Advancing Biochar in the Chesapeake:

A Strategy to Reduce Pollution from Poultry Litter

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Foreword

In July 2010, Forest Trends, the Chesapeake Fund, and the Carbon War Room convened a two-day feasibility and project design charrette on poultry litter biochar for sustainable nutrient management in the Chesapeake Bay watershed. This event brought together leaders in science, farming, the poultry industry, the energy industry, finance, and conservation to examine whether and how payments for ecosystem services—in the form of carbon or nutrient trading credits—could be combined with energy and agricultural revenues to attract private investment and improve the health of the Chesapeake.

This report highlights the insights gleaned from that workshop and from discussions that have since ensued with workshop participants and other experts in the field in order to illustrate whether and how biochar production and application may be a solution to poultry litter management in the Chesapeake Bay watershed. A unique contribution to the pool of reports available on poultry litter management in the Chesapeake Bay watershed, the report benefits from the comprehensive, practically-informed perspectives of its authors and contributors.

The solutions described in this report address the acute water quality problems facing the Chesapeake Bay watershed; we have defined this problem with a nuanced understanding of the policies, politics, and economics affecting water quality in the Chesapeake Bay and its people. For example, contributor Dan Nees has worked on water quality issues for years, beginning at the University of Maryland, continuing on to lead water quality efforts at the World Resources Institute, and currently spearheading the Chesapeake Fund. Moreover, West Virginian poultry farmer Josh Frye has been very active in working to find nutrient management solutions and has also contributed his experience and expertise to this report. The synergy of perspectives like these yields a definition of the Chesapeake's nutrient management problems and a description of the political-economic-regulatory context that is informed by the concerns and experiences of the conservation and farming communities alike. The authors of this report wish to emphasize the need to find fair solutions to this environmental problem that work for—rather than penalize—farmers and other vulnerable stakeholders in our community.

The report also benefits from expert insights on cutting-edge research on the technical aspects of biochar production and application. Widely published author and editor of perhaps *the* leading volume on the science of biochar, Dr. Johannes Lehmann contributed significantly to the technical analysis contained in this report. Similarly, Dr. Foster Agblevor and Dr. Rory Maguire contributed their expertise in, respectively, the engineering and soil science aspects of poultry litter biochar production and application. These contributors' technical understanding of the latest scientific research on biochar allows the report to describe how poultry litter biochar may add significant value to nutrient management and agriculture in the Chesapeake and elsewhere by communicating what is understood about its effects on nutrient flows, soil quality, and crop performance. We are also candid about those areas where biochar has underperformed and where its properties or effects are not well understood. What's more, these contributors' perspectives have helped us to identify the mechanisms that may be most helpful in advancing necessary research moving forward.

The report is further enriched by the practical experience of our contributors and authors. Contributor Mike McGolden produces and sells gasification units both domestically and abroad, Dr. Foster Agblevor and Josh Frye have worked on two of the few demonstration poultry litter biochar projects in the watershed, and author Lopa Brunjes has worked on wood-based biochar production in Colorado. The economic analyses presented in this report incorporate, wherever possible, values extracted from the real-world experience of these individuals and their colleagues. The economic model developed – and available to readers online – is sensitive to many of the uncertainties inherent to any biochar production business plan at this stage and is a particularly helpful tool for illustrating the opportunities for and challenges to achieving financial viability in this market.

Finally, the report benefits from international subject matter experts. Contributor Debbie Reed, Executive Director of the International Biochar Initiative, has spearheaded work on biochar certification and standardization and has worked extensively with biochar producers and consumers to advance research and incubate an international marketplace for the product. Author Suzanne Hunt is a senior advisor for the Carbon War Room and has worked directly with that organization's research and economic analyses of the opportunities for and barriers to scaling up biochar as a pivotal mechanism for reducing greenhouse gas emissions globally. Author Phil Covell of Forest Trends has advanced biochar in a developing world context and brings extensive organizational experience in developing payments for ecosystem service markets to work for conservation and people. Drawing on these diverse perspectives has allowed the authors to produce a report that takes into account the lessons learned from other regions and countries in order to offer a truly valuable and viable solution for the Chesapeake.

The unique perspectives, expertise, and experiences represented on this team of authors and contributors has delivered an end-product in this report that we feel is able to effectively grapple with the real challenges the situation presents in order to formulate the basis and recommendations for a truly sustainable, environmentally effective, efficient, and equitable solution to the challenge of poultry litter management in the Chesapeake.

Dan Nees	Michael Jenkins
Director, Chesapeake Fund, Forest Trends	President and CEO, Forest Trends

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1. Executive Summary

The Chesapeake Bay is the largest estuary in the United States and has provided sanctuary for more than 3,700 species of plants and animals for centuries. However, excessive nutrient loads from various sources—including wastewater treatment plants, urban runoff, fertilizer applications and animal waste—have resulted in eutrophication and related ecological shifts that adversely affect wildlife and aquatic resources. Despite the efforts of multiple regulatory agencies over the past three decades, the Chesapeake Bay watershed still fails to meet basic ecological and water quality standards.

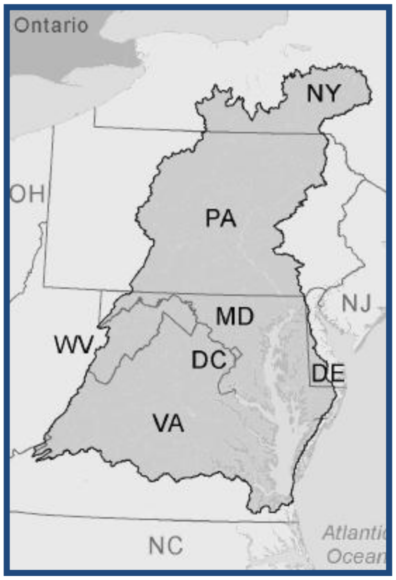

Figure 1. The Six Jurisdictions of the 200 Mile-Long Chesapeake Bay Watershed

Map: Chesapeake Bay Program (2008).

Agriculture is a substantial source of nitrogen and phosphorus loads to the Chesapeake Bay, and manure from the more than 185 million livestock animals in the watershed is a major component of agricultural impact. In 2009, animal manure accounted for 17 percent of the total nitrogen and 26 percent of the total phosphorus reaching the Bay (see Figures 3 and 4); poultry operations are estimated to be responsible for nearly one-third of the manure nitrogen reaching the Bay (Chesapeake Bay Foundation 2004).

To mitigate the impact of poultry litter across the watershed without adversely impacting the farming community, many scientists, entrepreneurs and policy makers are evaluating the efficacy of innovative manure management practices, including the thermal conversion of poultry litter to energy and nutrient-rich ash and biochar. These solid residues can be economically shipped out of the watershed or applied in the watershed to improve soil fertility while reducing reliance on chemical fertilizers. There are also emerging bodies of evidence showing that biochar made from poultry litter is a valuable tool for environmental remediation and that it reduces greenhouse gases in the atmosphere. Indeed, the economic and environmental value of poultry litter biochar products and services is potentially very high.

However, there are technical, economic, and policy barriers impeding the development of biochar production as an alternative poultry litter management practice. Significant questions persist about the water quality and agricultural impacts of biochar applications within the watershed with respect to nutrient release rates, biochar's impact on nutrient leaching and up-take by plants, and the behavior of biochar in different soil types. These questions are complicated by the fact that biochar can be generated with a wide range of physical and chemical properties according to the feedstocks used and technologies employed to produce them. These uncertainties, combined with high capital costs, low energy prices, and technological risks, make it difficult to finance waste-to-energy and biochar production projects at scale unless other income streams can be generated. To that end, the development of markets for ecosystem services such as water quality (nutrient trading) and climate change mitigation (carbon trading) constitute emerging opportunities for financing the production of biochar and realizing sustainable nutrient management in the region.

2. Nutrient Pollution in the Chesapeake Bay Watershed

2.1 The Chesapeake Bay Watershed

Covering more than 64,000 square miles, the Chesapeake Bay is the largest estuary in the United States. It supports more than 3,700 species of plants, fish, waterfowl, and other animals, making it one of the world's most biologically-rich waterways. Moreover, the Chesapeake Bay watershed is home to nearly 17 million people in Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia and the District of Columbia. That figure is projected to surpass 20 million by 2030 (Chesapeake Bay Program 2010).

Figure 2. Blue Crab Harvested from the Chesapeake Bay – Valued at $55 Million in 2000.

Photo: Chesapeake Bay Program (2011).

While the Bay represents one of the most ecologically valuable areas in the United States, it has been severely impacted by nutrient and sediment pollution for decades. Excess nitrogen and phosphorus from wastewater treatment plants, urban runoff, fertilizer applications, animal waste and atmospheric deposition result in algae blooms that create marine "dead zones" where fish and shellfish cannot survive due to oxygen depletion. These algae blooms also block sunlight that is needed for underwater grasses, further harming ecosystems at the bottom of the Bay. While efforts to improve the Chesapeake's health have won some small battles in recent years, the region still fails to meet nearly every ecological benchmark set under federal and state regulatory bodies. The Chesapeake Bay Program, a federal-state partnership established in the 1980s to address these challenges, scored the Bay's health at 45 percent against a range of indicators in 2009, highlighting the following challenges:

- Just 12 percent of the Chesapeake and its tidal tributaries met Clean Water Act standards for dissolved oxygen, a decrease from previous years.
- Only about a quarter of tidal waters met guidelines for water quality.
- Despite improving on previous years, the health of bottom-dwelling species in the Chesapeake is still at just 56 percent of the benchmark goal.

In May 2009, President Obama signed an executive order establishing the Federal Leadership Committee for the Chesapeake Bay and committing $491 million in federal resources toward a new strategy for restoring and protecting the Chesapeake Bay and its tidal tributaries. States are also beginning to crack down on nutrient pollution in the Bay and have outlined their strategies for reducing nutrient loads on the Bay in the watershed improvement plans recently submitted to the U.S. Environmental Protection Agency (EPA). As efforts are renewed to restore the health of the Bay, public, private, and non-profit entities alike are looking for innovative solutions to one of the greatest sources of regional nutrient pollution: poultry litter.

2.2 The Challenge of Poultry Litter Management

Over 180 million chickens are farmed in the watershed every year, producing over 185 million pounds of manure nitrogen and over 50 million pounds of manure phosphorus (Chesapeake Bay Foundation 2004). Though poultry litter is often applied on farm and cropland as a natural fertilizer, the concentrated volume of litter produced in the watershed leads to an over-supply in many localities. This problem is compounded by the fact that since the early 1980s the watershed has lost nearly 1.6 million acres—or 14 percent—of cropland and pastureland, significantly decreasing the regional land area available for manure application (National Resource Conservation Service 2003).

Though livestock operations populate the entire region—and counties in Pennsylvania, Maryland, Virginia, Delaware and West Virginia all face nutrient management challenges (U.S. EPA 2010)—the U.S. Department of Agriculture (USDA) has identified three hotspots of excess nutrients in the Chesapeake (see Figure 3)--Lancaster County, Pennsylvania, the Delmarva Peninsula (which includes Sussex County, Delaware, the top chicken-producing county in the nation), and Rockingham County, VA (the top turkey-producing county in the nation) together account for 53 percent of the watershed's manure nitrogen production (Aillery, Gollehon and Breneman 2005). These county-level nutrient overloads present an acute nutrient management issue, as the costs of transporting the manure for efficient land application outside of the county can be very high (Ribaudo, et al. 2003).[1]

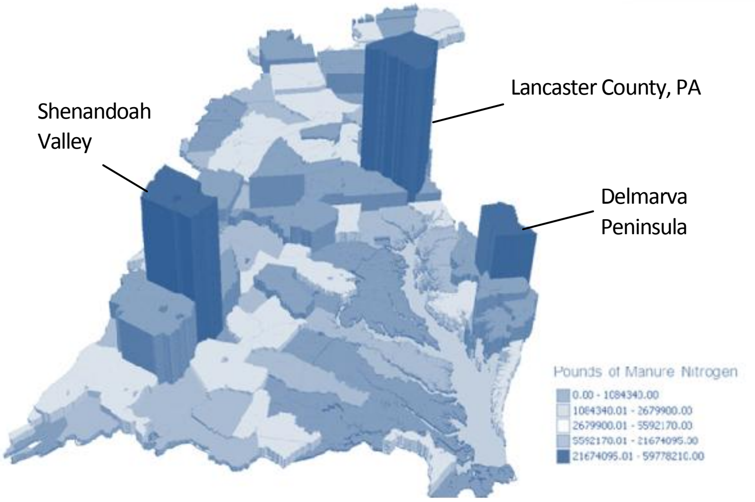

Figure 3. Total Manure Nitrogen by County in the Watershed

Map: EPA Chesapeake Bay Program, as in Chesapeake Bay Foundation (2004).

Similar nutrient overloads are evident at the state level. To illustrate, in 2010 Delaware's Department of Agriculture estimated that the poultry litter exceeding Delaware's absorptive capacity amounted to 107,000 tons annually, or 35 percent of the poultry litter produced every year in the state (Delaware Department of Agriculture 2010; see also Figure 15). Some of the excess manure in the watershed is currently utilized for alternative purposes (discussed in Section 3), but much of it accumulates on farmland or is over-applied to cropland and, as a result, runs off as nutrient pollution into the Bay.

The scale of the poultry litter management problem is evident in agriculture's footprint on nutrient pollution in the watershed. While agriculture accounts for about a quarter of land use in the watershed, it is responsible for about 40 percent of the total nutrient load reaching the Bay. Animal waste is a major component of agriculture's contribution to nutrient overload in the Bay--Figure 4 shows that manure is responsible for 17 percent of the total nitrogen pollution in the Bay, and Figure 5 shows that this number increases to 26 percent for phosphorus pollution. About one-third of the manure nitrogen produced in the watershed is attributable to poultry litter (Chesapeake Bay Foundation 2004).

