic review of 26 global meta-analyses. Global Change Biology Bioenergy 13(11): 1708-1730. https://doi.org/10.1111/gcbb.12889

Schmidt, H. P., S. Abiven, N. Hageman, and J. Meyer zu Drewer, J. 2022. Permanence of soil applied biochar. An executive summary for Global Biochar Carbon Sink certification. The Biochar Journal: 69-74. https://www.biochar-journal.org/en/ct/109

Schueler, T. 2016. Process for Handling Urban BMP Decision Requests. https://d18lev1ok5leia.cloudfront.net/chesapeakebay/documents/attach_b_revised_process_for_handling_urban_bmp_decision_requests_020116.pdf

Scientific and Technical Advisory Committee (STAC). 2023. Achieving water quality goals in the Chesapeake Bay: A comprehensive evaluation of system response (K. Stephenson & D. Wardrop, Eds.). STAC Publication Number 23-006, Chesapeake Bay Program Scientific and Technical Advisory Committee (STAC), Edgewater, MD. 129 pp.

Shaikh, W.A, A. Alam, O. Alam, S. Chakraborty, G. Owens, T. Bhattacharya, and N. Kumar Mondal. 2020. Enhanced aqueous phase arsenic removal by a biochar-based iron nanocomposite. Environmental Technology & Innovation 19: 100936. https://doi.org/10.1016/j.eti.2020.100936

Shaikh, W.A., A. Kumar, S. Chakraborty, R. Ul Islam, T. Bhattacharya, and J. Kumar Biswas. 2022. Biochar-based nanocomposite from waste tea leaf for toxic dye removal: from facile fabrication to functional fitness. Chemosphere 291: 132788. https://doi.org/10.1016/j.chemosphere.2021.132788

Shaikh, W.A., S. Chakraborty, R. Ul Islam, A.A. Ghfar, M. Naushad, J. Bundschuh, J. Prakash Maity, and N. Kumar Mondal. 2022. Fabrication of biochar-based hybrid Ag nanocomposite from algal biomass waste for toxic dye-laden wastewater treatment. Chemosphere 289: 133243. https://doi.org/10.1016/j.chemosphere.2021.133243

Siipola, V., S. Pflugmacher, H. Romar, L. Wendling, and P. Koukkari. 2020. Low-Cost Biochar Adsorbents for Water Purification Including Microplastics Removal. Applied Sciences 10(3): 788. https://doi.org/10.3390/app10030788

Silvani L., G. Cornelissen, A. Botnen Smebye, Y. Zhang, G. Okkenhaug, A.R. Zimmerman, G. Thune, H. Sævarsson, and S.E Hale. 2019. Can biochar and designer biochar be used to remediate per- and polyfluorinated alkyl substances (PFAS) and lead and antimony contaminated soils? Science of the Total Environment 694: 133693.

Singh, S., Kumar, V., Dhanjal, D. S., Datta, S., Bhatia, D., Dhiman, J., Samuel, J., Prasad, R., & Singh, J. (2020). A sustainable paradigm of sewage sludge biochar: Valorization, opportunities, challenges and future prospects. Journal of Cleaner Production, 269, 122259. https://doi.org/10.1016/j.jclepro.2020.122259. https://doi.org/10.1016/j.scitotenv.2019.133693.

Smalling, K.L., M. Lorah, G. Allen, L. Blaney, M. Cantwell, L. Fowler, T. Ihde, M. Mank, E. Majcher, G. Onyullo, and S. Phillips, S., 2023. Improving Understanding and Coordination of

Science Activities for Per- and Polyfluoroalkyl Substances (PFAS) in the Chesapeake Bay Watershed. STAC Publication Number 23-002, Edgewater, MD. 58 pp.

Smith, P. 2016. Soil carbon sequestration and biochar as negative emission technologies. Global Change Biology 22(3): 1315–1324. https://doi.org/10.1111/gcb.13178.

Sommer, F., V. Dietze, A. Baum, J. Sauer, S. Gilge, C. Maschowski, C., and R. Gieré. 2018. Tire Abrasion as a Major Source of Microplastics in the Environment. Aerosol and Air Quality Research 18(8): 2014-2028.

Sorengård, M., D.B. Kleja, and L. Ahrens. 2019. Stabilization of per- and polyfluoroalkyl substances (PFASs) with colloidal activated carbon (PlumeStop®) as a function of soil clay and organic matter content. Journal of Environmental Management 249: 109345. https://doi.org/10.1016/j.jenvman.2019.109345

Sørmo, E., G. Castro, M. Hubert, V. Licul-Kucera, M. Quintanilla, A.G, Asimakopoulos, G. Cornelissen, and H.P.H. Arp. 2023. The decomposition and emission factors of a wide range of PFAS in diverse, contaminated organic waste fractions undergoing dry pyrolysis. *Journal of Hazardous Materials, 454*, 131447. https://doi.org/10.1016/j.jhazmat.2023.131447

Sørmo, E., L. Silvani, N. Bjerkli, N. Hagemann, A.R. Zimmerman, S.E. Hale, C.B. Hansen, T. Hartnik, and G. Cornelissen. 2021. Stabilization of PFAS-contaminated soil with activated biochar. Science of the Total Environment 763: 144034. https://doi.org/10.1016/j.scitotenv.2020.144034.

Steiner, C., and H. Thomas. 2014. Biochar as growing media additive and peat substitute. Solid Earth 5(2): 995-999. https://doi.org/10.5194/se-5-995-2014.

Steiner, C., K.C. Das, N. Melear, and D. Lakly. 2010. Reducing nitrogen loss during poultry litter composting using biochar. Journal of Environmental Quality 39(4): 1236–1242. https://doi.org/10.2134/jeq2009.0337.

Tan, X., Y. Liu 2, G. Zeng, X. Wang, X. Hu, Y. Gu, and Y. Zhongzhu. 2015. Application of biochar for the removal of pollutants from aqueous solutions. Chemosphere 125: 70–85. https://doi.org/10.1016/j.chemosphere.2014.12.058

Tang, L., J. Yu, Y. Pang, G. Zeng, Y. Deng, J. Wang, X. Ren, S. Ye, B. Peng, and H Feng. 2018. Sustainable efficient adsorbent: alkali-acid modified magnetic biochar derived from sewage sludge for aqueous organic contaminant removal. Chemical Engineering Journal 336, 160–169. https://doi.org/10.1016/j.cej.2017.11.048.

Testa, J.M., W.C. Dennison, W.P. Ball, K. Boomer, D.M. Deidre, L. Lewis, M.C. Runge, and L. Sanford. 2023. Knowledge gaps, uncertainties, and opportunities regarding the response of the Chesapeake Bay estuary to restoration efforts. STAC Publication Number 23-004. Chesapeake Bay Program Scientific and Technical Advisory Committee (STAC), Edgewater, MD. https://www.chesapeake.org/stac/wp-content/uploads/2023/05/23-004_Estuary-updated.pdf

Tewari, A., P.K. Singh, and S. Gaur. 2022. Engineered hyporheic zones: design and applications in stream health restoration – a review. Water Supply 22(2): 2179. https://doi.org/10.2166/ws.2021.366.

Thies, J.E., and M.C. Rillig. 2009. Characteristics of biochar: Biological properties. https://www.researchgate.net/publication/284041311

Tirpack, R.A., A.M. Afrooz,, R.J. Winston, R. Valenca, , K. Schiff., and S.K. Mohanty. 2021. Conventional and amended bioretention soil media for targeted pollutant treatment: A critical review to guide the state of the practice. Water Research 189: 116648. https://doi.org/10.1016/j.watres.2020.116648.

Tong, M., L. He, H. Rong, M. Li, and H. Kim. 2020. Transport behaviors of plastic particles in saturated quartz sand without and with biochar/Fe3O4-biochar amendment. Water Research 169: 115284. https://doi.org/10.1016/j.watres.2019.115284.

United States Biochar Initiative (USBI) and International Biochar initiative. 2023. Global Biochar Market Report 2023. Retrieved from https://biochar-international.org/2023-global-biochar-market-report/

USDA NRCS. (n.d.). Soil Carbon Amendment 336 Conservation Practice Standard. https://www.nrcs.usda.gov/resources/guides-and-instructions/soil-carbon-amendment-ac-336-conservation-practice-standard

USDA NRCS. 2023. Biochar. Conservation Innovation Grants. Accessed November 21, 2023. https://cig.sc.egov.usda.gov/site-search?search_api_fulltext=biochar&type=All

USGCRP. 2017. Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program. doi: 10.7930/J0J964J6.