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[1] For a further discussion of costs relating to transporting poultry litter, see Section 5.2.2.

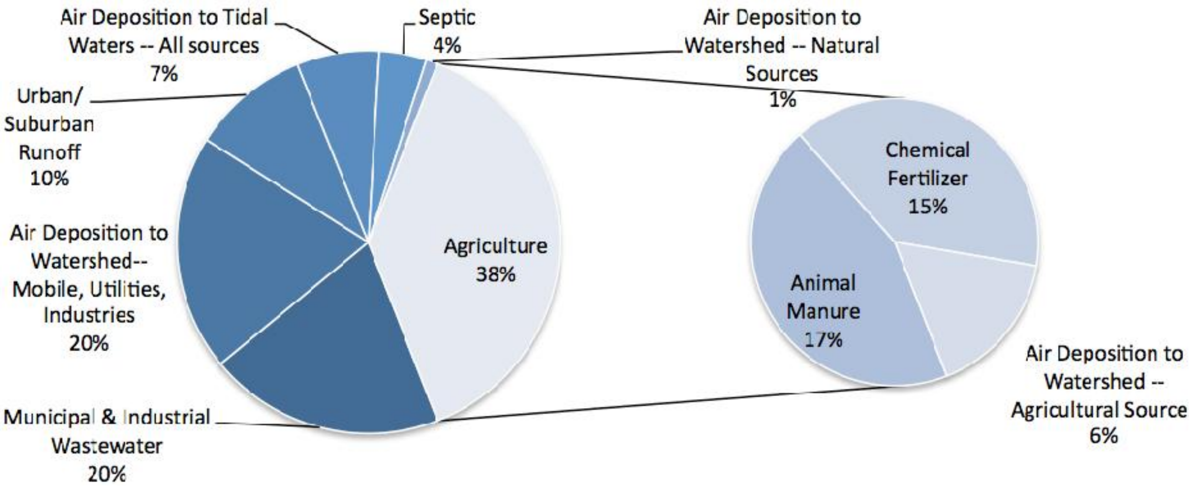

Figure 4. Sources of Nitrogen Pollution Reaching the Chesapeake Bay
Source: Chesapeake Bay Program (2009).

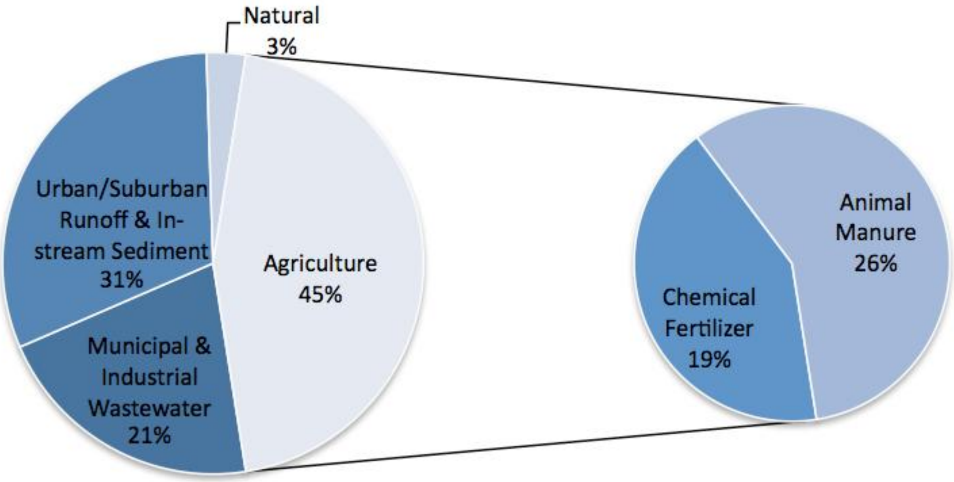

Figure 5. Sources of Phosphorus Pollution Reaching the Chesapeake Bay
Source: Chesapeake Bay Program (2009).

2.3 Regulatory Efforts to Mitigate Nutrient Overload in the Chesapeake

A range of regulatory efforts at the federal, state, and regional levels address the issue of nutrient management in the watershed. Although recent efforts in Congress to establish a watershed-wide nutrient trading market have failed, early-stage nutrient trading markets do exist in Maryland, Pennsylvania, Virginia, and West Virginia.

2.3.1 Federal Regulation

The major federal law affecting water quality—and, by extension, animal manure management—is the Clean Water Act (CWA), which requires states and the District of Columbia to establish appropriate uses for their waters and adopt water quality standards that are protective of those uses. The CWA also requires that jurisdictions submit to the EPA a list of waterways that do not meet water quality standards due to excess pollutants. For those waterways, a Total Maximum Daily Load (TMDL) is developed; this is essentially a "pollution diet" that identifies the maximum amount of a pollutant the waterway can receive and still meet water quality standards.

Total Maximum Daily Load

=

Individual waste load allocations for point sources

+

Load allocations for non-point sources and natural background

+

Margin of safety

In addition to the TMDLs developed by individual jurisdictions to protect local waters, the six watershed states and the District of Columbia have worked with the EPA and the Chesapeake Bay Commission—all partners in the Chesapeake Bay Program—to create a Bay-wide TMDL to ensure that appropriate nutrient loads on a Bay-wide scale are met. By the end of 2010, each jurisdiction had developed and submitted for public and EPA review their first Watershed Implementation Plans—documents which describe how each jurisdiction plans to meet the new nutrient loading requirements under the Bay TMDL.

The CWA's National Pollutant Discharge Elimination System (NPDES) program covers large animal feeding operations as well as other industrial and municipal facilities that discharge pollution into surface waters. Under the NPDES permitting, entities designated as concentrated animal feeding operations (CAFOs) are considered a point source. As such, they are included in the wasteload allocations specified by TMDLs and are required to implement a site-specific nutrient management plan to ensure that manure, litter, and process wastewater are applied in accordance with site-specific practices to ensure that nitrogen and phosphorus in the manure will be used appropriately.

Animal feeding operations that do not fall under the NPDES definition of a CAFO—and therefore do not require an NPDES permit—may still be subject to regulation of manure management. For instance, animal feeding operations of a certain size in coastal zones are subject to the Coastal Zone Management Act and face regulations contained in the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990. The EPA requires that discharges from these operations be limited through appropriate storage and an appropriate waste utilization system. These management measures are applied to all new facilities, regardless of size, and to all existing facilities with more than 300 beef cows, 200 horses, 70 dairy cows, 15,000 layers or broilers, or 200 swine. Generally, however, non-point source agricultural operations that do not require an NPDES are explicitly exempted from regulation under the Clean Water Act; as such, all regulation of these entities falls to the states.

In 1999, the USDA and the EPA joined to form the Unified National Strategy for Animal Feeding Operations, which sets forth a framework to minimize impacts to water quality and public health from animal feeding operations and to establish a national performance expectation for animal feeding operations. Under the Unified Strategy, all CAFO owners and operators are expected to develop and implement technically sound, economically feasible, and site-specific comprehensive nutrient management plans (CNMPs) for properly managing the animal wastes produced at their facilities, including on-farm application and off-farm uses.

2.3.2 State-Level Regulation and Nutrient Trading Markets

State regulatory agencies complement federal regulatory efforts to manage nutrient loads on the Bay. All Chesapeake states require animal producers above a certain size to produce and implement nutrient management plans. The minimum threshold for animal production nutrient management planning ranges from as little as 1.6 animal units in Delaware to 8 animal units in Maryland.[2] The rigor required in the planning also varies by state; in Maryland and Pennsylvania the more limiting nutrient standard of phosphorus is uniformly applied, whereas other states are more flexible in allowing a nitrogen standard. Historically, compliance in the implementation of nutrient management plans has been subpar. To illustrate, in 2009, inspectors in Maryland found that just 69 percent of farmers were compliant in implementing their nutrient management plans (Ritter 2010), and a 2004 survey in Virginia found that just 60 percent of farmers self-reported that they always implement nutrient management plans as required (Joint Legislative Audit and Review Commission 2005).

Regulators in Maryland, Pennsylvania, Virginia, and West Virginia are developing nutrient trading markets as a tool to meet water quality standards required to restore the health of the Bay and meet federal regulatory standards. These markets give major point-source polluters, such as wastewater treatment plants (WWTPs), the option to purchase offsets for nutrient emissions that cannot be economically reduced by means of investments within the plant.[3] Trades must be consistent with all existing water quality regulations, including requirements set by local and Bay-wide TMDLs. The future of nutrient trading in the Chesapeake is uncertain and varies by state.

In Pennsylvania, the market will be brokered by the Pennsylvania Infrastructure Investment Authority (PennVEST), which has been designated as the trading program's clearinghouse; as such, PennVEST will enter into contracts with nutrient credit sellers to buy credits that they will subsequently sell to regulated point source polluters. Pennsylvania has already certified projects expected to generate 3 million pounds of nitrogen reductions in 2011 alone, and at least eight contracts for private nutrient trades have already moved forward (Chesapeake Bay Program 2010). The volume of nutrient trading is currently low while the first verified nutrient credits are being generated, and potential buyers are generally not relying on nutrient trading to meet their compliance objectives. As a result, in Pennsylvania market prices are currently between $3 and $9 per pound of nitrogen.[4]

Although the picture in Pennsylvania looks promising, a potential problem facing nutrient trading markets across the region is a lack of demand due to high nutrient load caps and, consequently, the failure of nutrient trading markets to deliver the scale of pollution mitigation required under the new Bay-wide TMDL. Low demand is expected to keep nearly all nutrient trading transactions between major point-source polluters for the foreseeable future. For example, wastewater treatment plants in Virginia are expected to only trade with each other to meet their regulatory obligations for the next 15-20 years. In Maryland, no non-point sources have traded or even certified any nutrient credits. Nevertheless, state programs are endeavoring to include non-point agricultural operations (AOs) into nutrient trading markets, and all four markets have created some mechanism by which these entities are technically eligible to participate in the market. In order to be allowed to enter the market and sell credits, however, AOs must meet the minimum level of nutrient reduction prescribed by applicable water quality strategies. This "baseline requirement" may be based on either results or practices.

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[2] An animal unit equals 1,000 pounds of the farmed animal. As such, about 250 broiler chickens equal one animal unit (Natural Resources Conservation Service 1995).

[3] All of the markets trade both nitrogen and phosphorus. Only point sources, such as WWTPs, are regulated such that they are eligible to offset pollution through purchased credits. In essence, the caps of the markets are set by annual load limits determined through existing regulatory frameworks, such as NPDES permits and TMDLs. See Table 1 for details on purchaser eligibility in the nutrient trading markets.

[4] See http://www.dep.state.pa.us/river/Nutrient%20Trading.htm for a current ledger of nutrient trades in Pennsylvania.

For example, in Maryland, a per-acre annual load rate is calculated from the appropriate watershed's TMDL, while in Virginia AOs are instead required to implement a series of Best Management Practices (BMPs), as applicable (see Table 1). The purpose of the baseline requirement to ensure that each credit represents an additional reduction of nutrient pollution, beyond what is already required, or, in some cases, set as a regulatory target.[5] In most cases, however, these baselines are not mandatory for non-point agricultural entities operating outside of the nutrient trading markets and may well be a prohibitive barrier to market entry.

Aside from concerns about baselines, the new TMDLs may stimulate demand for nutrient credits, thereby bolstering nutrient trading markets and creating opportunities for non-point credit certification and trade. The first phase of watershed improvement plans submitted in late 2010 show that states will rely heavily on nutrient trading to meet their TMDL requirements.[6]

Table 1. Key Characteristics of Chesapeake State Nutrient Trading Programs

	Maryland	Pennsylvania	Virginia	West Virginia
General eligibility requirements for credit purchases	Existing significant point sources must have ENR[a] technology in operation before purchasing credits or offsets. Point sources accommodate growth (any new or expanded loads) by purchasing offsets generated by point or non-point sources.	Existing point sources may purchase credits generated by point or non-point sources to meet annual load limits, subject to additional conditions of NPDES permits.	Existing point sources may purchase credits generated by other point sources to meet annual load limits, subject to additional conditions of NPDES permits.	Existing point sources must have NPDES permits and may purchase credits generated by point or non-point sources to meet annual load limits, subject to conditions of the permits.
General eligibility requirements for credit and/or offset sales	Significant point sources must have ENR in operation before selling credits WLA[b] cannot be sold until it has been adopted in a NPDES permit through the public review process. Non-significant point sources must have annual load limits for nutrients.[c] Sellers must meet baseline requirements. Facilities trading excess credits based on excess capacity must demonstrate consistency with water and sewerage plans.	Sellers must meet baseline and applicable threshold requirements before selling credits.	WLAs or compliance credits and offsets cannot be sold unless the facility for which the WLA was granted has been constructed and is operating. Sellers must meet baseline requirements before selling offsets.	Point sources must have NPDES permits that contain annual load limits for nutrients and/or sediment. Sellers must meet baseline requirements before selling credits.

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[5] *Point sources* wishing to trade in nutrient markets also must meet a baseline requirement, which is simply the permitted annual load of the individual facility (Branosky, Jones and Selman 2011).

[6] See, for example, Pennsylvania Department of Environmental Protection (2011) and Commonwealth of Virginia (2010).

	Maryland	Pennsylvania	Virginia	West Virginia
Baseline requirements that must be fulfilled before agricultural operations (AOs) may generate credits or offsets	AOs must first achieve their portion of the state nutrient reduction goal for non-point agriculture.[d] Additionally, AOs must comply with all applicable regulations; develop and implement a current nutrient management plan; and develop and implement a soil and water conservation plan including, if applicable, a waste management system plan.	AOs must first comply with all applicable regulations for nutrient management, manure management, and erosion control. Additionally, AOs must meet a threshold requirement beyond the state baseline by (1) implementing a 100-foot manure setback, (2) implementing a 35-foot vegetative buffer, or (3) reducing the farm's total nutrient balance by 20 percent below the reductions achieved through regulations.	AOs must fulfill their portion of the state nutrient reduction goal for non-point agriculture defined as implementing the following BMPs (as applicable): - Soil conservation plan - Nutrient management plan - Cereal cover crops - Exclusionary livestock fencing - Vegetative buffers	AOS must first fulfill their portion of the state nutrient reduction goal for non-point agriculture defined as the Tributary Strategies[e] per acre annual loading rate (lbs N/acre, lbs P/acre, lbs sediment/acre) and implementation of a whole-farm nutrient management plan.
Are BMPs financed through state and/or federal cost-share funds eligible to generate credits?	No.	Yes, unless the cost-share agency places restrictions on the funds.	No.	Yes.
Agency responsible for credit and/or offset certification for non-point sources	Maryland Department of Agriculture	Pennsylvania Department of Environmental Protection	Virginia Department of Environmental Quality	West Virginia Department of Environmental Protection

a. Enhanced Nutrient Removal, referring to technologies for wastewater treatment plants.

b. Waste Load Allocation, which is the portion of the receiving water's loading capacity allocated to one of its existing or future point sources of pollution.

c. The cutoff discharge for non-significant discharges to participate in the Maryland trading program is 6,100 lbs total nitrogen or 457 lbs total phosphorus or more per year

d. That portion, the *de facto* baseline for agricultural operations, is calculated as a per-acre annual loading rate based on the TMDL goals for cropland in the watershed where the credits are generated.

e. The Tributary Strategies are the plans developed by Chesapeake Bay jurisdictions in the early 2000s to demonstrate their progress toward meeting voluntary pollutant-reduction goals.

Adapted from Branosky, Jones, and Selman (2011).

3. Existing Options for Poultry Litter Management

Land Applications

Applying manure to cropland is the predominant way of managing it. Federal regulations stipulate that manure may be applied to land at the rate of the limiting nutrient—i.e., the rate at which either nitrogen or phosphorus will be absorbed by crops.[7] State agencies usually specify whether the application rate may follow a nitrogen standard or a more limiting phosphorus standard. Manure application rates based on a nitrogen standard supply all of the nitrogen recommended for the crop and will usually result in over-application of phosphorus. Likewise, a phosphorus standard supplies all of the phosphorus required for a crop while not supplying the recommended amount of nitrogen, necessitating the application of additional nitrogen from other sources. Most regulations in the Chesapeake have now moved to a phosphorus standard (Ritter 2010).

The USDA's manure management model estimates that 2.5 million acres of crop and pastureland (40 percent of the region's agricultural land base) would have to be available for manure application if a nitrogen standard were applied throughout the watershed. However, if a phosphorus standard were uniformly applied—as is now more common in the watershed—almost double the amount of land—4.8 million acres—would be required (Ribaudo, et al. 2003).

Land applications of manure are limited by a number of factors, including:

- *Farmers' willingness to accept manure*
  As is evident by the acreage of land required for nutrient-appropriate land application of manure, animal feeding operations in the watershed having to meet either a nitrogen or a phosphorus standard would run out of land on which to spread manure within an economical transportation radius if willingness to accept manure falls below certain thresholds. Specifically, the willingness to accept manure threshold at which available land reaches its capacity for assimilating manure nutrients is estimated at 60 percent for a phosphorus standard and 20 percent for a nitrogen standard (Aillery, Gollehon, and Breneman 2005). Most studies have found that just 20 percent of farmers near a poultry operation are typically willing to use poultry litter as a fertilizer (Ribaudo, et al. 2003).

- *Nutrient value of the manure to specific crops*
  National surveys have found that the crops that utilize the most amount of poultry litter—compared to other animal sources of manure—are peanuts and cotton (see Figure 6). The dominant crops in the Chesapeake are pasture, hay, corn, wheat, soybeans, vegetables, and fruits (U.S. EPA 2010).

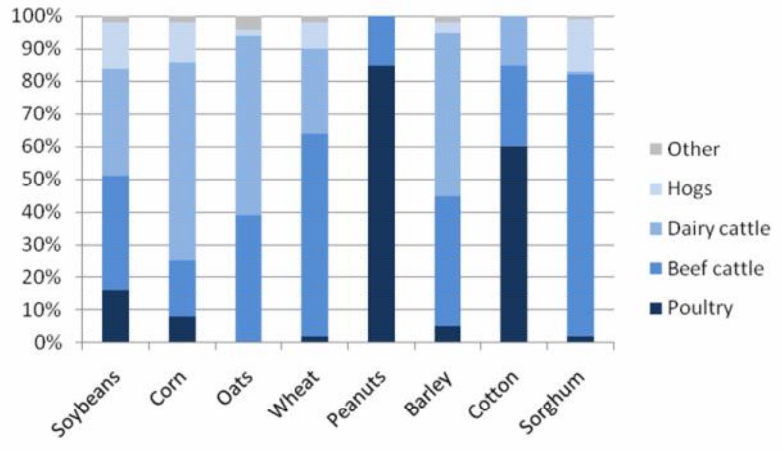

Figure 6. Animal Source of Manure by Crop

Source: MacDonald, et al. (2009).

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[7] USDA regulations permit manure application rates that are determined either a nitrogen or phosphorus standard. The NRCS permits use of the nitrogen standard on sites for which there is a recommendation to apply phosphorus, or when the use of a risk assessment tool has determined that the site has acceptable risk for offsite transport of phosphorus. For example, where the phosphorus runoff potential is low, poultry litter can be applied to land at the crop nitrogen removal rate. (Aillery, Gollehon and Breneman 2005)

- *Costs of transporting manure*
  Assuming a regional willingness to accept manure of 20 percent and a watershed-wide nitrogen standard, the USDA estimates watershed costs of transporting manure for land application to approach $90 million per year. Chesapeake jurisdictions offer subsidies for transporting poultry manure for appropriate management. In Maryland, for instance, animal producers that are not able to apply manure on their own land can receive up to $18 per ton for transportation of the manure to other farms. A similar program in Virginia between $5 and $12 per ton in transportation cost assistance (Ritter 2010).
- *Other handling costs*
  Other costs associated with land application of manure may include the costs of manure cleanout and handling, testing, and application itself.

State programs currently exist to maximize the amount of litter that can be effectively applied to farmland in the watershed without harming water quality. In addition to subsidizing transportation costs, several watershed states offer free "manure matching" programs, which connect farmers who have excess animal manure with nearby farms or alternative use projects that can use the manure. This service is typically free and is available in Maryland, Delaware, and Pennsylvania; a similar program, the Poultry Litter Hotline, exists in Virginia (Ritter 2010).

Currently, poultry farmers in the watershed can earn between $5-15 per ton of raw poultry litter for land applications. However, willingness to accept manure in the watershed is likely to decrease, along with the price paid for poultry litter, as increasingly stringent regulations from federal and state agencies require manure to be applied at the appropriate rate of nutrient absorption.

Disposal

In some areas, states have incentivized poultry farmers to dispose of excess litter by transporting it completely out of the watershed for disposal. For example, in 2009, Maryland farmers trucked 52,000 tons of poultry out of the watershed (Maryland Department of Agriculture 2010). When transported as raw manure, these costs can be exorbitant.

Feed Management

As an upstream solution, poultry growers can reduce surplus animal manure and poultry litter nutrients by adjusting their animals' diets. In one approach, farmers supplement their chicken feed with phytase, an enzyme that allows chickens to absorb more phosphorus from their feed, thereby reducing phosphorus content in manure without affecting the health or commercial value of the chickens. Phytase is currently used in nearly all poultry operations throughout the watershed. In the Delmarva Peninsula, the result of this proactive practice has been a 16 percent reduction in manure phosphorus (Delaware Department of Agriculture 2010).

Composting

A small portion (1-2 percent) of poultry litter in the region is composted. Where poultry litter is composted, it occupies a very specific niche, as in the mushroom industry in Pennsylvania (Lichtenberg, Parker, and Lynch 2002). For more on composting poultry litter in the watershed see Branyai and Bradley (2008).

Anaerobic Digestion

Anaerobic digestion of manure is also an alternative poultry litter management option. Greenhouse gases (GHGs), including methane and carbon dioxide, are the primary products of this process. The captured methane can be used for electricity generation and is eligible for carbon offset credits. Currently, anaerobic digesters are mainly used on dairy and hog farms. It is unclear whether this process would be appropriate for poultry litter management, though, as significant amounts of water have to be added for poultry litter to be amenable for anaerobic digestion. Layer manure with higher moisture content is considered a better choice for such technology.

Industrial conversion of manure to fertilizer

Pelletization converts raw poultry litter into a commercial fertilizer. One such plant, operated by Perdue AgriRecycle in Seaford, Delaware, processes 12 percent of the excess poultry litter in the Delmarva Peninsula and produces about 50,000 tons of pellets each year. The final product is an organic fertilizer listed with the Organic Materials Review Institute and is marketed for precision agriculture in the Midwest, Maine, and Florida. This enterprise was partly financed by the States of Delaware and Maryland, both of which assisted with costs of transporting the raw poultry litter to the plant. Poultry farmers are paid $4 per ton of raw poultry litter and are not charged at all for the service of hauling the manure off of their land.

Another example of an industrial processing plant was the Harmony Farms Shenandoah Valley plant, which was designed to process 60,000 tons of poultry litter per year to produce both energy and a blended organic-inorganic fertilizer for the golf course and landscaping markets. The plant used a gasification technology that produces thermal energy, coupled with a mixing and blending process using a liquid urea binder. It operated for several years below full capacity before closing in 2004 (Gollehon, Aillery, and Christensen 2004), apparently not able to establish a sustainable business model.

Combustion

Combustion is the process of burning manure directly as a fuel. At the high temperatures (typically 3600 ˚F) generated by combustion, most of the material is oxidized or volatized, leaving mainly ash as a solid residue. Combustion completely removes nitrogen from the solid phase and concentrates the manure's phosphorus and potassium content in the ash.

Serious concerns remain about particulate removal, slagging, and fouling as a result of the high ash content produced by combustion. Additionally, organo-arsenic compounds present in poultry feed persist in the poultry litter feedstock. At combustion temperatures, these compounds become airborne, producing harmful air pollutants.

4. Biochar: Production, Properties, and Benefits

Existing poultry litter management practices in the watershed have failed to adequately address the scale of the nutrient pollution problem: the Bay still suffers from nutrient overload, and there is still an excess of poultry manure produced each year. One alternative management practice that has not yet been sufficiently explored in the watershed is the thermal conversion of poultry litter to ash and biochar.

Biochar is produced when raw biomass, such as wood or poultry manure, is chemically broken down by heating it in an oxygen-starved environment. The process produces heat, combustible gases, and a charred material that can be used as an agricultural additive.

4.1 Biochar Production Technologies

There is a wide range of biochar production technologies, representing an equally wide range of maturity, product and by-product characteristics, and opportunities and challenges for commercialization. Similar to combustion, these technologies catalyze a thermal conversion of the poultry litter, creating energy in the process. Distinct from combustion, however, gasification and pyrolysis technologies create the valuable biochar product and do not release harmful air pollutants (Baranyai and Bradley 2008).

Gasification

Gasification is the process of converting biomass or other organic materials into carbon monoxide and hydrogen by reacting the raw material at high temperatures (ranging from 2000-3000 ˚F) in an oxygen-deficient environment. Ash and a small amount of biochar remain as by-products. The process also produces thermal energy and a gas mixture called synthetic gas—or syngas—which is a fuel. The syngas can be used on-site or captured, processed, and then marketed as a distinct product. Thus far, however, gasification technologies have only been deployed on a pilot basis or relatively small scale. For an examination of one pilot gasification project in the Chesapeake, see Box 1.

Pyrolysis

Pyrolysis occurs at lower temperatures (from 390-1100 ˚F) in an oxygen-deprived environment, producing gases, liquids, heat, and biochar. Pyrolysis is the same process used to produce charcoal from wood. Pyrolysis systems are classified as slow, intermediate, or fast – faster systems utilize higher temperatures and shorter residence times. Figure 7 illustrates the wide variance of products (char, gas, and liquid) yielded through pyrolysis and gasification technologies and also shows the variance of this yields based on feedstocks.

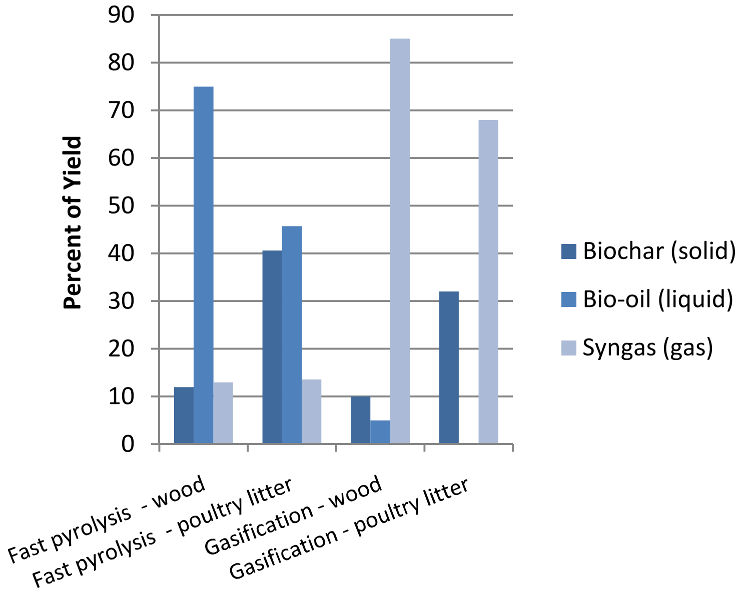

Figure 7. Relative Yields of Fast Pyrolysis and Gasification Technologies Using Wood and Poultry Litter as Feedstocks

Sources: Bridgwater (2007), Agblevor, et al. (2010), and McGolden (2011).