Valev, D. 2022. A brief history of biochar – The black earth of the Amazons, December 12, 2022. https://www.carbonbalance.fi/biochar-news-and-articles/the-black-earth-of-the-amazons

Wang, H., S.J. Lee, M.V. Olarte, and A.H. Zacher. 2016. Bio-oil stabilization by hydrogenation over reduced metal catalysts at low temperatures. ACS Sustainable Chemistry and Engineering 4(10): 5533–5545. https://doi.org/10.1021/acssuschemeng.6b01270

Wang, J., S. Zhang, H. Cao, J. Ma, L. Huang, S. Yu, X. Ma, G. Song, M. Qiu, M., and X. Wang. 2022a. Water purification and environmental remediation applications of carbonaceous nanofiber-based materials. Journal of Cleaner Production 331: 130023. https://doi.org/10.1016/j.jclepro.2021.130023.

Wang, J., Z. Xiong, and Y. Kuzyakov. 201. Biochar stability in soil: meta-analysis of decomposition and priming effects. Global Change Biology Bioenergy 8(3): 512–523. https://doi.org/10.1111/gcbb.12266.

Waqas, M., A.S. Nizami, A.S. Aburiazaiza, M.A. Barakat, I.M.I. Ismail, and M.I. Rashid, M. I. 2018. Optimization of food waste compost with the use of biochar. Journal of Environmental Management 2016: 70-81. http://dx.doi.org/10.1016/j.jenvman.2017.06.015

Web of Science Core Collection Database. 2023. Biochar. Accessed May 24, 2023. http://apps.webofknowledge.com

Wiedner, K., and B. Glaser. 2015. Traditional use of biochar. In J. Lehmann and S. Joseph (Eds.), Biochar for environmental management-science and technology (2nd ed., pp. 15–38). Routledge.

Wiedner, K., J. Schneeweiß, M.A. Dippold, and B. Glaser. 2015. Anthropogenic Dark Earth in Northern Germany —The Nordic analogue to terra preta de Índio in Amazonia. Catena 132: 114–125. https://doi.org/10.1016/J.CATENA.2014.10.024.

Xiao, F., P. Challa Sasi, B. Yao, A. Kubátová, S.A. Golovko, M.Y. Golovko, and D. Soli. 2020. Thermal Stability and Decomposition of Perfluoroalkyl Substances on Spent Granular Activated Carbon. Environmental Science Technology Letters 7(5): 343–350. https://doi.org/10.1021/acs.estlett.0c00114.

Xin, D. 2021. Understanding the Electron Storage Capacity of Pyrogenic Black Carbon: Origin, REDOX Reversibility, Spatial Distribution, and Environmental Applications. Masters Theses, University of Delaware.

Xin, D., N. Saha, M.T. Reza, J. Hudson, and P. Chiu. 2021. Pyrolysis Creates Electron Storage Capacity of Black Carbon (Biochar) from Lignocellulosic Biomass. ACS Sustainable Chemistry & Engineering 9(19): 6821–6831. https://doi.org/10.1021/acssuschemeng.1c01251.

Zama, E.F., B.J. Reid, H.P.H. Arp, G. Sun, H. Yuan, and Y. Zhu. 2018. Advances in research on the use of biochar in soil for remediation: A review. Journal of Soils and Sediments 18: 2433–2450. https://doi.org/10.1007/s11368-018-2000-9.

Zhang, K., A.H. Hamidian, A. Tubić, Y. Zhang, J.K.H. Fang, C. Wu, and P.K.S. Lam. 2021. Understanding plastic degradation and microplastic formation in the environment: A review. Environmental Pollution 274: 116554. https://doi.org/10.1016/j.envpol.2021.116554.

Zheng, Y., Q. Li, C. Yuan, Q. Tao, Y. Zhao, G. Zhang, and J. Liu. 2019. Influence of temperature on adsorption selectivity: Coal-based activated carbon for CH4 enrichment from coal mine methane. Powder Technology 347: 42–49. https://doi.org/10.1016/j.powtec.2019.02.042.

Zhou, X., Y. Zhu, Q. Niu, G. Zeng, C. Lai, S. Liu, D. Huang, L. Qin, X. Liu, B. Li, H. Yi, Y. Fu, L. Li, M. Zhang, C. Zhou, and J. Liu. 2021. New notion of biochar: A review on the mechanism of biochar applications in advanced oxidation processes. Chemical Engineering Journal 416: 129027.

Zhu, D., Y. Chen, H. Yang, S. Wang, X. Wang, and S. Zhang. 2020a. Synthesis and characterization of magnesium oxide nanoparticle containing biochar composites for efficient phosphorus removal from aqueous solution. Chemosphere 247: 125847. https://doi.org/10.1016/j.chemosphere.2020.125847.

Zhu, S., J. Zhao, N. Zhao, X. Yang, C. Chen, and J. Shang. 2020c. Goethite modified biochar as a multifunctional amendment for cationic Cd(II), anionic As(III), roxarsone, and phosphorus in soil and water. Journal of Cleaner Production 247: 119579. DOI:10.1016/j.jclepro.2019.119579.

Zhu, S., S. Wang, X. Yang, S. Tufail, C. Chen, X. Wang, and J. Shang. 2020b. Green sustainable and highly efficient hematite nanoparticles modified biochar-clay granular composite for CrVI removal and related mechanism. Journal of Cleaner Production 276: 123009. https://doi.org/10.1016/j.jclepro.2020.123009.

Zhu, X., B. Chen, L. Zhu, and B. Xing. 2017. Effects and mechanisms of biochar-microbe interactions in soil improvement and pollution remediation: A review. Environmental Pollution 227: 98-115. http://dx.doi.org/10.1016/j.envpol.2017.04.032.

Zou, H., J. Zhao, F. He, Z. Zhong, J. Huang, Y. Zheng, Y. Zhang, Y. Yang, F. Yu, M.A. Bashir, and B. Gao. 2021. Ball milling biochar iron oxide composites for the removal of chromium Cr VI from water: performance and mechanisms. Journal of Hazardous Materials 413: 125252. https://doi.org/10.1016/j.jhazmat.2021.125252.

Zou, Y. T., Y. Z. Hu, Z. W. Shen, L. Yao, D. Y. Tang, S. Zhang, S. Q. Wang, B. W. Hu, G. X. Zhao, and X. K. Wang. 2022. Application of aluminosilicate clay mineral-based composites in photocatalysis. Journal of Environmental Sciences 115: 190–214. https://doi.org/10.1016/j.jes.2021.07.015.

Appendix A: Workshop Agenda

Chesapeake Bay Program's (CBP)
Scientific and Technical Advisory Committee (STAC)
Using Carbon to Achieve Chesapeake Bay (and Watershed)
Water Quality Goals and Climate Resiliency:
The Science, Gaps, Implementation Activities and Opportunities
May 25-26th, 2023
Workshop Webpage
Hotel Hershey (100 Hotel Rd, Hershey, PA 17033)

Workshop Desired Outcomes: Provide recommendations to Bay Science and Technical Assessment and Reporting as well as by Science and Technical Advisory Committees for

- Integration of biochar in Chesapeake Bay model for nutrients and climate and
- Biochar credit in existing BMPs and protocols

Thursday, May 25th 2023
Zoom Registration Link

8:30 am **Coffee & Light Breakfast (Provided)**

9:00 am **Introduction & Workshop Objectives - What Brought Us Here**
– Jason Hubbart, Ph.D. (Professor, *West Virginia University*), Jennifer (Jenny) Egan, Ph.D. (Program Manager, *University of Maryland Environmental Finance Center*)

9:15 am **Biochar Industry - Fact or Fiction?**
– Tom Miles (Executive Director, *US Biochar Initiative*), Chuck Hegberg (Senior Project Manager, *Resource Environmental Solutions LLC*)

10:00 am **Questions, Answers & Comments**

10:15 am **Break**

10:30 am **Existing Protocol Review and Group Discussion**
Facilitated by TBD
Protocol speaker: David Wood (Executive Director, *Chesapeake Stormwater Network*)

- **Expert Panel:**
  - David Wood (Executive Director, *Chesapeake Stormwater Network*)
  - Chris Brosch (Nutrient Management Program Administrator, *Del. Dept of Agriculture*)
  - Carol Wong, P.E. (Water Resources Engineer, *Center for Watershed Protection*)
  - Larry Trout Jr., P.E. (*Straughan Environmental*)

11:30 am **The TMDL for the Chesapeake Bay –** Gary Shenk (Hydrologist, *USGS*)
Gary Shenk will discuss the Total Maximum Daily Load for nitrogen, phosphorus, and sediment including recent additional reductions necessary to offset climate change effects.

12:00 pm **Lunch – Keynote Address**

"A Maryland State Change Agent's Journey to Produce and Utilize Biochar for Good"
– Charles Glass, Ph.D., P.E. (Executive Director, *Maryland Environmental Services*)

1:15 pm **Break**

State of the Science on Biochar

Topics exploring the State of the Science for biochar are split into sessions, with each featuring researchers and practitioners in the topic area. Presentations are ~15-20-minutes with a mix of facilitated and open Q&A discussion within each session.

1:30 pm **Climate-Smart Agriculture and Forestry (CSAF) Work Group**
Facilitated by Wayne Teel, Ph.D. (*James Madison University*)

- **State of the Science speaker:** Brandon Smith, Ph.D. (*Allied Soil Health Services*)
- **Expert Panel:**
  - Chris Brosch (Nutrient Management, *Del. Dept of Agriculture*)
  - Kristin Trippe, Ph.D. (Microbiologist, *USDA*)
  - Brandon Smith, Ph.D. (*Allied Soil Health* Services)
  - Debbie Aller, Ph.D. (Soil Health, *Cornell University*)
  - Sabina Dhungana (Utilization & Marketing Program Manager, *VA Dept of Forestry*)

2:30 pm **Break**

2:40 pm **Urban Landscapes (Stormwater) Work Group**
Facilitated by Chuck Hegberg, (*RES, LLC/USBI*)

- **State of the Science speaker:** Paul Imhoff, Ph.D. (*University of Delaware*)
- **Expert Panel:**
  - Paul Imhoff, Ph.D. (Civil Engineer, *University of Delaware*)
  - Carolyn Voter, Ph.D. (Civil Engineer, *University of Delaware*)
  - Debbie Aller, Ph.D. (Soil Health, *Cornell University*)
  - Carol Wong, P.E., (Water Resources Engineer, *Center for Watershed Protection*)
  - Larry Trout Jr., P.E. (*Straughan Environmental*)
  - David Wood (Executive Director, *Chesapeake Stormwater Network*)
  - Jim Doten (Carbon Sequestration Program Manager, *City of Minneapolis*)

3:55 pm **Break**

04:05 pm **Emerging & Toxic Contaminants (ETC) Work Group**
Facilitated by Dominique Lueckenhoff (Senior Vice President, *Hugo Neu*)

- **State of the Science speaker:** Isabel Lima, Ph.D. (*USDA ARS*)
- **Expert Panel (Facilitated):**
  - Isabel Lima, Ph.D. (*USDA ARS*)
  - Charles Glass, Ph.D. (Executive Director, *Maryland Environmental Service*)
  - Mark Johnson, Ph.D. (*US EPA*)
  - Sean Sweeney, P.E. (Vice President, *Barton & Loguidice*)
  - Ken Pantuck (Senior Scientist, *US EPA Region III)*

5:20 pm **Day 1 Wrap-up and Objectives for Day 2**

5:35 pm **Recess**

6:00 pm **Optional Dinner at Smoked Bar & Grill**

<u>Friday, May 26th 2023</u>

Zoom Registration Link

8:00 am **Coffee & Light Breakfast (Provided)**

9:00 am **Focus of Day 2**

9:15 am **City of Minneapolis Biochar Story: Bloomberg Climate Challenge**
– Jim Doten, Carbon Sequestration Program Manager *(City of Minneapolis)*

10:00 am **Facilitated Group Discussion on Biochar State of the Science**
30-minute Q&A session on the presentations from the first day.

10:30 am **Break**

10:45 am **Set-up for Breakout Sessions**

11:00 am **Technical Breakout Groups**

12:00 pm **Working Lunch (Provided)**

1:00 pm **Break**

1:15 pm **Breakout Group: Report-out**

2:00 pm **Synthesize Results and Recommendations**

2:30 pm **Workshop Adjourns**

Workshop Attendee Notice

The STAC Biochar Committee and the technical experts that will be participating in this workshop are looking forward to this focused discussion on the scientific merit, policy and protocol aspects of biochar within the Chesapeake Bay watershed to accelerate its restoration. While there will be much conversation around the various topics identified in the agenda, the workshop will not provide any introductory information about biochar. The committee assumes that the attendees are knowledgeable about the topic of biochar and thus will spend the time we have delving into the specifics outlined in the agenda. It is not the intention of the committee to exclude anyone from the conversation, the time allowed is limited and our objectives are clearly related to the purpose of this workshop. For those not familiar with biochar and want to prepare in advance of the workshop, we have provided some information and key links to additional information for your use. Please go to https://tinyurl.com/2p9ezmp3 for more introductory information on biochar.

Appendix B: Workshop Participants

WORKSHOP PARTICIPANTS (IN PERSON/REMOTE)

Name (First)	Name (Last)	Affiliation	May 25th	May 26th
Adam	Mowery	Mowery Environmental Services	Remote	Remote
Alan	Workman	NJ DEP	Remote	Remote
Alicia	Ritzenthaler	DOEE	Remote	Remote
Andy	Raines	Restoration Bio	Remote	Remote
Angela	Possinger	Virginia Tech/Virginia Soil Health Coalition	Remote	Remote
August	Goldfischer	CRC	Not Attending	Remote
Ben	Livelsberger	PA DEP	Remote	Remote
Bonnie	Arvay	Delaware Gov.	Remote	Remote
Brandon	Smith, PH.D.	Allied Soil Health, LLC	In-person	Remote
Brecc	Avellar	Avellar Energy	Remotely	Remote
Brendan	Diener	US EPA	Remotely	Remote
Bruce	Pluta	US EPA	Remotely	Remote
Carol	Frerker	Willoughby Farm & Conservation Reserve	Remotely	Remote
Carylyn	Voter, Ph.D.	University of Delaware	In-person	In-person
Cecilia	Lane	Washington DC DOEE	In-person	Remote
Chris	Brosch, Ph.D.	Delaware Department of Agriculture - STAC	In-person	In-person
Chris	Fields-Johnson	Davey Institute	In-person	In-person
Chris	Roelke	Barton and Loguidice	In-person	In-person
Chris	Bradshaw	USDA	Remote	Remote
Chris	Lawrence	USDA	Remote	Remote
Chris	Tersine	PA Gov.	Remote	Remote
Chuck	Hegberg	USBI/RES, LLC - Workshop Chair	In-person	In-person
Clare	Billett	William Penn Foundation	Remote	Remote
Dan	Kramer	Allterra, LLC	In-person	In-person
David	Hirschmann	Hirschman Water	Remote	Remote
Debsree	Mandal	West Virginia University	Remote	Remote
Denise	Coleman	USDA	Remote	Remote
Dominique	Lueckenhoff	Hugo Neu	Remote	Remote
Efeturi	Oghenekaro	DC gov.	Remote	Remote
Ekaterina	Bazilevskaya	Penn State	In-person	Remote
Elaine	Webb	Delaware Gov.	Remotely	Remotely
Emad	Rezk	Maryland Gov.	Remotely	Remotely
Emily	Trethewey	Center for Watershed Protection	In-person	In-person
Emily	Heller	US EPA	Remote	Remote

Evelyn	Thomchick	Penn State University	Remote	Remote
Faprajha	Faprajha	Univerisity of Maryland	In-person	Remote
Gary	Shenk	Chesapeake Bay Program - STAC	In-person	In-person
George	Onyullo	DC Gov.	Remote	Remote
Ginny	Snead	AMT Engineering	Remote	Remote
Heather	Beaven	NRCS	Remote	Remote
Holly	Walker	Delaware Gov.	Remote	Remote
Hong-Shing	Shim	Reaction Engineering	Remote	Remote
James	Lee	University of Maryland	Remote	Remote
Jared	Beard	NRCS	In-person	In-person
Jason	Hubbart, Ph.D.	West Virginia University - STAC	In-person	In-person
Jayme	Arthurs	USDA/NRCS	Remote	Remote
JC	Kim	Tetra Tech	Remote	Remote
Jennifer	Egan, Ph.D.	UMD EFC - Workshop Co-Chair	In-person	In-person
Jennifer	Allen-Key	City of Waynesboro, VA	Remote	Remote
Jimmy	Dick	Environmental Quality Resources, LLC	In-person	In-person
John	Sandkuhler	Nanticoke Watershed Alliance	Remote	Not Attending
John	Bushey	USDA	Remote	Remote
John	Seitz	YCPC	Remote	Remote
Jonathan	De Olden	SF Biochar	In-person	In-person
Joseph	Berg	Biohabitats	Remote	Remote
Julienne	Bautista	DC DOEE	Remote	Remote
Junchul	Kim	Tetra Tech	Remote	Remote
Karl	Strahl	Char Direct	Remote	Remote
Kateri	Simon	Luck Ecosystems	In-person	In-person
Kayle	Brown	Biohabitats	Remote	Remote
Kelley	Attenborough	Standard Biocarbon	Remote	Remote
Ken	Pantuck	US Environmental Protection Agency	In-person	In-person
Kevin	Costello	BGE	Remote	Remote
Kevin	Mclean	Virginia DEQ	Remote	Remote
Kimberly	Plank	US EPA	Remote	Remote
Kristen	Keene	RES, LLC	Remote	Remote
Larry	Trout, Jr.	Straughan Environmental Services, Inc.	In-person	In-person
Lew	McCreery	UDSA	Remote	Remote
Liz	Sweitzer	Land Logics Group	Remote	Remote
Lori	Lilly	Howard EcoWorks	Remote	Remote
Louis	McDonald	West Virginia University	Remote	Remote
Marc	Ricker	Ashwood Trinity	Remote	Remote