4.2 Properties of Biochar

The biochar produced by gasification and pyrolysis is fundamentally distinct from the raw material from which it is derived. Chemically, it has a higher carbon content; physically, it is has a much more porous surface area. It is also drier, lighter, and sterile—when poultry litter is converted to biochar, its mass is decreased by about 60 percent. The unique characteristics of biochar make it especially promising as a product to—*inter alia*—improve soil composition and water retention, increase nutrient uptake in plants, and ultimately increase crop yields. In fact, a recent review of 24 studies of the agricultural value of biochar commissioned by the United Nations found that the biochar increased soil productivity in all instances, with productivity improvement rates ranging from 20 percent to 220 percent (UNFCCC 2008).

Poultry litter biochar is chemically distinct from other biochars (e.g., those made from wood or crop residues) because of its higher nutrient content. Its nitrogen, phosphorus, potassium, and other nutrients may give it some of the amendment qualities of fertilizer (see Table 2).[8] However, not all of the nutrients contained in the biochar are available to plants; more research must be done to understand how poultry litter biochar interacts with specific crops and soils to reduce nutrient leaching and increase nutrient uptake in crops. Although poultry litter biochar is endowed with nitrogen, phosphorus, and potassium, its agricultural benefits may have more to do with its physical structure than its chemical composition. Generally, biochars are extremely porous, with some exhibiting surface areas exceeding 400m^2 per gram (see Figure 8).[9]

Still, the relatively porous structure of poultry litter biochar – especially as compared with raw poultry litter -- appears to provide a good habitat for soil bacteria and fungi that help to make nutrients more bioavailable, increasing plant nutrient uptake (Thies and Rillig 2009). Its porosity also appears to allow the soil to retain more water; combined with the effect of the biochar's carbon bonds and high charge density, this trait enables the biochar to also hold onto nutrients, reducing leaching (Novak, et al. 2009, 199).

This combination of traits makes poultry litter particularly effective as an agricultural input in many soil-crop combinations, as shown in Figure 9.

Table 2. Nutrient Analysis of Poultry Litter Biochar Produced in a Fixed Bed Gasifier

Nutrient	Lbs./ton
Total Kjeldahl Nitrogen	17.30
Plant available nitrogen	8.18
P_2O_5	108.68
K_2O	190.72
Ammonium	4.27
Calcium	144.48
Magnesium	38.91
pH = 9.64	

Source: Collins, Basden, and McDonald (2009).

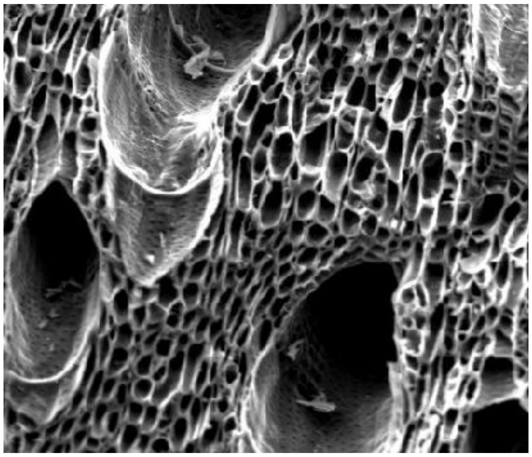

Figure 8. A Micrograph of a Piece of Biochar Illustrating its Porosity

Source: Best Energies.

4.3 Benefits of Biochar to Nutrient Management

The properties discussed above make poultry litter biochar a potentially highly valuable resource for nutrient management.

Production of Biochar

The production of biochar transforms the nutrients in poultry litter into a much more manageable form. Thermal conversion reduces the concentration of nitrogen in the poultry biochar, to a greater or lesser degree depending on the temperature. Most nitrogen is converted to an elemental form and released benignly to the atmosphere, though in fast pyrolysis some of the nitrogen is retained by the bio-oils. Thus, the process directly

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[8] As noted earlier, thermal conversion of the poultry litter reduces its nitrogen content. However, compared to biochars produced from other feedstocks, poultry litter biochar still has a higher nitrogen content.

[9] However, it has been observed that poultry litter biochar is much less porous than other, wood-based biochars, because of the high ash content of the poultry litter feedstock. Still, its porosity is not insignificant and may still aid in nutrient and water retention; here, further research is needed.

reduces the amount of nitrogen reaching the Bay. Poultry litter biochar does, however, retain high levels of phosphorus and moderate levels of potassium (see Figure 10).

Concentrations of these nutrients are increased during thermal conversion. These remaining nutrients can be transported out of the watershed as biochar much more easily than they could be as raw poultry manure. Biochar weighs less, takes up less space, and is free of pathogens (Lehmann and Joseph 2009).

Agricultural Application of Biochar

Poultry litter biochar applied on land in the watershed may still have a reduced impact on Bay water quality compared to the application of raw poultry litter for several reasons.

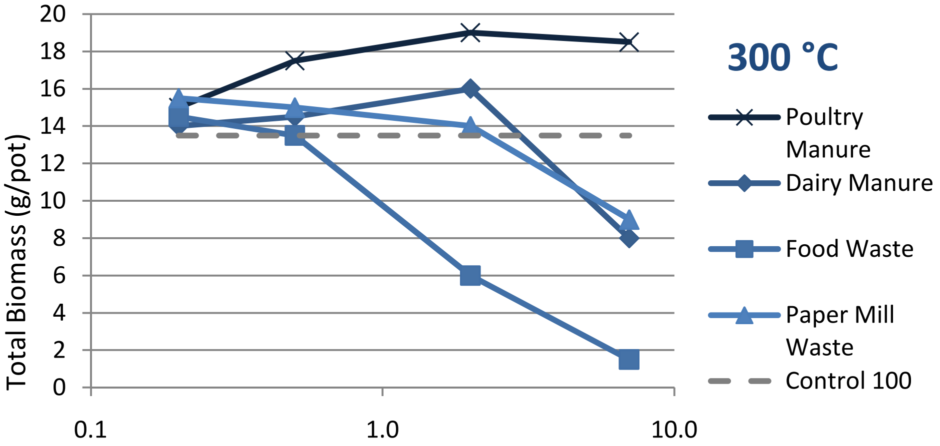

Figure 9. Effect of Biochars from Poultry Litter and Other Raw Materials on Plant Growth.
Corn greenhouse trial, upstate NY loamy soil. N=2 (mean +-SE). Source: Rajkovich, et al. (unpublished data).

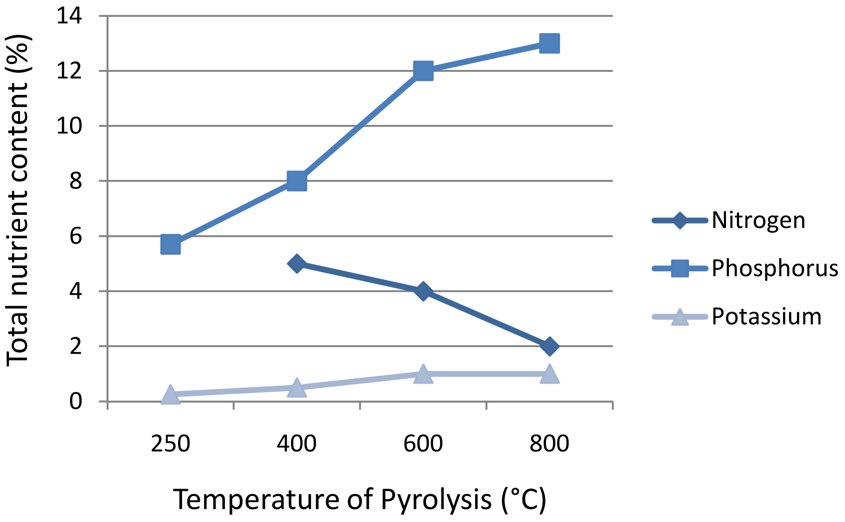

Figure 10. The Effect of Pyrolysis Temperature on Nutrient Content in Sewage Sludge
Source: Yu, et al. (2005).

First, phosphorus is adsorbed by biochar (i.e., it adheres to its extensive surface area), which may make it more stable in soils (see Figure 12). This may increase the ability of the land to store phosphorus and other nutrients, though other research shows that phosphorus in biochar is plant-available when it is applied to acidic soils. More research is required to fully understand nutrient retention and release rates of poultry litter biochar applied in the Chesapeake Bay watershed.

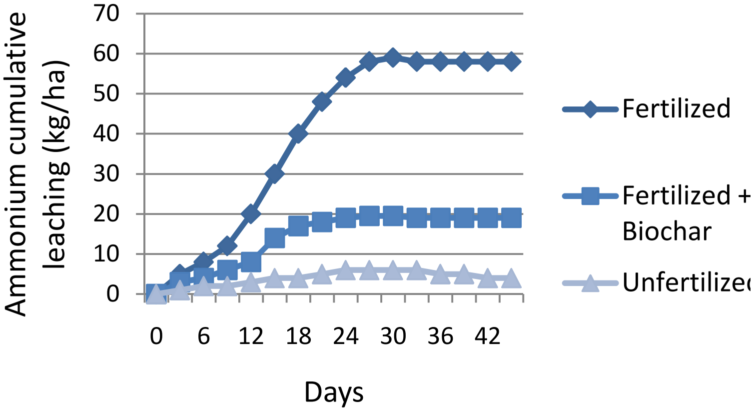

Figure 11. The Effect of Biochar and Fertilizer Application on NH4+ Leaching in Soil

Source: Lehmann, et al. (2003).

Second, as indicated in the previous section, numerous studies show that biochar as a soil amendment can improve plant growth and agricultural production. To the extent that biochar is successful in increasing nutrient uptake by crops in the watershed, thereby reducing leaching (see Figures 11 and 13), farmers could apply less nutrients to farmland—particularly, from chemical fertilizer—and fewer nutrients would be available to pollute the Bay. The combined effect of lower rates of fertilizer application and nutrient run-off could significantly improve water quality.

Furthermore, if poultry litter biochar is proven to be a valuable soil conditioner or amendment to soils in the Midwest, it may generate sufficient demand to be shipped out of the watershed for application in the soils that produce much of the corn, and other crops, used in poultry feed. In such a scenario, the production and application of poultry litter biochar would offer an economically-viable mechanism for closing a considerable nutrient loop in the American agricultural system (see Figure 14).

Unfortunately, studies on nutrient flows from biochar application in soils have yielded inconsistent results, owing mainly to variations in the biochar used (production methods, feedstocks, and temperatures), soil conditions, and crops. Further research in this field is clearly needed.

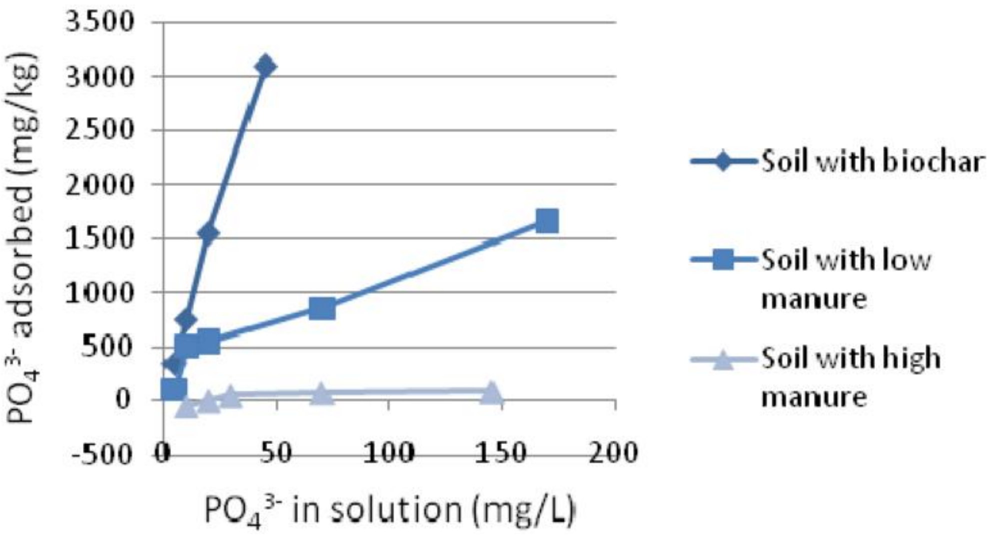

Figure 12. Phosphorus Adsorption in Soils Treated with Manure and Biochar from Black Locust (N=3).
Source: Lehmann (2007).

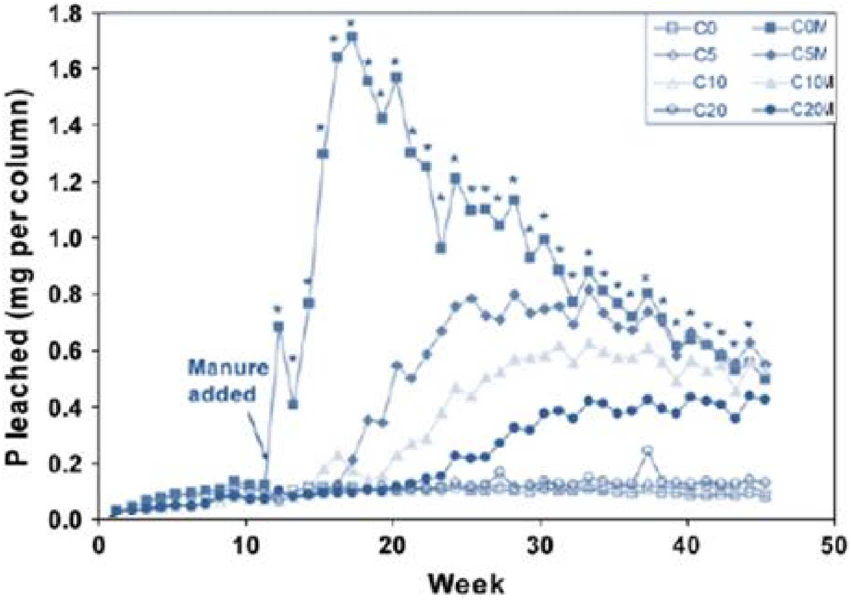

Figure 13. Effect of Hardwood Charcoal on Phosphorus Leaching.
Source: Laird, et al. (2010).