Mark	Goodson	USDA Natural Resources Conservation Service	In-person	In-person
Mark	G. Johnson	U.S. EPA	In-person	In-person
Mark	Symborski	Montgomery Co. Planning	Remote	Remote
Mary	Sketch Bryant	Virginia Tech/Virginia Soil Health Coalition	Remote	Remote
Matthew	Gallagher	DC Gov.	Remote	Remote
Maura	Ross	MD Clean Energy	Remote	Remote
Meg	Cole	CRC	In-person	In-person
Megan	Blackmon	Lancaster Clean Water Partners	In-person	Not Attending
Mellissa	Chatham	Maryland Gov.	Remote	Remote
Mev	Egbegbadia	MDE	Remote	Remote
Michael	Collins	American Climate Partners	In-person	In-person
Mohammad	Abu-Orf	Hazen and Sawyer	Remote	Remote
Mohsin	Siddique	DC Water	Remote	Remote
Morvarid	Ganjalizadeh	DC Gov.	Remote	Remote
Narghis	Sarwari	AB Tech Industries	Remote	Remote
Nicole	Christ	Maryland Department of Environment	In-person	In-person
Nitin	Nitin	UC Davis	Remote	Remote
Normand	Goulet	NVRC	Remote	Remote
Oren	Wool	Quantum Loophole	In-person	In-person
Patrick	Sherren	Metzler Forest Products	In-person	In-person
Patrick	Brown	NJ DEP	Remote	Remote
Paul	Imhoff, Ph.D.	University of Delaware	In-person	In-person
Paul	Sturm	Ridge to Reefs	Remote	Remote
Peter	Ettinger	Bioenergy Devco	In-person	In-person
Rachel	Lamb	Maryland Department of the Environment	In-person	In-person
Rachel	Stahlman	York County Planning Commission	In-person	In-person
Rachel	Tardiff	Rachel Tardiff LLC	In-person	In-person
Rayne	Metzer	Student	In-person	In-person
Robbie	Corville	PA Gov.	In-person	In-person
Robert	Gillett, Ph.D.	University of Maryland	In-person	In-person
Robert	Adair	Convergent Water Technologies	Remote	Remote
Rohan	Tikekar	University of Maryland	In-person	Remote
Ruth	Cassilly	UMD CBPO	In-person	Remote
Sabina	Dhungana	VA Dept. of Forestry	In-person	Remote
Salil	Kharkar	DC Water	Remote	Remote
Sally	Holbert	Land Logics Group	In-person	In-person
Sam	Dunlap	Carbon Harvest	Remote	Remote
Samuel	Canfield	West Virginia DEP	In-person	In-person

Sarah	Roberts	Biohabitats	In-person	In-person
Scott	Gorneau	Convergent Water Technologies	In-person	In-person
Sean	Sweeney	Barton and Loguidice	In-person	In-person
Shaun	Preston	Baltimore City Camp Small	In-person	In-person
Skyler	Yost	Stelmo Community Builders	Remote	Remote
Steve	Findley	Montgomery Co. Planning	Remote	Remote
Suchithra	Thangalazhy-Gopakumar	Nottingham University	Remote	Remote
Susan	Minnemeyer	Nature Plus	In-person	In-person
Sushanth	Gupta	CRC	In-person	In-person
Suzanne	Trevena	US EPA	Remote	Remote
Taqi	Raza	Unknown	Remote	Remote
Thomas	Burke	USDA	Remote	Remote
Tim	Peters	USDA NRCS	In-person	Not Attending
Tina	Metzer	NCRD	In-person	In-person
Tom	Miles	US Biochar Initiative	In-person	In-person
Tony	Myers	Biochar Now	Remote	Remote
Tou	Matthews	CRC	In-person	In-person
Wanhe	Hu	West Virginia University	Remote	Remote
Wayne	Bowen	Pennsylvania Recycling Markets Center	In-person	In-person
Wayne	S. Teel, Ph.D.	James Madison University	In-person	In-person
Carol	Wong	Center for Watershed Protection	In-person	In-person
Young	Tsuel	DC Gov.	Remote	Remote

	DAY 1	**DAY 2**
ROMOTE	82	92
IN PERSON	54	45
NOT ATTENDING	1	3
TOTAL	137	137

Appendix C: Special Guest Presentations

See recordings at https://www.chesapeake.org/stac/events/using-carbon-to-achieve-chesapeake-bay-and-watershed-water-quality-goals-and-climate-resiliency-the-science-gaps-implementation-activities-and-opportunities/

"A Maryland State Change Agent's Journey to Produce and Utilize Biochar for Good"
Charles Glass, Ph.D., P.E. (Executive Director, Maryland Environmental Services)

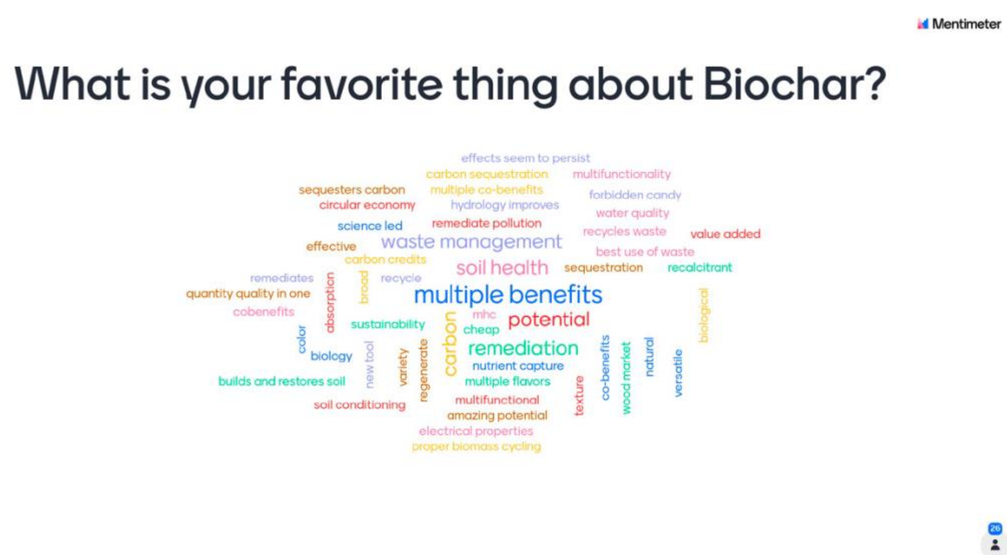
City of Minneapolis Biochar Story: Bloomberg Climate Challenge
Jim Doten, Carbon Sequestration Program Manager (City of Minneapolis)

Appendix D: Interactive Presentation Responses

During the workshop, both virtual and in-person participants were prompted to engage with questions through an interactive presentation tool: Mentimeter. Using Mentimeter, participant feedback was collected in various formats, including contributions to a group word cloud, open-ended responses, and votes displayed on bar graphs. Responses were shown in real-time, allowing for group discussion at the workshop.

Word cloud

At the start of Day 1, participants were asked to submit their “favorite thing about Biochar”. Mentimeter built a word cloud based on the 29 responses received (shown below). A word cloud is a visualization tool used to represent data, with the size of each word in the cloud corresponding to the frequency in which that or a similar response was submitted. As seen by the figure, popular submissions included “multiple benefits”, “potential”, “soil health”, “waste management”, and “remediation.”



Open-ended questions
Following expert presentations on Day 1, participants were invited to share their thoughts in response to reflective open-ended questions using Mentimeter. Input was gathered in real-time and served as a catalyst for a concurrent 30-minute facilitated group discussion. During this session, steering committee members collectively reviewed the feedback and encouraged participants to share their interpretations of the responses. Responses from participants to open-ended Mentimeter questions are provided below.

There were 47 responses to the question, "what do you think is the most important issue to work out as related to biochar in the Chesapeake Bay Watershed?" For the purposes of this report, similar responses are grouped into 5 buckets: crediting and regulatory frameworks, technical specifications and best practices, supply chain and production, education and awareness, and measuring and quantifying effects.

- Crediting and regulatory frameworks
    - Crediting.
    - Crediting.
    - Credit.
    - Crediting strategy that will incentive win-win adoption for water quality and other goals; states could finance it if local governments will seek to use it.
    - Getting credit in the bay to encourage counties and states to use it more.
    - What are the suitable uses and variables that determine how biochar is credited?
    - Getting stormwater credit for biochar use in existing and new green stormwater infrastructure. Second, getting more field data quantifying performance. Specifications on biochar amendments.
    - Streamlined permitting process in all states.
    - Protocols for remediating excess phosphorus in farm souls.
    - If the focus is meeting TMDL requirements, crediting issues seem key.
    - Is prescribed fire management eligible for credit.
- Technical specifications and best practices
    - Getting through agriculture protocols.
    - Application(s), and corresponding credits/qualifying conditions so that jurisdictions know where and how to apply this technique.
    - The use of Artificial Intelligence and optimizing specific feedstocks and processes for the best results consistently.
    - Recommending the right char for the right job.
    - Distilling research results into specific methods for the right biochar for the right application.
    - Guidance for proper use.
    - Provide biochar application standards (feedstock and characteristics parameters) for the various BMPs.
    - Develop a concise menu of biochar practices and assign appropriate stormwater credits to them.
    - Biochar for nutrient management in agriculture and helping farmers in the transition.
    - What feedstock to use and what temperature should it be pyrolyzed at?

    - Protocols for addressing runoff and compacting associated with utility scale solar.
    - There needs to be a comprehensive layman's terms field guide for technical folks. and interested parties alike.
- Supply chain and production
    - Right kind of biochar, right place, right time. What, when, where how…
    - Shortening linkages between feedstock, supply, and demand.
    - Local supply.
    - Where it will be produced.
    - Getting the material to the partners who can use it now.
    - market to project connections.
    - An adequate local supply of high-quality biochar.
    - Sorting out the scale/scope of the crediting effort.
    - Local supply of biochar is still limited and needs to increase before large scale applications are possible.
    - Commercializing products ... benefits to add biochar to Leafgro, Bloom (bio solids compost).
    - We need pyrolyzers in each locality.
- Education and awareness
    - Education, permits and specifications
    - Must continue to educate and make people aware of biochar and what it can do. No change is possible if people don't know about it.
    - Good communication about biochar GHG lifecycle - is biochar always carbon negative or only if heat is used to replace fossil fuel energy?
    - Support from political officials.
    - Consultant/Contractors ability to select and utilize the proper biochar for the project. If a good product is produced, but not implemented properly, then it is worthless.
    - Ecologists, Fisheries biologists, Ecotoxicologists are not yet part of the discussions. Information on how Biochar remediation improves aquatic life is an important piece for bay wide adoption.
    - Need for consistent language on how we talk about biochar and have consistent recommendations across organizations.
- Measuring and quantifying effects
    - How to target applications most effectively (where and when biochar is most useful as a soul amendment for runoff reduction in a watershed).
    - Measurable outcome.
    - How will we measure the reductions?
    - Valorization of biochar feedstocks and uses as part of having solid but modular means of producing consistent products and results, especially in the future
    - Do a better job defining goals and context, to allow focus and progress.
    - Quantifying the effects of use.

When if the information shared at the workshop changed their opinion on biochar being a "no brainer" (why/why not), 16 participants provided a response. 7 respondents noted that biochar is an obvious choice and that they were previously and still are in support of its utilization in the Chesapeake Bay region:

- Biochar works.
- There are numerous applications for biochar.
- It works.
- It's a no brainier! Let's go for it! We need to do a lot more research at the same time.
- I have been working on this space for 10 years and I am already up to date on the state of the science. The new things I learned confirmed my previous understanding.
- Didn't change my mind because I had already agreed that it is a no brainer.
- I have only learned even more reasons why biochar works and should be used more.

Two participants were now in support of pursuing biochar because of the workshop:

- This workshop has reinforced my thinking that there is enough evidence to pursue accrediting a variety of biochar practices now.
- Pursuing the use of biochar is a no brainer. As has been pointed out in this workshop, that doesn't mean it can and should be used in all situations. Every site and project are unique.

7 respondents still need more information to consider biochar a “no-brainer”:

- Seems like lots of win wins possible with biochar and few downsides, although I do still have lots of questions about exactly how/when/where it works best as an intervention.
- There's a lot to consider about biochar use for the specific situation and desired goals, so it’s not a "no-brainer."
- Concern about benefits not matching problems at local scale. i.e., poultry litter -> Biochar -> mine land and spoil reclamation.
- Feedstock for biochar defines its properties and application. Costs versus benefits
- Economics and sequestration reversibility.
- Nothing is a no brainer. Still work to do to adequately describe all effects.
- More studies needed. How does this improve different ecosystems health in the CB? Great potential so far.

There were 11 responses to the question, “what are the most important considerations for Biochar in the Bay based on what was presented and your experience?”

- Evolve from narrative (including continuously stating that there are thousands of articles) to targeting trusted experts at CBW institutions for quantification.
- What biochar balances nutrient capture with sequestration and moisture holding capacity.
- Support and grow the eastern Biochar group.
- Return on investment.
- Cost share for Ag practices is not permanent and therefore not often sustainable as a business model.
- What kind, where, when how; Economics, politics.
- Acceptance and approval.
- Finding local sources of wood-based Biochar.
- Is research at this point sufficient to quantify biochar benefits for CBP's crediting system
- Continued education.
- Runoff reduction and nutrient removal benefits.

In addition to 18 participants voting 'yes' on whether biochar should be given an enhancement credit to existing approved BMPs, three participants submitted an additional comment:

- Biochar can enhance a variety of existing practices and approving these enhancements will be more streamlined.
- The data I have seen are sufficiently strong to warrant its use as a tool in the toolbox. However, given the spareness of field studies, I would advocate field verification.
- There appears to be enough research to inform predictive models about the quantified impacts of biochar in relevant applications to be credited, in existing BMPs.

Finally, to the question, "what did you learn – anything new?", 24 responses were submitted:

- I was a novice to biochar in total, so a lot.
- We have more work to do to better identify what, where, when, how of BIOCHAR use.
- How many Biochar projects are happening.
- Biochar improved infiltration through soil aggregation.
- Poultry litter is very effective as a feedstock, so is bamboo (invasive, plentiful, woodyish), gotta educate people with a solid narrative and examples, listen to communities, keep forging ahead!!!!!!
- Large amount of research available
- All the potential uses of biochar!
- Chicken manure has high sorption capability towards metals.
- The strong support and interest in biochar.
- City and local government interest.
- All new to me.
- Commoditization of Biochar seems to be limited more by capital expense of project sites than demand and feedstock supply.
- We still have work to do!
- Poultry litter biochar feedstock potential.
- Lots! About biochar (studies that have been and are being done) and about the processes within the Chesapeake bay program.
- Biochars are not all created equal.
- A lot of important details. So now I have more questions!
- The utility of manure biochars to bind metal contaminants.
- Bacteria removal benefits of biochar.
- The biochar practitioners at this meeting are incredibly innovative and are really moving biochar use forward at an amazing pace. It's exciting to learn from them and to learn about their ideas.
- The role of bio solids.
- People are using biochar in urban settings to make the grass grow better, trees to survive, and shrubs to thrive. Today, this is what drives use in urban areas.
- The benefits that manure feedstock provides for contaminants removal.
- Biochar as a tool for Remediation works. More studies needed in the CBW.

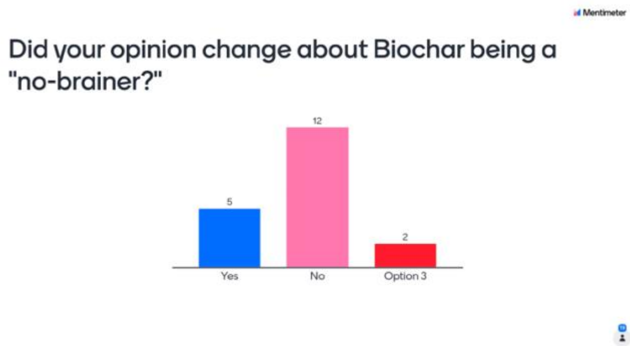
Voting questions

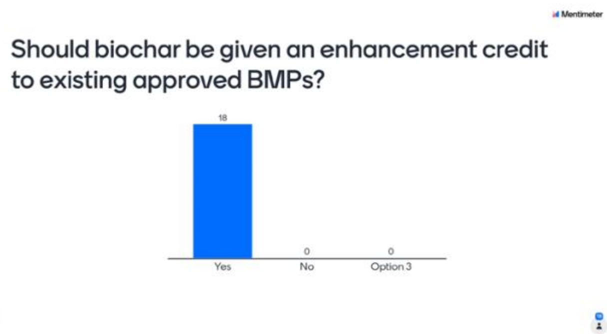
At the end of Day 1, participants were asked to reflect on the presentations given and group discussions by answering the following three questions via Mentimeter:

- Did your opinion change about Biochar being a “new brainer”?
- Should biochar be given an enhancement credit to existing approved BMPs?
- Do you believe that biochar should go the route of enhancement credits for approved practices or as a new expert panel protocol?