Application of Biochar as a Feed and Litter Amendment

The nutrient loop can be further closed, if biochar is added to poultry feed and/or litter to complement and reduce commercial feedstocks and amendments that currently ship in nutrients from outside the watershed. As a feed supplement, biochar adds phosphorus and reduces nutrient leaching, thereby reducing the need for nutrient inputs from imported food. As a litter amendment, biochar has demonstrated the ability to capture airborne ammonia in the chicken houses. In one pilot, biochar was used in approximately the same quantity as a commercial litter amendment with similar results (Coaltec Energy 2009).

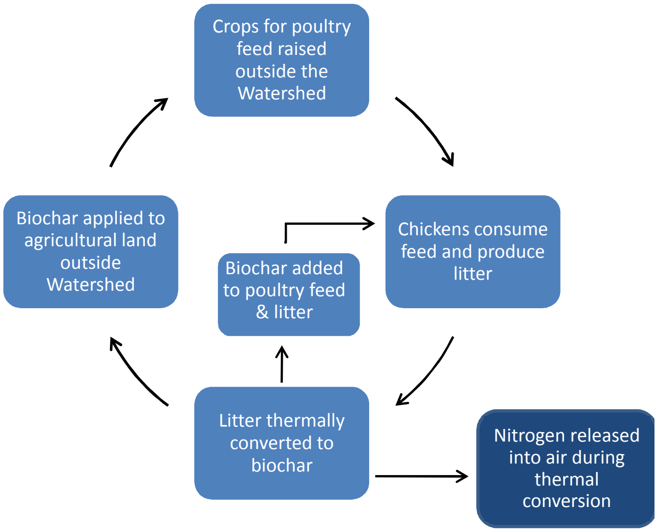

Figure 14. Potential Sustainable Nutrient Cycling Loop Using Biochar

Preliminary Estimate of Nutrient Benefits

Given the variables affecting the flow of nutrients during pyrolysis or gasification, and the many more unknowns about the impacts of biochar application on the behavior of nutrients in soils, it is difficult to estimate the potential impact of biochar production on the Bay. However, as long as the right manure matching programs are in place, there is enough feedstock available (see Figure 15) to produce this potentially valuable commodity (biochar) at a scale that can substantially contribute to nutrient management in the bay. Indeed, given the significant nitrogen reduction through thermal conversion and the reduced cost of transporting the resulting solids out of the watershed, it is reasonable to suggest that this method of poultry litter treatment, if it can be done economically (see section 5.2), could significantly reduce –if not eliminate -- this source of nutrient loading in the Chesapeake Bay.

4.4 Co-Benefits of Biochar

Environmental Remediation

In early testing, biochar has performed exceptionally well as an agent of environmental remediation. USDA laboratory tests have found that biochar is an effective filter for heavy metals—such as copper and mercury—in water (Uchimiya, et al. 2010, 2011). In fact, biochar produced from poultry litter performed better on this metric than conventional charcoal. These results, coupled with the fact that the fertility benefits of biochar are

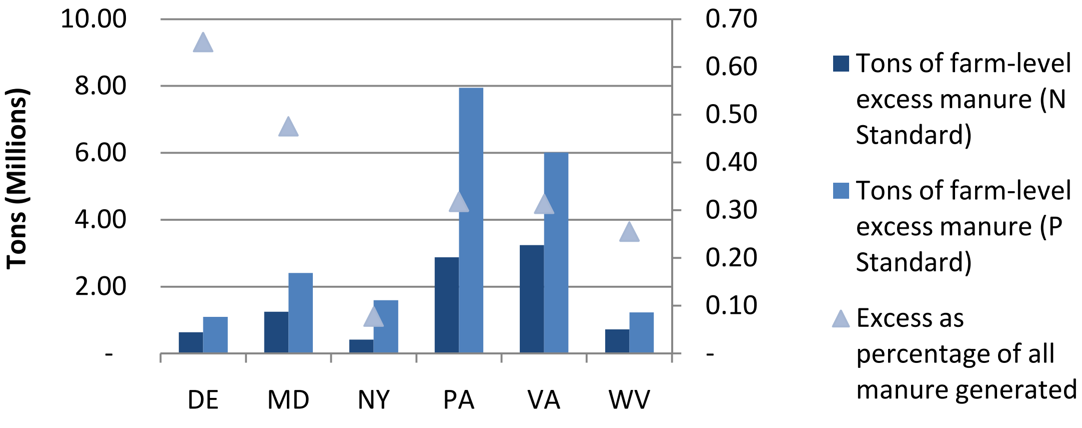

Figure 15. Excess Manure (All Livestock) in Chesapeake States.
Source: 2007 Agriculture Census.

especially pronounced in poor and degraded soils (Kimetu, et al. 2008),[10] make it an attractive option for mine reclamation and other environmental remediation activities.

Renewable Energy Production

The thermal heat, syngas, and bio-oils produced during the thermal conversion process of litter to biochar can all be used to generate renewable energy, which can add value on-site by displacing fuel costs or off-site by contributing electricity to the grid.

All three types of thermal conversion technologies discussed above (combustion, gasification and pyrolysis) can effectively utilize poultry litter for direct energy production because of its relatively high energy content as compared to other manures. However, the variable moisture content of poultry litter can affect its caloric value; as such, producers may need to first dry out the poultry litter before using it as a feedstock.[11] Table 3 illustrates the characteristics of poultry litter as they compare to coal and wood.

The energy generated by litter-to-energy (LTE) systems has been used to offset local energy consumption, which is most ideal if the form of energy needed is heat. If a generator is added to the system and the site is connected to the electric grid, it may be eligible for net metering incentives in every Chesapeake state. Electricity generation adds a level of complexity and capital expense that may be difficult to overcome, especially in smaller biochar production facilities, but net metering at least will raise the top-line economic benefit from about 2 cents to 10 cents per kWh.

Table 3. Comparison of Poultry Litter versus Wood and Coal as Fuel for Energy Conversion

	Broiler litter	Coal	Wood
Carbon, Dry wt (%)	39.6	74	49.7
Hydrogen, Dry wt (%)	5.05	5.1	5.4
Nitrogen, Dry wt (%)	3.35	1.6	0.2
Oxygen, Dry wt (%)	34.05	7.9	39.3
Ash, Dry wt (%)	21.45	9.1	5.3
Moisture, Dry wt (%)	33.35	5.2	50
Dry Gross Energy (HHV), MJ/kg	15.75	30.82	20.47

Source: Murphy (2000) and Kim, Agblevor, and Lim (2009).

Renewable Energy Credits and Subsidies

A limited number of tax credits are available to renewable energy production entities in the watershed, provided they are qualified renewable energy resources. Closed-loop bioenergy facilities, such as litter-to-energy operations, are eligible for the federal renewable energy production tax credit (PTC), a per kilowatt-hour tax credit for electricity generated from renewable sources. The PTC provides a maximum 2.1 cents per kilowatt-hour benefit for the first ten years of a renewable energy facility's operation.

Until recently, Maryland was the only state in the watershed providing renewable energy credits available to litter-to-energy facilities. The Clean Energy Production Tax Credit is worth a minimal $0.085 per kilowatt-hour, with a maximum total incentive of $2.5 million over five years. Starting in October 2010, Tennessee Valley Authority began to offer incentives to mid-sized generators of renewable energy, including biomass, in Virginia. The incentives come in the form of long-term price contracts (up to 20 years), with a base price average of $0.0561/kWh, increasing at a rate of 3 percent per year.

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[10] See also Steiner et al. (2007).

[11] It should be noted that broiler litter usually has a lower moisture content (20-35 percent) than that of egg-layers (around 50 percent).

Avoided Carbon Emissions

Biochar has been argued to combat climate change throughout its lifecycle.[12] Specifically, poultry litter biochar may reduce net greenhouse gas (GHG) emissions though several mechanisms:

- *Avoided GHG emissions when raw litter is diverted as feedstock for biochar*

  Raw poultry litter left to decompose on farmland, in landfills, or in compost will emit methane (CH4) and carbon dioxide (CO2). However, producing biochar from the litter captures much of the carbon responsible for those emissions in a relatively stable form that resists decay. During the conversion of biomass to biochar about half of the original carbon is retained in the biochar, compared to the low amounts retained after other management practices, such as direct burning (3 percent) and biological decomposition (less than 10-20 percent after 5-10 years) (Lehmann, Gaunt and Rondon, 2006). Although actual carbon residence times may range widely depending on the type of biochar, type of soil, and conditions under which it remains in the soil, estimates for mean residence times in the scientific literature range from 1,000 to 10,000 years (Cheng, et al. 2008).13 Mean residence times for poultry litter biochar produced in the region would have to be tested.

- *Avoided carbon emissions where biochar displaces a fossil fuel feedstock for electricity or heat*

  Where the thermal energy, syngas, or bio-oils produced during gasification or pyrolysis are used to generate energy or electricity that would otherwise be generated by fossil fuels, biochar production contributes to further avoided GHG emissions (as in any bioenergy process).

- *Avoided carbon and nitrous oxide emissions through reduced application of chemical fertilizers*

  As discussed in Section 4.1.2, biochar's properties as a soil conditioner and nutrient amendment reduce the need for application of chemical fertilizers. As fertilizer production is itself a fossil fuel-intensive process, any displaced fertilizer application equates to GHG reductions.[14] Additionally, biochar has been reported to reduce nitrous oxide (N_2O) soil emissions that result from nitrogen fertilizer applications, perhaps through increasing the ability of crops to absorb available nitrogen (Singh, et al. 2010).

In addition to tallying these benefits, any calculation of the net impact of poultry litter biochar production would also need to account for the GHG emissions resulting from the production process itself. Emissions may be produced in the construction and operation of a gasification or pyrolysis facility, transportation of the feedstock and biochar products (additional to the baseline), and pre-treatment of the feedstock such as drying. The magnitude of these emissions can vary widely depending on regional characteristics and facility design; for instance, many pyrolysis technologies reduce reliance on fossil fuels for their operation by powering the unit with syngas created from the process itself.

Although no lifecycle analysis of the GHG impact of poultry litter biochar production has been conducted, Gaunt and Cowie's (2009) analysis of the GHG impact of several types of biochar across a multitude of scenarios provides an indicative account of what poultry litter biochar production and application may offer in GHG emissions reductions.[15] First, that analysis examined the biochar production phase, which included avoided emissions from the baseline feedstock management practice, carbon sequestration during biochar production,

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[12] For an overview, see (Woolf, et al. 2009)

[13] See also (Baldock and Smernik 2002)

[14] The scale of such reductions is potentially massive – the United Nations' Food and Agriculture Organization projects that the increased use of fertilizers alone will account for a 35-60 percent increase in GHG emissions from the agricultural sector by 2030.

[15] (Gaunt and Cowie 2009)

and fossil fuel displacement due to energy produced in the process. One of the feedstocks examined in this phase was cattle manure, where the alternative management treatment was solid storage and land application (see Table 4 for a comparison of cattle manure and poultry litter characteristics).[16] The authors found that with avoided GHG emissions from the baseline management practice of 0.37 tons carbon dioxide equivalent (t CO_2e) per ton of feedstock, .58 t CO_2e stabilized in the biochar per ton of feedstock, and avoided fossil fuel emissions ranging from 0.09 – 0.18 t CO_2e per ton of feedstock, the conversion of cattle manure feedstock to biochar resulted in a net reduction of GHG emissions in the range of 1.04 – 1.13 t CO_2e depending on whether biochar replaced gas or coal (see Appendix).

Table 4. Comparable Properties of Cattle Manure and Poultry Litter Feedstocks

	Cattle manure	Broiler litter
Energy density (GJ t DM)	17	21.43
Moisture content (% FW)	38%	33%
Biochar yield (% DM)	42%	33.8%
Energy yield (GJ t DM)	2.5	4.9

Sources: Gaunt and Cowie (2009), Kim, Agblevor, and Lim (2009), and Murphy (2000).

Table 5. Net GHG Impact of Biochar Generated from Cattle Manure Feedstock over a 10-Year Period (tCO_2e/t feedstock)

		Replacing gas		Replacing coal	
		Broccoli	Maize	Broccoli	Maize
Soil impact	Low	-1.59	-1.20	-1.68	-1.29
	High	-3.19	-2.03	-3.28	-2.12

Source: Gaunt and Cowie (2009).

The analysis then moved to examine the GHG impact of the biochar application in agriculture, aggregating emissions reductions from avoided N2O soil emissions,[17] reduced field operations, fertilizer savings, and carbon capture due to increased crop productivity. In addition to examining the impact of biochar on five different crops, the study builds in a sensitivity analysis to account for the uncertainties surrounding biochar's performance in different soils by running scenarios for low, medium, and high biochar performance in the soil.[18] The authors assume a one-time application at a rate of 5 tons biochar per hectare, which is comparable to early recommendations for application rates for poultry litter biochar. In a medium-performance scenario, the total reduction in GHG emissions ranged from 0.22-1.56 t CO_2e per ha/yr, depending on the crop (see Appendix).

Table 5 illustrates the results for the estimated net lifecycle GHG impact of biochar produced from cattle manure feedstock, replacing one of two fossil fuels for energy production, and applied to two crops with varying results (represented by "low" and "high" soil impact). The negative numbers represent the magnitude tonnage of reduced CO_2e emissions per ton feedstock/ ha over a ten year period. This may give us a sense of the potential magnitude of greenhouse gas reductions achievable through poultry litter biochar production and application.

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[16] The other feedstocks examined were green waste (with three different baseline management practices) and wheat straw; however, the results for the cattle manure feedstock are clearly most relevant for the purposes here.

[17] Some data is available for the nitrous oxide impact of poultry litter biochar. Interestingly, Singh et al. (2010) found that poultry manure converted to biochar at 550°C – about the temperature of a fast pyrolysis process – significantly reduced nitrous oxide temperatures against a control in the first month of application. However, poultry litter biochar produced at a lower temperature of 400˚C actually produced an early spike in nitrous oxide emissions, followed by a level slightly under that of the control. It is possible that the lower temperature of thermal conversion does not allow as much nitrogen to be fixed and is, therefore, still available when applied to the soil.

[18] The study assumes an application rate of 5 tons biochar per hectare per year.

Box 1. Poultry Litter Gasification at the Frye Poultry Farm

Frye Poultry is a small, family-owned poultry operation in Wardensville, West Virginia that supplies broiler chickens to Pilgrims Farms. The farm hosts three 20,000 sq. ft. chicken houses, each housing a flock of about 32,000 chickens. As with other contracted growers, Frye Poultry is responsible for managing the birds' environment to stimulate the maximum growth rate, managing the manure produced by the chickens, and ultimately delivering a healthy flock.

In 2007, supported by a grant from the Natural Resources Conservation Service, Coaltec Energy installed a small-scale gasifier on the Frye Poultry Farm for converting poultry manure to biochar and ash. At capacity, the system can produce three tons of biochar per day. The costs of the equipment and installation totaled about $1 million. After running the system for several years, Frye Poultry and Coaltec have identified several potential revenue streams generated by the gasifier technology:

Benefit	Value	Notes
Energy production (fuel switch)	$40,000 - $50,000 per year	When operated the gasifier produces up to 3 MMBTU/hr of energy, enough to replace all propane previously used to heat the chicken houses.
Mortality disposal	Unclear	Chicken carcasses that would have had to have been transported off-site were instead included with the poultry litter as a feedstock. Frye Poultry's mortality rate is about 3%, equating to about 20,000 mortalities per year.
Accelerated chicken growth	$30,000 per year	Thermal energy generated by the gasifier was used to heat one of the chicken houses beyond the standard temperature. In that test case, birds reached the target weight about 2 days quicker than birds in the control houses. Consistently accelerated growth rates would allow Frye Poultry to grow an extra flock a year, worth about $30,000.
Improved animal health	Unclear	Chicken houses heated with propane would often have a higher-than-ideal humidity level, whereas the gasifier consistently maintained a desirably low humidity level (20% lower than the houses heated with propane). Frye Poultry attributed a lower mortality rate and an estimated 8% increase in growth rates to these changes. If captured in Pilgrims Farms' pay structure, this change would confer material value.
Ash/biochar	$0 - 800/ton	The price for biochar is highly variable, largely reflecting the lack of a market that can connect buyers and sellers, as well as the lack of standardization and certification for biochar products. At times, especially during the winter, Frye Poultry has been unable to sell any biochar at all.

5. Barriers to Realizing Biochar Solutions

5.1 Technological Barriers

While both commercial and scientific interest in the biochar field is strong and increasing, there are still many unknowns holding the industry back from achieving full commercialization and integration into key markets.

Biochar Production Technology

Biochar production technologies have yet to achieve full-scale production. As such, they have not shown that they are capable of producing biochar to the extent needed to supply large-scale agricultural consumers or environmental remediation sites. Likewise, it has not yet been demonstrated that efficient pyrolysis and gasification systems can be cost-effectively scaled-up and tailored to specific market conditions (Hofstetter 2011). The necessary proof-of-concept also includes demonstration that a dependable supply of feedstock is available to biochar producers.

Pilot projects in this field—especially in the specific area of poultry litter biochar—are still discovering how to control the quality of the product they produce. The state of the raw litter when it is treated (e.g., if it has been dried or separated from mortalities), the length of heating, and the temperature at which the litter is heated all contribute to define the final product. New equipment for feedstock handling and conditioning may have to be specifically developed to control quality in the sector. As the industry moves towards product standardization and differentiation, biochar producers will need to demonstrate that their process produces a consistent, marketable product with predictable chemical and physical properties.

Biochar Product Application

While it is clear that the creation of biochar transforms poultry litter's nutrients into a form that would be much easier to transport out of the watershed, the effects of biochar application are not so clearly understood. That is, despite the growing body of research on biochar, its application as an effective, efficient nutrient management practice has not been conclusively shown to the extent that it could earn either nutrient trading certification or the confidence of farmers seeking to optimize their production and profits. In order to achieve the necessary clarity on this topic, a model will need to be developed to calculate accepted nutrient reduction benefits of biochar applications within the watershed. Further research related to biochar impacts on soil chemistry, leaching, nutrient release rates, and uptake by plants – among other topics – will be required to develop such a model.

Furthermore, the value of biochar as a soil conditioner or amendment is not sufficiently understood with regard to specific biochar types and soil-crop combinations. Indeed, the wrong kind of biochar applied to the wrong soil-crop combination can produce undesirable results. To illustrate, poultry litter biochar typically has a pH of about 8 or higher, meaning that it should not be applied to a soil with a moderate or high pH. Other relevant factors to determining the compatibility between biochars and soil-crop combinations include the soil's existing water retention rates and nutrient levels as well as the nutrient uptake of specific crops. Because the characteristics of biochars vary significantly depending on the type of feedstock and technology used to produce it (see, for example, Table 3), findings from one study may not be easily generalized to a wide range of biochars or applications. Furthermore, it should be noted that in contrast to fertilizers and many other soil amendments, biochar more permanently alters soil chemistry and dynamics. This may be one of its main advantages, but it can also be one of its greatest risks. In order to identify the most effective use of each type of biochar, further testing is needed on a plethora of soil-crop-biochar combinations.

Other questions that need to be addressed include:

- What is the release rate of nitrogen and phosphorus in poultry litter biochar, and how do these rates differ by soil type? Early evidence suggests nutrient release rates from poultry litter biochar may be 95 percent slower than from raw poultry litter, while it has also been observed that the phosphorus in biochar is plant-available in acidic soils. Understanding this balance will be essential to determining appropriate application rates.
- What is the aggregate impact of poultry litter biochar on nutrient leaching from soils within the watershed?
- What is the impact of nutrient up-take by crops within the watershed? There is a large and growing body of research showing that biochar applications increase plant growth by improving the efficiency of nutrient uptake by plants. To what extent does this nutrient absorption offset the nutrients released by the poultry litter biochar itself?
- To what extent does poultry litter biochar influence denitrification?
- Under which conditions – including soil type, crop, and geography – is poultry litter biochar most effective? Biochar does not behave equally in all soil types, and results in terms of nutrient flows may vary from crop to crop. Also, some soils may not benefit or could be impaired from biochar additions, especially biochar on which tars from the pyrolysis process have been allowed to condense onto the biochar itself.
- Under what conditions is poultry litter biochar valuable to environmental remediation?
- What is the lifecycle carbon impact of poultry litter biochar produced in the Chesapeake?
- To what extent does biochar absorb ammonia in the air? I.e., what is its value compared to commercial litter additives used in chicken houses?

Safeguarding Environmental Quality & Addressing Risks

Assuming technical challenges are overcome, the nature of biochar production presents several safety and environmental concerns that would need to be addressed:

- *Environmental impacts of biochar facilities*

  To some degree, depending on the quality and design of the facility, thermal conversion technologies can present air quality concerns, and any biochar facility would have to meet both Clean Air Act and state regulatory requirements. The environmental impacts of a biochar facility would also involve emissions and traffic resulting from transporting litter to, and biochar from, the facility.

- *Risk of impairment of local water quality*

  Both EPA's nutrient trading policy and the Clean Water Act prohibit nutrient trades that would result in the violation of water quality standards. Hence, the risk of local water quality impairment is minimal if the required permitting procedures are followed and an appropriate phosphorus standard for biochar applications is followed.

- *Biosecurity risks*

  Some stockpiling of poultry litter would be expected in biochar production facilities. It will be important for operators to adhere strictly to biosecurity standards to avoid outbreak of poultry related diseases.

5.2 Economic Barriers

Ultimately, the viability of biochar as a solution to the nutrient management challenges facing the Bay will depend on the economic feasibility of biochar production. Currently, there are two fundamental barriers to market entry for poultry litter biochar production:

- *Technical risk*

  As discussed in the previous section, the ability of biochar production technologies to deliver at scale and with standardized quality assurances has not been adequately demonstrated.

- *Uncertainty in the market value of biochar products and services*

  Biochar is a new product, and much has yet to be learned about the performance of poultry litter biochar in multifarious agricultural scenarios and environmental remediation contexts. Consequently, consumer awareness and interest in biochar is very low, and a consistent market price for biochar—or biochar products—remains illusory.

  Likewise, the market currently suffers from an absence of production standardization, classification, and quality certification mechanisms. Consequently, consumer knowledge of and confidence in biochar products low, producers are uncertain about what price their product will fetch in a variety of markets, and the global market lacks transparency and fluidity. Indeed, the industry as a whole could suffer considerably "if defective or inferior products are sold by unqualified or ill-meaning producers" (Hofstetter 2011).

  Although the potential to generate revenue from the environmental services provided by biochar production is encouraging, whether these markets will be robust enough to support the types of biochar projects discussed here is highly uncertain. Worldwide, carbon markets are in limbo, and it is not clear that state-level nutrient trading markets in the Chesapeake will be regulated tightly enough to generate the type of demand needed to bring biochar projects into the fold. Furthermore, gaps in scientific knowledge about the precise impacts of biochar on both greenhouse gas emissions and nutrient flows will impede efforts to create a credible, systematic methodology for incorporating biochar production into these markets.

As a result of these risks and uncertainties, investors are cautious about poultry litter biochar production, or even the very research that might allow these barriers to be overcome. However, the success of similar business models utilizing manure for energy and fertilizer production (particularly, the Perdue AgriRecycle facility discussed in Section 3) indicate that these economic challenges are surmountable.

5.2.1 Potential Revenue Streams

This section examines the potential value of multiple revenue streams for poultry litter biochar enterprises as well as the general costs incurred by biochar facilities. The figures presented here are broad estimates based on indicative or anecdotal information. Moreover, variables such as facility size, feedstock source, and end-product differentiation can affect the costs and revenues of biochar operations enormously.

As discussed above, biochar creates value in nutrient management (by transforming nutrients into manageable forms, by reducing the need for chemical fertilizers, and by supplementing animal feed) and in other areas (such as environmental remediation, carbon sequestration, and renewable energy production).

Table 6 identifies some of the revenue streams that may be available to a poultry litter biochar producer. It should be noted that this is not an exhaustive list of potential revenue streams; see, for example, Box 1 for a discussion of a specific case study that benefited from alternative, site-specific revenue streams. Some revenue streams are complementary and can be "stacked." However, in most enterprises the biochar producer will choose to optimize one product or service (e.g., energy production or biochar for environmental remediation), thereby incurring the opportunity costs of revenues that could have been realized or maximized in other streams. Each revenue stream value is calculated assuming that the operation is maximized for that value stream, and all values are converted into comparable units of dollars per ton of poultry litter feedstock.[19] Importantly, this method of reporting the value of the final biochar product should not be construed as an appropriate value of the poultry litter feedstock itself; we merely use this convention to compare revenue potential without regard to the costs of material handling, thermal conversion, processing, marketing, transportation, etc.

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[19] In calculating these conversions, we assume that one ton of undried poultry litter converts to .4 tons of biochar.

Table 6. Value Estimates for Major Poultry Litter Biochar Revenue Streams
(per ton poultry litter feedstock)

	Product/Service	Near-term market value	Notes
Nutrient management	Biochar applied as a soil conditioner, soil amendment, or composting additive	$115	If biochar-amended soils require 50% less chemical fertilizer, the savings in avoided fertilizer application would be in the range of $270-$300 per ton of biochar, or $115 per ton of feedstock. This price may be higher for organic agriculture markets, which may pay a premium for the plant-available, organically-produced phosphorus in the biochar. The additional value of water retention qualities may raise this price further, especially for markets such as golf course turf.
	Feed supplement	$0	Small-scale biochar producers – or commercial producers' feedstock suppliers – can use biochar as a feed supplement for broiler chickens and other livestock. However, the authors are not aware of any established market price for biochar in this regard.
	Nutrient credits	$344-688	Early prices for nitrogen credits in Chesapeake trading programs range from a weighted average of about $5.50/lb in Pennsylvania to $11/lb (as a market relief price[20]) in Virginia. Broiler litter contains 62.58 lbs nitrogen/ton.[21]
	Environmental remediation	$150-200	As discussed in Section 4.1.4, biochar may add significant value to environmental remediation activities. One researcher at the USDA Economic Research Service estimates this value at $2/lb of biochar (or $1600 per ton feedstock);[22] however, the experimental nature of current applications to remediation sites dictates a much lower near-term price.
Co-Benefits	Electricity production (net metering)	$409.46	Positing that poultry litter exhibits similar properties to cattle manure, we assume that poultry litter has a moisture content of 33% (see Table 3) and an energy yield of 2.5 GJ per ton dry feedstock (see Table 6). This correlates to 430.5 kWh per ton (wet) poultry litter. We also assume a price of electricity of $0.951/kWh, the average retail price in South Atlantic states in December 2010.[23] Depending on their electric company, facilities connected to the grid in Chesapeake states may be eligible for these net metering credits (see Section 4.1.4).
	Electricity production (bulk power)	$8.61	Here we use the same assumptions as above but substitute a standard bulk power price of $0.02/kWh.
	Renewable energy subsidies/credits	$9.04 - 45.63	The federal renewable energy tax credit provides $0.021/kWh for renewable energy, such as that produced by a biochar facility (see Section 4.1.4). Additionally, the credits are available to some biomass-sourced renewable energy producers in Virginia (at a rate of $0.0561/kWh) and Maryland ($0.085/kWh).
	Heat production (on-site fuel switch)	$7.34 - $44.04	When used as an on-site fuel, the revenue from energy production is the avoided cost of purchased fuels. The given range is based on an assumed price of natural gas of $5/MMBTU and propane of $30/MMBTU.
	Carbon credits	\$4.80 – 26.24	Moderate prices in the voluntary carbon markets—as will be discussed in Section 5.3.2, the only markets that would support biochar projects in the near term at all—traded in 2009 at a rate of \$4-8/tCO$_2$e (Hamilton, et al. 2010). We apply this price to estimates for the lifecycle GHG impact of cattle manure biochar (discussed in Section 4.1.4), which range from 1.2 to 3.28 tCO$_2$e in avoided emissions per ton of feedstock.