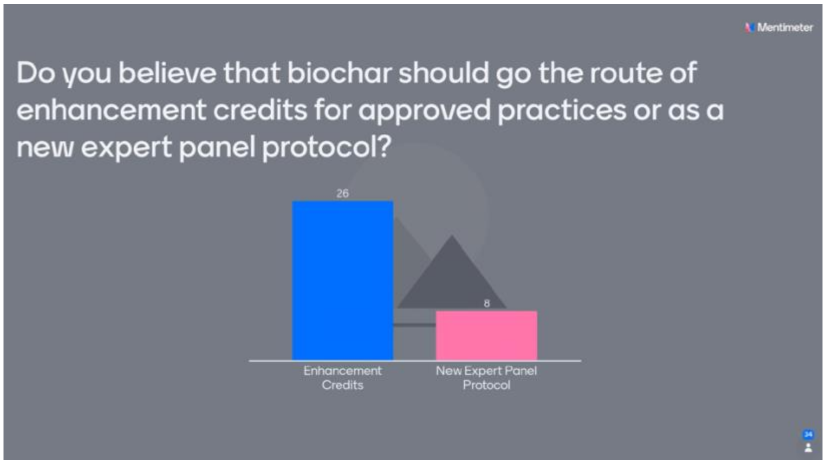
Collected responses were displayed using bar graphs (shown below), which enabled the steering committee to perform a comparative analysis quickly of the summary responses, such as any obvious patterns, and outliers among the group. Participants had a choice of 2-3 responses for each question.

A total of 19 responses were collected for the question regarding changes in opinion about biochar being a "no-brainer." Out of 19 participants, 5 indicated a shift in their opinion, stating "yes," while 12 maintained their original stance, answering "no." 3 respondents selected an alternative option labeled "option 3." All respondents (18) to the question of whether biochar be given an enhancement credit to existing approved BMPs responded “yes.”





Later on, Day 2, a similar question was asked: “do you believe that biochar should go the route of enhancement credits for approved practices or as a new expert panel protocol?” 34 participants responded, with 26 in support of enhancement credits and the remainder, 8, in support of a new expert panel protocol.



Appendix E: List of Figures

Appendix F: List of Tables

Appendix E: Literature Review

STAC Biochar Literature Review

By: James Oliver Lee
Chesapeake Conservation Corps Member
Environmental Finance Center, University of Maryland

Introduction

Biochar is defined by the US Department of Agriculture's Agricultural Research Service as black carbon produced from biomass sources for the purpose of transforming the biomass carbon into a more stable form. This stable form of carbon sequestration can be leveraged in a multi-pronged approach towards water/soil remediation and resilience building.

The research performed had four intertwined areas of focus whose nexus was the use of biochar to assist with reducing the TMDL of the Chesapeake Bay. These areas are Agriculture and Forestry, Toxins, Emerging Contaminants, and Stormwater Management, and Policy, Sustainability, Resiliency, and Economics.

This literature review assesses the remediation, soil improvement, and waste reuse capabilities of bio-charcoal (biochar) by coalescing and synthesizing the last decade of English-language research and reviews into a cohesive document made for decision makers to highlight the viability of biochar as a multipurpose soil and wetland amendment for the Chesapeake Bay watershed. Biochar's viability comes from its thoroughly documented ability to consistently boost phyto-agricultural output, sequester nutrients, neutralize toxins, improve water retention in soil, enable beneficial microorganism propagation, and be cost effective.

Biochar can be advantageous in that it has strong absorption, immobilization, aging properties, excellent electron transfer ability, and is a sustainable way to repurpose waste biomass. Biochar can effectively immobilize heavy metals and promote the circular economy.[3] However, biochar can be detrimental because the different feedstocks and pyrolysis temperatures lead to different properties of biochar which might induce toxicity inhibition in ADs and in soil.[4] This does not detract from its viability but should be noted moving forward as no soil amendment is perfect across the board.

[3] Sachdeva S, Kumar R, Sahoo PK, Nadda AK. Recent advances in biochar amendments for immobilization of heavy metals in an agricultural ecosystem: A systematic review. Environ Pollut. 2023 Feb 15;319:120937. doi: 10.1016/j.envpol.2022.120937. Epub 2023 Jan 3. PMID: 36608723.

[4] Xu, Xi-Jun, et al. "Enhanced Methane Production in Anaerobic Digestion: A Critical Review on Regulation Based on Electron Transfer." Bioresource Technology, vol. 364, 2022, https://doi.org/10.1016/j.biortech.2022

Biochar has shown its ability to improve phyto-agricultural output, arboreal resilience, and the cost effectiveness of waste reuse in spades. Such indicators of biochar's performance enhancement within the agricultural and forestry sectors are its improvement of microorganism propagation in soil, its ability to decrease emissions and odors from vermicomposting if used sparingly, its enhancement of anaerobic digestion, and how it contributes to rural and urban economic circularity.

When biochar is pyrolyzed, the biomass' fuel derivatives are extracted, while a charcoal like husk remains. The improvement of microorganism propagation in the soil stems from this porous structural matrix that pyrolysis creates, which hosts a wide variety of microscopic life, which in turn help maintain healthy soils. The literature indicates this based on biochar's large surface area given its structure, and capacity to adsorb soluble organic matter and inorganic nutrients, biochar is the ideal environment for microbes to thrive.[5] According to their physical and chemical characteristics, bacteria, rhizo-organisms, actinomycetes, and arbuscular mycorrhizal fungi can all preferentially colonize biochar. They claimed that the addition of biochar increased microbial abundance.[6] This applies to bacteria, rhizo-organisms, actinomycetes, and arbuscular mycorrhizal fungi, all of which have a preference for colonizing biochar depending on their physicochemical properties.[7] This is further built upon by the fact that plant rhizomes have an affinity for biochar amended soil because of the beneficial bacterial and nutrient load it sequesters.[8] The nutrient and pollutant sequestration, structure, and the recalcitrant nature of biochar enable it to remain in the soil and act in a remediative capacity for years depending on where it has been used.

It needs to be noted however that biochar has a variety of effects on soil properties, whether they be chemical, biological and physical, and this in turn affects the wellbeing and effectiveness of microbes and microscopic organisms. Increased soil pH and buffering capacity from biochar improve acidic soils. In order to do so, one needs to know the pH and salinity of the biochar one is using in acidic soils. In fine-grained soils, biochar can improve infiltration and hydraulic conductivity. In addition, it appears that biochar has a stronger impact on hydraulic conductivity in coarse-textured soils than in fine-textured soils. By adding biochar to the surface, one can enhance particle transport by both water and wind (dust). Factors such as the characteristics of the soil and biochar, the type of crop, and any potential costs all play a role in determining the rate at which biochar will be mixed into the soil. Use of biochar as an environmentally friendly sorbent for soil immobilization and agricultural soil improvement is critical. Pyrolysis

---

[5] Thies JE, Rillig MC (2009) Characteristics of biochar: biological properties. In: Lehmann J, Joseph S (eds) Biochar for environmental management: science and technology. Earthscan, London, UK, pp 85–105

[6] Abujabhah IS, Bound SA, Doyle R, Bowman JP (2016) Effects of biochar and compost amendments on soil physico-chemical properties and the total community within a temperate agricultural soil. Appl Soil Ecol 98:243–253

[7] Karabulut, F., Shameem, N., Shafi, N., Parray, J.A., Hashem, A., Abd-Allah, E.F. (2023). Over View of Symbiosis Mechanisms and Soil Quality Management Practices to Combat Environmental Changes. In: Parray, J.A. (eds) Climate Change and Microbiome Dynamics. Climate Change Management. Springer, Cham. https://doi.org/10.1007/978-3-031-21079-2_14

[8] Karabulut et al., (2023)

conditions, biochar precursors, and soil properties all have an impact on its utility. The pH changes caused by biochar application, as well as the potential toxicity of biochar due to volatile pyrolysis product emissions, have a big impact on the way soil microbial communities work and what they eat.[9] The complexities of biochar's effect on soil, as well as differences in soil properties, can lead to conflicting data, making it difficult to compare experiment results. Biochar's action on soil and microorganisms requires more research.

Notwithstanding, while more research is needed as to different biochars' effects on soil health, there are other indications that biochar research has reached maturity to the point where using it actively as a soil amendment and remediation measure is advantageous. Such an indicator is how biochar improves vermicomposting. Co-composting agricultural waste with biochar markedly reduces the combination's odor/GHG emissions and increases nutrient capture.[10] The ratios for the agricultural waste co-composting are at least 20:1, but should not exceed 5:1 (biomass: biochar); the reason for this is that earthworms and other detritivores produce the best compost at the 20:1 mark, while going over 5:1 reduces compost quality markedly.[11]

These clear delineations on what amount of biochar works for enabling improved soil health indicate the maturity and depth of available research, and thus requires decision makers to act with celerity to integrate biochar into their approaches of reducing, valorizing, and reusing waste.