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[20] Entities regulated under the Virginia nutrient trading market that fail to meet their required emissions reductions through either on-site or offset means have the option to pay a penalty into the state's relief fund, which is in turn used to fund pollution-reduction activities.

[21] (Pelletier, Pease and Kenyon 2001)

[22] (Peabody 2005)

[23] (U.S. Energy Information Administration 2011)

Product/Service	Near-term market value	Notes
Bio-oil or syngas as fuel	$141.12	Bio-oil can be marketed as industrial heating oil with a value of about $1.68 per gallon. A refining upgrade to fuel oil for residential heating, power generation and vehicle use could bring the value up to about $2.26 per gallon; however, multiple refining stages and handling considerations make this option rather uneconomical (Hofstetter 2010). Fast pyrolysis produces about .45 tons of bio-oil per ton feedstock (Agblevor, et al. 2010, 300), and the density of bio-oil is estimated at about 10 gallons/ton.
Biochar/ash as litter amendment	$0	Biochar used in the same quantity as commercial poultry litter amendment has demonstrated, in at least one instance, the ability of the porous biochar to absorb ammonia and promote denitrification in chicken houses. If used on-site, this could represent a cost savings of about $500 per ton commercial amendment, or about $200 per ton feedstock. However, the authors are not aware of any instances where poultry litter biochar has been traded for this purpose.

5.2.2 Costs of Biochar Production

The costs of running a biochar production facility include start-up equipment and installation costs, operation costs (including labor and fuel costs), transportation costs, and product processing and marketing costs. These will vary considerably based on the size and efficiency of the facility, the target or service for which the facility is optimized, the amount of labor required to run the facility, the distance that feedstocks must be transported to reach the facility, and so on. Though a full analysis of costs of a hypothetical facility is beyond the scope of this paper, we can examine the range of values for two of the most significant cost categories: capital and transportation.

Table 7. Estimated Capital Costs for a Poultry Litter Biochar Facility

	Small scale / Farm use (~1k tons/yr)	Large scale / Commercial use (~6k tons/year)
Pyrolyzer	$300,000	$2-4 million
Gasifier	$600,000	$1.5 million

Capital costs include all of the equipment and installation costs of pyrolysis and gasification systems and can vary significantly. At a commercial level, the cost for building a 2 ton per hour fast pyrolyzer is estimated at $2-4 million (Brown, Wright and Brown 2010). Further estimates, based on the expertise of the authors and contributors, are reported in Table 7.

Transportation costs include hauling the poultry litter feedstock from farms in the watershed to the production facility and then transporting the biochar product to farms either in or out of the watershed for application – or to a disposal site. For the analyses here, we estimate that the cost of transporting both poultry litter and biochar in an 18-wheeler walking trailer with a 25-ton capacity is about $0.40 per ton-mile, without a backhaul (McGolden 2011). If poultry litter is sourced from within the watershed and the biochar is also applied in the watershed, within a 50-mile radius of the production facility, we estimate that transportation will cost about $28.00/ton. On the other hand, if the poultry litter is sourced within the watershed but transported out of the watershed an average of 500 miles – about the distance necessary to reach major corn-producing regions in the Midwest, the total procurement and distribution transportation costs would reach $100/ton.

If the biochar production facility were incorporated into existing state subsidy systems for poultry litter transportation, these costs may be somewhat mitigated. As current subsidy rates range from $5 to $18 (see

Section 3), a biochar production facility able to recover $12 for transportation costs could recover a significant amount of the costs – nearly half of those in the first scenario.

Despite the seemingly large start-up costs, biochar production (and application or even simple shipment for safe storage outside of the watershed) is a potential game-changer for cost-effective nitrogen mitigation in the Chesapeake Bay. Figure 16 illustrates the relative mitigation costs, in dollars, of a ton of nitrogen across various sectors and practices. By far, the most expensive way to mitigate nitrogen pollution is to retrofit storm water systems or wastewater treatment plants (WWTPs) with new technologies – these practices range in costs from $15.80 to over $200 per ton, on an annual basis. In contrast, improved agricultural management is a much more cost-effective option. Even still, biochar production has the potential to be one of the cheapest mitigation options available, second only to restoring or constructing wetlands.

Table 8 shows the cost analysis of one hypothetical scenario of biochar production that is represented in Figure 16. Here, a relatively small-scale pyrolysis unit with capital costs of $500,000 and a 10-year lifetime processes 2,000 tons of poultry litter per year. The biochar is transported to the site from within a 50-mile radius and then transported out of the watershed 500 miles. The producer pays $15 per ton for the raw poultry litter, roughly what poultry farmers are able to receive now for land applications. Without accounting for *any* potential revenue streams, the cost of nitrogen mitigation through biochar production and transportation out of the watershed is $2.91 per pound of nitrogen.

Table 8. Estimated Costs for Hypothetical Biochar Producer

	Cost per unit	Annualized cost
Capital costs – Small, fast pyrolysis unit with 10-year lifetime	$500,000	$50,000
Operating costs (annual, processing 2,000 tons feedstock per year)	$40,000	$40,000
Transportation costs (raw litter to plant and biochar out of watershed, 500 miles)	$0.40/ton-mile	$200,000
Raw litter	$15/ton	$75,000
Total annual cost		$365,000
Annual cost per ton poultry litter		$182,500
Annual cost per pound N[1]		**$2.91**

Indeed, the fact that biochar production is able to generate revenue streams additional to any generated through nutrient credits or mitigation subsidies sets it apart as a real opportunity for change. There are too many possible financing strategies for biochar production to go into here, however, considering the various combinations of technologies, costs, target markets, and scale that are could form a viable biochar business strategy. Readers who are interested in exploring these different possibilities may consult the economic model available alongside this publication at http://forest-trends.org/publications.[24]

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[24] We have endeavored to make transparent our assumptions and underlying calculations on subsequent pages of the model workbook, but readers should note that these are rough estimations that will clearly vary in local contexts and conditions.

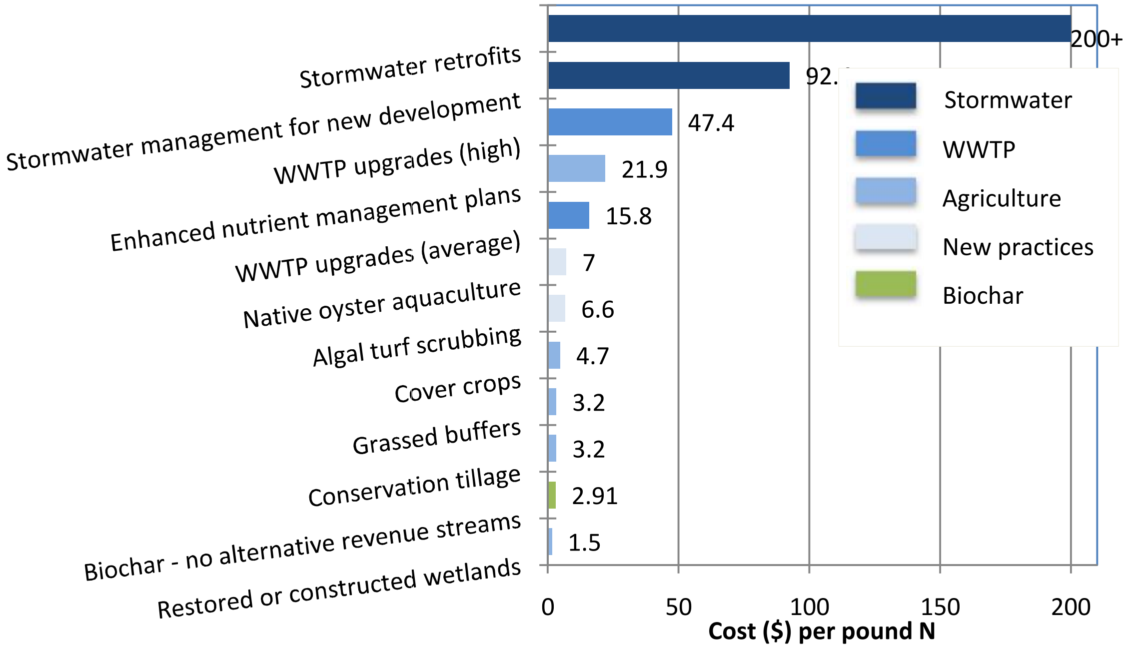

Figure 16. Relative Costs of Nitrogen Mitigation by Sector and Practice.
Adapted from Jones et al. (2010), with original analysis.

5.2.3 Overall Analysis of Benefits and Costs

The small sample of promising success stories in the biochar industry typically involves the development of a niche product and the maximization of multiple revenue streams. Most often, no single revenue stream can alone support the biochar operation; moreover, because the market for biochar and derivative products—like nutrient and carbon credits—are so young and underdeveloped, investors will seek to hedge risks by targeting multiple revenue sources. A market survey conducted in 2010 found that 72 percent of private-sector biochar technology producers considered co-benefit production—particularly from process heat and bio-oils—to be a "significant focus" in the design and manufacture of their equipment. The same study found that 40 percent of private-sector biochar producers expected these co-products to bring in more revenue than the biochar itself (Hofstetter 2011).

Critically for biochar project developers, to the extent that biochar enterprises *can* capitalize on these multiple revenue streams, they do not have to recover all costs in any single market. Many studies that have previously examined the economic feasibility of different litter-to-energy technologies have failed to recognize this, focusing exclusively on energy revenues.[25] However, the sum of these multiple revenue streams over time may justify the relatively large start-up and operating costs incurred by a biochar operation.

5.3 Policy Barriers

Just as markets are only beginning to be able to recognize its value, biochar is likewise a new tool to arena of nutrient management policy. As such, it faces significant barriers to entry: for instance, where it could contribute materially to nutrient management – if only by making it easier to ship poultry litter out of the

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[25] See, for example, (Antares Group, T.R. Miles Technical Consulting, Inc., and Foster Wheeler 1999).

watershed – it is not supported as a Best Management Practice. Furthermore, as individual poultry growers – rather than corporate poultry integrators – own the manure that the integrators' chickens produce under their care, poultry integrators have little incentive to capitalize on their resources, contacts, and systems to productively utilize the millions of tons of excess poultry manure produced annually in the Chesapeake. The most important policies for catalyzing biochar production, however, have to do with properly valuing the environmental services it generates – particularly with regard to water quality.

5.3.1 Nutrient Trading Market Barriers

Impediments to Certification

Although EnergyWorks has secured certification for nutrient trading credits based on a proposed poultry litter gasification plant in Pennsylvania, the certification is contingent on removal of the biochar and ash from the watershed. No procedures for biochar application are recognized yet in any Chesapeake nutrient trading markets as an eligible nutrient offset, and the case for nutrient offset certification for biochar application in the watershed will have to be based on substantial, peer-reviewed evidence of reduced nutrient loading in the Bay. Maryland offers a nutrient trading program by which new technologies – such as biochar production – can be phased into the scheme, where credits from new technologies may be certified at a 4 to 1 ratio (i.e., credits would be worth 25 percent of those produced by an accepted point-source polluter, such as a wastewater treatment plant). This system may serve as a starting platform for certifying biochar application under nutrient trading, provided the effects are studied to verify the actual impacts on nutrient flows in the watershed.

Generous Caps

As discussed earlier, nutrient trading throughout the region suffers from a lack of demand; currently, point source polluters such as power plants and waste water treatment plants are able to comfortably meet their regulatory obligations by trading with each other. Specifically, the markets only require WWTPs to offset new or expanded loads—even new facilities that are established to take over the load of an existing, but retiring, plant need not be offset (see Table 1 for details on the regulations affecting the purchase of offsets under state nutrient trading markets). In Maryland, regulators have set a total load cap for wastewater treatment plants high enough that plants are likely to remain in compliance for at least a decade through investments at the plant and nutrient trading with other treatment plants. To increase demand for nutrient trading, regulatory bodies in the watershed will have to either lower the cap on allowed nutrient emissions or include more polluters under the existing cap.

Baseline Requirements

In order to sell credits under a nutrient trading scheme, agricultural enterprises (which are not currently regulated/capped under the current nutrient trading markets) are required to meet baselines determined either by the TMDLs or another, practice-based state regulatory framework. As long as biochar production falls under the purview of manure management, it will likely not qualify for credits, since this is ostensibly covered by currently-required (but hardly enforced) nutrient management plans. To the extent that biochar production will qualify for credits, it will have to show that the biochar is shipped out of the region or that less fertilizer (i.e., nutrients shipped in from outside the watershed) is applied as a result of improved soils from biochar application.

Furthermore, it is critical to note that in two of the four state nutrient trading markets, BMPs that are supported by state and/or federal funds are ineligible for credits, although state and/or federally-financed BMPs may be used to meet baseline requirements. As such, any policies that aim to bring biochar into the fold will need to account for whether they will be most appropriately supported by such cost-share funding or by credits.