Furthermore, when it pertains to waste reuse, anaerobic digestion (AD) and biochar's improvement of it are very key to creating economic circularity. AD, when converting biomass into usable gas/liquified fuels, needs conductive materials (CMs) to facilitate electron transfers between the microbes breaking down the digestate and the microbes producing the fuels.[12]

The supplementation of iron/carbon-based conductive materials (CMs), but in this case specifically biochar, to the AD process has been shown to effectively enhance the methane production, shorten lag phase and accelerate the organics degradation. The underlying mechanism was possibly due to the promoted DIET (direct interspecies electron transfer) between anaerobic microbes and methanogens by using CMs as electron conduits.[13] Of the CMs used in the literature, biochar has the least explicit disadvantages when added to the AD process.[14]

In all three of the aforementioned cases, biochar serves as a process enhancer, and the improvement of such process hinges on the manner in which and sources from which it is produced. Therefore, tweaking the chemical composition, pyrolization, and feedstocks of engineered biochars (EBCs), is key to ensuring that they have the desired effects when put into soil. The potential environmental risks and preparation cost of EBCs should be fully taken into

---

[9] Karabulut et al., (2023)

[10] Wu, Y., Li, Q., Zheng, Y. et al. Optimizing biochar addition for vermicomposting: a comprehensive evaluation of earthworms' activity, N2O emissions and compost quality. Biochar 5, 4 (2023). https://doi.org/10.1007/s42773-022-00203-9

[11] Wu et al., (2023)

[12] Xu et al., (2022)

[13] Xu et al., (2022)

[14] Xu et al., (2022)

account. With the popularization and application of EBCs, extensive use of EBCs in alkaline soil may lead to extreme lime effect in soil, resulting in a threat to the survival of biota.[15] Besides, EBCs that interact with contaminants in the soil during application can migrate in the soil through surface runoff and infiltration, causing a potential impact to soil biota and humans.[16] Therefore, how to reduce the possible environmental risks and developing low-cost, high-efficiency, green, and environmentally friendly EBCs for soil remediation and amendment needs to be an area of focus in the future.

Nonetheless, EBCs can be applied to the soil to promote stability, which ensures that the physical structure of the soil is protected, thereby improving soil fertility.[17] EBCs are generally recommended based on the literature as soil amendments to improve soil water retention, especially in dry climates where water is scarce. The literature points to the fact that increased water retention and the increase in diversity of the microbial community indicate that the presence of EBCs strengthens soil resilience and biodiversity when used within reason.

Compounding upon the multi-faceted uses of biochar is the fact that in all of its uses, it builds into economic circularity. Biochar manufacturing promotes a circular bioeconomy for agricultural waste in that the biomass, when it is tested and pyrolyzed, with its fuel and charcoal derivatives extracted, feeds into itself by way of having the biochar fertilize crops and the biofuels power equipment, the former's waste being used for further pyrolysis and fuel.[18] Waste has enormous amounts of value that is otherwise going to the landfill, and this repurposing imparts ecological and economic value to what was once discarded. Lifecycle assessments of biochar production processes showed that it can consistently impart its environmental benefits. Even if the biochar market prices become low farmers can apply it on farms and accrue the ecological benefits. Biochar's influence in numerous applications is well proven, and the need of the hour is to build a continuous supply chain to commercialize biochar's use in these fields is what the research strongly indicates.[19]

---

[15] Tang, Hui, et al. "Engineered Biochar Effects on Soil Physicochemical Properties and Biota Communities: A Critical Review." Chemosphere, vol. 311, 2023, https://doi.org/10.1016/j.chemosphere.2022.137025.

[16] Tang et al., (2023)

[17] Tang et al., (2023)

[18] D. Phadtare, Prajakta, and S. R. Kalbande. "Biochar Production Technologies from Agricultural Waste, Its Utilization in Agriculture and Current Global Biochar Market: A Comprehensive Review." International Journal of Environment and Climate Change, 2022, pp. 1010–1031, https://doi.org/10.9734/ijecc/2022/v12i1131078.

[19] Phadtare, Prajakta and Kalbande, (2022)

Research and Analysis: Toxins, Emerging Contaminants, and Stormwater Management

Biochar has the ability to immobilize toxins such as heavy metals and "forever chemicals", so EBCs, in concert with bacterial breakdown and phytoremediation, can accomplish a wide variety of toxin and waste management duties. This is made evident by the outstanding redox property of biochar, which promotes microbial remediation by accelerating electron transfer. Biochar can also be used as an excellent carrier for loaded strains to better promote the process of bioremediation of pollution.[20]

Adequately mitigating soil pollution is acknowledging not only the presence of a single pollutant, but the coexistence and intermingling of multiple pollutants. Researchers can select or cultivate microorganisms that are resistant to coexisting pollutants, and effectively combine them with biochar to boost the treatment efficiency of combined pollution.[21] It is necessary to reduce the presence of harmful substances such as heavy metals, PAHs, and VOCs that exist in biochar as much as possible before adding the amendment to any soil.[22] Systematic studies and summaries of the methods for reducing the potential risk of biochar on microorganisms are required.[23] As is described in the Agriculture and Forestry section, this need is met by being precise when engineering biochars for desired qualities such that soil biota and abiotic factors are accounted for, and the former enabled to thrive. Pertaining to selecting properties of EBC for which to engineer, the nonmetal functional groups (NFGs) must be accounted for and structured accordingly.[24] The NFGs in EBCs include OFGs (oxygen functional groups), NFGs (nitrogen functional groups), SFGs (sulfurous functional groups), PFGs (phosphoric functional groups) and SiFGs (silicate functional groups), most of them in their inorganic and organic states. The regulation of functional groups has certain rules:(i) compared with BC prepared from plants, the biomass of biological precursors contains more nitrogen content; (ii) the increase of pyrolysis temperature makes the inorganic functional groups tend to convert into organic states; (iii) chemical modification of reagents containing specific elements is an effective modification idea. At present, the attention in the application of BC to remove pollutants is the performance effect. In the future, the reaction mechanism of BC to remove pollutants and the role of functional groups in it should be focused on, and economical and convenient preparation and modification methods should be vigorously developed, thereby expanding the prospect of BC in practical applications. What is more, in the process of soil bioremediation, whether to add key microbial species that are loaded on the biochar to the soil or to influence the selection of soil key microbial species through the addition of biochar to achieve the best treatment and economic effect, researchers need to further explore.

---

[20] Zheng, Xuemei, et al. "The Effects of Biochar and Its Applications in the Microbial Remediation of Contaminated Soil: A Review." Journal of Hazardous Materials, vol. 438, 25 Sept. 2022, https://doi.org/10.1016/j.jhazmat.2022.129557.

[21] Zheng, Xuemei, et al., (2022)

[22] Zheng, Xuemei, et al., (2022)

[23] Zheng, Xuemei, et al., (2022)

[24] Yang, Yadong, et al. "Nonmetal Function Groups of Biochar for Pollutants Removal: A Review." Journal of Hazardous Materials Advances, vol. 8, Nov. 2022, https://doi.org/10.1016/j.hazadv.2022.100171.

Some strains in soil, such as sulfate-reducing bacteria and methanogens, also respond positively to the amendment of biochar, which will create competition for electrons used for microbial reduction of pollutants and inhibit pollutant reduction. Hence, there is a requirement for researchers to explore the exact inhibition mechanism of pollutant reduction and ways to maximize the availability of electrons for pollutant reduction.[25] It is necessary to select an appropriate modification method according to the characteristics of the EBCs' raw materials and the application purpose to control the physical and chemical properties of the end product, including pretreatment methods, activation methods and N doping methods.[26] The appropriate modification methods such as ball milling, microwave pyrolysis, and redox-active metal preloading for biochar can effectively improve its corresponding properties.[27] Hence, researchers need to select suitable modification methods that can fully exploit the characteristics of biochar as a microbial carrier and electron transporter to promote microbial degradation of pollutants.

Additionally, biochar can be used as a substitute for materials such as cement and sand to enhance the mechanical properties and durability of biochar-concrete composites in green/blue infrastructure. It improves the functionality of construction materials, such as hydrothermal and acoustic properties.[28] Biochar mainly acts synergistically with external carbonation by promoting the generation of hydration products inside the concrete, and its own pore structure and high surface properties are decisive factors for the adsorption and storage of CO2.[29] The incorporation of biochar can effectively reduce the net carbon emissions of composite materials and improve the carbon sequestration performance of cementitious composites.[30] Overall, biochar has a very high potential as a carbon capture material in concrete and has good environmental and economic benefits for the industry if adopted at scale.