5.3.2 Carbon Market Barriers

For biochar projects to access carbon revenues, biochar-derived carbon offsets must be approved under the UN Framework Convention on Climate Change (UNFCCC), written into national-level cap-and-trade legislation, or validated under voluntary carbon standards. Efforts are under way to include biochar in each of these mechanisms, with earliest recognition likely to come from voluntary markets. Carbon War Room and its partner organizations are sponsoring the development of carbon accounting methodologies under the Verified Carbon Standard through an initiative known as the Biochar Protocol (www.biocharprotocol.org). These efforts, however have been somewhat curtailed by the lack of evidence available on the GHG impact of biochar—especially the mean residence times of the carbon stored in biochar for different feedstocks and under different conditions. If reasonable consensus on biochar carbon accounting is reached, even if carbon prices alone may not be sufficient to drive biochar production, carbon markets will become a valuable revenue stream for biochar projects.

6. Conclusion and Recommendations

The thermal conversion of poultry litter into biochar and various forms of energy appears to represent one of least cost means of reducing or eliminating the impact of this waste stream on the health of the Chesapeake Bay. This would reduce nitrogen pollution by 6 percent and phosphorus pollution by approximately 9 percent.

The viability of this nutrient management solution can be enhanced by leveraging fertilizer and soil conditioning markets through the production of biochar, while satisfying some of the region's energy needs. Carbon markets, nutrient trading, and environmental remediation may provide additional revenues to improve the financial feasibility of biochar production. Currently, however, uncertainties about the production technology, the precise value of poultry litter biochar to specific applications, and the policy and market environment are preventing poultry litter biochar from achieving viability.

Following discussions with a range of key stakeholders and experts in the field, the authors have identified five intermediary goals (outlined below) critical to appropriately valuing the environmental services provided by poultry litter biochar and attracting sustainable, private capital to poultry litter biochar production in order to ultimately deliver poultry litter biochar as an effective, efficient solution to nutrient management in the Chesapeake Bay watershed. The Recommendations Roadmap (Box 2) illustrates the relationships between these goals, associated needs, and key interventions that policymakers, regulators, researchers, and private sources of capital can support.

- *Demonstrate the viability of poultry litter biochar technologies in the Chesapeake context.*

  Confidence in the ability of biochar production technologies to deliver regionally-appropriate products at an economically-viable scale will—to some extent—build upon lessons learned through trial and error. Existing programs that support pilot projects like the gasification unit installed at the Frye Poultry Farm (see Box 1) or larger-scale projects like the EnergyWorks litter-to-energy plant in Pennsylvania, such as NRCS's Conservation Innovation Grants and state funding programs, should be complemented with programs that aim to identify common lessons learned and market-wide implications from the experiences and data drawn from those pilots. Similar programs may explore the viability of biochar production technologies at various scales.

- *Establish the value of reliable revenue streams from poultry litter biochar products and services.*

  Products and services associated with biochar production must generate some combination of reliable revenue streams that, together, justify investment in biochar production technologies. Before savvy entrepreneurs can construct a viable business plan that strategically leverages biochar production in this way, however, we must have a better understanding of the value of poultry litter biochar to multiple applications, including in agriculture as a soil conditioner and/or an organic soil amendment and in environmental remediation sites.

  In order to ensure that this research is conducted efficiently and effectively, private, public and academic research efforts should be coordinated across the region to maximize their practical impact. A similar program in Colorado has been successful at encouraging research on a specific set of types of wood-based biochar across a given set of indicators, thereby creating a more comprehensive set of comparable data that addresses the needs and realities of that location. The Chesapeake Bay Program would be an ideal focal point for such coordination.

  Moreover, existing policies for sustainable nutrient management can be modified to incentivize productive research for new technologies in this space. For instance, the current provision in Maryland that allows new, “unproven” technologies (like biochar application) to be certified in the state’s nutrient trading market at a 75 percent discount could be altered to allow revenues generated beyond the 25 percent benchmark to be conditioned on conducting coordinated research on biochar application and sharing monitoring data.

- *Increase end-user knowledge of and confidence in poultry litter biochar products.*

  While confidence in poultry litter biochar products and services will increase (as appropriate) with more and better coordinated research efforts, consumer confidence in these products will require a systematic, transparent way of differentiating between different kinds and qualities of biochar.

  The International Biochar Initiative is currently developing an early-stage standardization and certification prototype that is scheduled for publication in late 2011. The certification program should raise awareness in the market about biochar products and instill confidence in consumers about the basic qualities of the products. Furthermore, it will, in later phases, allow for product differentiation and recommendations for product application.

  Efforts such as those underway by the International Biochar Initiative (IBI) to certify biochar according to standardized criteria are essential to the market deployment of biochar and should be supported.

- *Integrate poultry litter biochar into robust state nutrient trading markets.*

  In order to appropriately value the nutrient management services provided by poultry litter biochar, these services must be more clearly understood, and the mechanisms through which they can be valued must function well. State-level nutrient trading markets are promising tools for managing nutrient loads, but in their current nascent stage there is a dearth of both confidence and demand. Public and charitable entities could inspire confidence in these markets by purchasing early credits, as is currently being done by the Chesapeake Fund, or guaranteeing a floor price for offset credits. Demand can be increased by lowering the market caps by, perhaps, integrating larger scale agricultural entities – such as CAFOs – into the regulatory framework as point-sources with requirements for offsetting a portion of their nutrient loads through improved non-point agricultural practices.

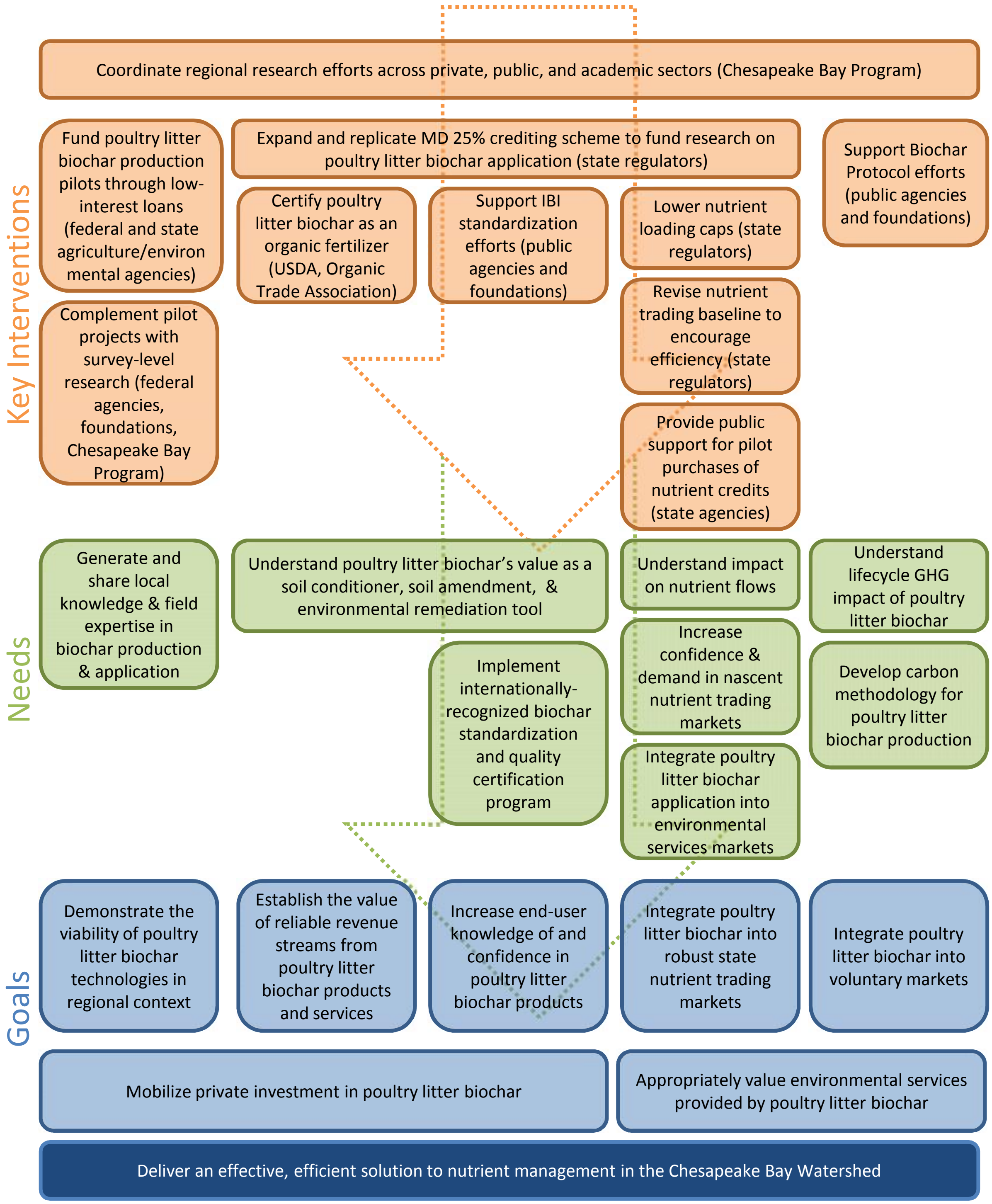
  Likewise, states should consider altering the standard for additionality from meeting baseline requirements – defined as the implementation of practices or the achievement of targets that (many recognize) are unlikely be met in any scenario – to one that requires the entity seeking to generate credits to prove that the project would not have been viable without the financing provided by the credits.

In addition to improving the efficiency of state-level nutrient trading markets, the application of poultry litter biochar should be considered for integration into these markets, perhaps following the integration model set by the Maryland trading program. That would require not only a better understanding of the impact of such application on nutrient flows in the watershed—informed by data from research supported by crediting schemes and coordinated efforts discussed above—but also a way to account for the avoided nutrient inputs attributable to biochar application.

- *Integrate poultry litter biochar into voluntary carbon markets.*

  In order to value the environmental services that poultry litter biochar production and application would provide to the climate, a standardized methodology for calculating the lifecycle impact of (poultry litter) biochar would have to be developed and accepted by a major voluntary market certification system, such as the Verified Carbon Standard. Development of such a methodology principally requires a better understanding of the mean residence times of the carbon captured in biochar produced and stored under varying conditions. International research on this front can be complemented by regional efforts that examine the specific attributes of poultry litter biochar applied to local soils. Furthermore, the efforts of the Biochar Protocol to develop a methodology that would allow biochar to be integrated into voluntary or compliance carbon markets likewise merits support from public and private funding sources.

Box 2. Recommendations Roadmap



Key Interventions

Coordinate regional research efforts across private, public, and academic sectors (Chesapeake Bay Program)

Fund poultry litter biochar production pilots through low-interest loans (federal and state agriculture/environmental agencies)

Expand and replicate MD 25% crediting scheme to fund research on poultry litter biochar application (state regulators)

Support Biochar Protocol efforts (public agencies and foundations)

Certify poultry litter biochar as an organic fertilizer (USDA, Organic Trade Association)

Support IBI standardization efforts (public agencies and foundations)

Lower nutrient loading caps (state regulators)

Revise nutrient trading baseline to encourage efficiency (state regulators)

Complement pilot projects with survey-level research (federal agencies, foundations, Chesapeake Bay Program)

Provide public support for pilot purchases of nutrient credits (state agencies)

Needs

Generate and share local knowledge & field expertise in biochar production & application

Understand poultry litter biochar's value as a soil conditioner, soil amendment, & environmental remediation tool

Understand impact on nutrient flows

Understand lifecycle GHG impact of poultry litter biochar

Implement internationally-recognized biochar standardization and quality certification program

Increase confidence & demand in nascent nutrient trading markets

Develop carbon methodology for poultry litter biochar production

Integrate poultry litter biochar application into environmental services markets

Goals

Demonstrate the viability of poultry litter biochar technologies in regional context

Establish the value of reliable revenue streams from poultry litter biochar products and services

Increase end-user knowledge of and confidence in poultry litter biochar products

Integrate poultry litter biochar into robust state nutrient trading markets

Integrate poultry litter biochar into voluntary markets

Mobilize private investment in poultry litter biochar

Appropriately value environmental services provided by poultry litter biochar

Deliver an effective, efficient solution to nutrient management in the Chesapeake Bay Watershed

Appendix

Table 9. GHG Impact (tCO_2e per t feedstock) of Biochar Production from Cattle Manure Feedstock

	Replacing gas	Replacing coal
Conventional feedstock management (cattle manure: solid storage, land spread)		
CH_4	0.00	(same)
N_2O	.37	(same)
C stored in biomass	0.00	(same)
Feedstock pyrolyzed for biochar and energy		
Net emissions from electricity: fossil fuel substitution	-0.09	-0.18
C stabilized as biochar	-0.58	(same)
Net emissions (Pyrolysis - Conventional feedstock management)	-1.04	-1.13

Source: Gaunt and Cowie (2009).

Table 10. GHG Impact (tCO_2e per t feedstock over 10 years) of Biochar Agricultural Application

Assumed application rate: 5t/ha.

		Canola	Broccoli	Wheat (UK)	Maize	Wheat (Aus.)
N_2O emissions	Low	-0.02	-0.52	-0.19	-0.13	-0.03
	Medium	-0.04	-1.10	-0.39	-0.26	-0.04
	High	-0.06	-1.77	-0.63	-0.42	-0.07
Field operations	Low	0.00	0.00	-0.01	0.00	0.00
	Medium	0.00	-0.01	-0.02	-0.01	0.00
	High	-0.01	-0.02	-0.04	-0.03	0.00
Fertilizer savings	Low	-0.03	-0.13	-0.09	-0.06	-0.03
	Medium	-0.06	-0.26	-0.18	-0.12	-0.07
	High	-0.09	-0.39	-0.27	-0.18	-0.10
Carbon capture	Low	0.00	0.00	0.00	0.00	0.00
	Medium	-0.11	-0.19	-0.28	-0.28	-0.14
	High	-0.23	-0.38	-0.55	-0.55	-0.28
Total	Low	-0.05	-0.66	-0.28	-0.19	-0.06
	Medium	-0.22	-1.56	-0.87	-0.67	-0.25
	High	-0.39	-2.57	-1.49	-1.18	-0.45

Source: Gaunt and Cowie (2009).

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