[25] Zheng, Xuemei, et al., (2022)

[26] Gao, Wenran, et al. "A Review on N-Doped Biochar for Enhanced Water Treatment and Emerging Applications." Fuel Processing Technology, vol. 237, 1 Dec. 2022, p. 107468, https://doi.org/10.1016/j.fuproc.2022.107468.

[27] Zheng, Xuemei, et al., (2022)

[28] Liu, Jun, et al. "Application Potential Analysis of Biochar as a Carbon Capture Material in Cementitious Composites: A Review." Construction and Building Materials, vol. 350, 3 Oct. 2022, https://doi.org/10.1016/j.conbuildmat.2022.128715.

[29] Liu, Jun, et al., (2022)

[30] Liu, Jun, et al., (2022)

Biochar remaining recalcitrant, soil compatible, and effective are cornerstones of what impedes it from being adopted.

According to the most recent literature, the effects of aging on biochar properties have been revealed: (1) increasing oxygen content, CEC (cation exchange capacity), SSA (specific surface area), and formation of OFGs; and (2) decreasing carbon content, aromatic components, ash content, and pH value. The enhanced adsorption of heavy metals by aged biochar is mainly due to the increase of OFGs.[31] The inhibition of adsorption is dependent on the reduction of ash in aged biochar.[32] This is a reminder to carefully use high-ash biochar for long-term remediation of heavy metals.[33] Specifically for the adsorption of organic pollutants, the aging poses a negative effect on the sorption capacity of biochar derived from high pyrolysis temperature (>500 °C). It is mainly due to the reduction of aromatic components and the formation of three-dimensional water clusters caused by proliferation of OFGs. It indicated that the adsorbed organics on these high-temperature biochars could be released into the environment after long-term aging. In the soil amendment, biochar inevitably contacts the soil components. The existing research has revealed that soil minerals (kaolinite, FeCl3, AlCl3, and CaCl2) could enhance the oxidation resistance of biochar, due to forming a physical barrier and decreasing the biochar reactivity.[34]

As for biochar standardization, it was found that the optimum pyrolysis temperature must be around 400 and 600 °C according to the literature.[35] It was also emphasized that biochar can be amended to construct wetlands as a waste treatment enhancement for sequestering heavy metals, VOCs, excess nutrients, and malignant biota.[36]

---

[31] Liu Y, Chen J. Effect of aging on biochar properties and pollutant management. Chemosphere. 2022 Apr;292:133427. doi: 10.1016/j.chemosphere.2021.133427. Epub 2021 Dec 23. PMID: 34954191.

[32] Liu and Chen, (2021)

[33] Liu and Chen, (2021)

[34] Liu and Chen, (2021)

[35] El Barkaoui, Sofiane, et al. "A Critical Review on Using Biochar as Constructed Wetland Substrate: Characteristics, Feedstock, Design and Pollutants Removal Mechanisms." Ecological Engineering, vol. 190, May 2023, p. 106927, https://doi.org/10.1016/j.ecoleng.2023.106927.

[36] El Barkaoui, Sofiane, et al., (2023)

Conclusion

Exploration of the wide applicability of biochar through bibliometric analysis suggested that global research on biochar has increased tremendously in the recent past. Biochar could be produced from a wide variety of waste biomass, which enables waste management. Biochar could enable food security management by augmenting soil fertility and plant productivity, mitigate climate change by sequestering carbon and minimizing greenhouse gas emission, produce bio-energy (i.e. bio-oil and syngas), and remediate contaminants from soil, water, and air. The wide applicability suggests the key role biochar could play in sustainable development worldwide. Artificial intelligence, data-driven machine learning and artificial neural network modeling could play a critical role in producing and screening application-specific biochar.[37] Moreover, it is crucial to incorporate life cycle assessment (LCA) for assuring environmental sustainability and determining the fate of biochar along with probable ecological and health consequences.

[37] Kumar, A., Bhattacharya, T., Shaikh, W.A. et al. Multifaceted applications of biochar in environmental management: a bibliometric profile. Biochar 5, 11 (2023). https://doi.org/10.1007/s42773-023-00207-z

References

Abujabhah, I.S., S.A. Bound, R. Doyle, and J.P. Bowman. 2016. Effects of biochar and compost amendments on soil physico-chemical properties and the total community within a temperate agricultural soil. Applied Soil Ecology 98:243–253. https://doi.org/10.1016/j.apsoil.2015.10.021.

El Barkaoui, S., L. Mandi, F. Aziz, M. Del Bubba, and N. Ouazzani. 2023. A critical review on using biochar as constructed wetland substrate: characteristics, feedstock, design and pollutants removal mechanisms. Ecological Engineering 190: 106927. https://doi.org/10.1016/j.ecoleng.2023.106927.

Gao, W., Z. Lin, H. Chen, S. Yan, Y. Huang, X. Hu, and S. Zhang. 2022. A review on n-doped biochar for enhanced water treatment and emerging applications. Fuel Processing Technology 237: 107468. https://doi.org/10.1016/j.fuproc.2022.107468.

Karabulut, F., N. Shameem, N. Shafi, J.A. Parray, A. Hashem, and E.F. Abd-Allah. 2023. Over View of Symbiosis Mechanisms and Soil Quality Management Practices to Combat Environmental Changes. In: Parray, J.A. (eds) Climate Change and Microbiome Dynamics. Climate Change Management. Springer, Cham. https://doi.org/10.1007/978-3-031-21079-2_1

Kumar, A., T. Bhattacharya, W.A. Shaikh, A. Roy, S. Chakraborty, M. Vithanage, and J.K. Biswas. 2023. Multifaceted applications of biochar in environmental management: a bibliometric profile. Biochar 5, 11. https://doi.org/10.1007/s42773-023-00207-z

Liu, J., G. Liu, W. Zhang, Z. Li, F. Xing, and L. Tang. 2022. Application potential analysis of biochar as a carbon capture material in cementitious composites: a review. Construction and Building Materials 350: 128715. https://doi.org/10.1016/j.conbuildmat.2022.128715.

Liu, Y., and J. Chen. Effect of aging on biochar properties and pollutant management. 2022. Chemosphere 297: 133427. https://doi.org/10.1016/j.chemosphere.2021.133427.

Phadtare, P.D., and S.R. Kalbande. 2022. Biochar production technologies from agricultural waste, its utilization in agriculture and current global biochar market: a comprehensive review. International Journal of Environment and Climate Change 12(11): 1010–1031. https://doi.org/10.9734/ijecc/2022/v12i1131078.

Sachdeva, S., R. Kumar, P. Kumar Sahoo, A. Kumar Nadda. 2023. Recent advances in biochar amendments for immobilization of heavy metals in an agricultural ecosystem: A systematic review. Environ Pollutution 319. https://doi.org/10.1016/j.envpol.2022.120937.

Tang, H., M. Chen, P. Wu, M. Faheem, Q. Feng, X. Lee, S. Wang, and B. Wang. 2023. Engineered Biochar Effects on Soil Physicochemical Properties and Biota Communities: A Critical Review. Chemosphere 311: 137025. https://doi.org/10.1016/j.chemosphere.2022.137025.

Thies, J.E., and M.C. Rillig. 2009. Characteristics of biochar: biological properties. In: Lehmann J, Joseph S (eds) Biochar for environmental management: science and technology. Earthscan, London, UK, pp 85–105.

Wu, Y., Q. Li, Y. Zheng, X. Xiong, Y. Chen, M. Shaaban, and R. Hu. 2023. Optimizing biochar addition for vermicomposting: a comprehensive evaluation of earthworms' activity, N2O emissions and compost quality. Biochar 5(4). https://doi.org/10.1007/s42773-022-00203-9.

Xu, X.-J., J. Yan, Q.-K. Yuan, X.-T. W, Y. Yuan, N.-Q. Ren, D.-J. Lee, and C. Chen. 2022. Enhanced Methane Production in Anaerobic Digestion: A Critical Review on Regulation Based on Electron Transfer. Bioresource Technology 364: 128003. https://doi.org/10.1016/j.biortech.2022.

Yang, Y., Y. Piao, R. Wang, Y. Su, N. Liu, Y. Lei. 2022. Nonmetal Function Groups of Biochar for Pollutants Removal: A Review. Journal of Hazardous Materials Advances 8: 100171. https://doi.org/10.1016/j.hazadv.2022.100171.

Zheng, X., W. Xu, J. Dong, T. Yang, Z. Shangguan, J. Qu, X. Li, and X. Tan. 2022. The Effects of Biochar and Its Applications in the Microbial Remediation of Contaminated Soil: A Review. Journal of Hazardous Materials 438: 129557. https://doi.org/10.1016/j.jhazmat.2022.129557.