CHAPTER 3:

Recommended Funding Strategies

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OVERALL STRATEGY

Major Priority Areas

To address the challenges and opportunities identified in Chapter 2 and maximize the benefits that biochar can provide to communities across the region, nation, and globe, we recommend that private, governmental, and philanthropic investments be directed towards four major areas. First, a **long-term coordinated program of research** is needed to help resolve the remaining scientific and engineering knowledge gaps with respect to biochar production, use, and climate impact. Transfer of this knowledge to practice, however, will require equally important efforts to 2) conduct **near-term, market-focused research** on issues related to regional implementation and expansion of biochar markets, 3) strengthen the **infrastructure to support business** by providing financial tools and incentives, a trained workforce, and an engaged customer base, and 4) collaboratively develop **environmental regulations and ecosystem-service-pricing policies** aligned with biochar technology. Success in all four of these priority areas will require **engagement with the public**, both to educate them with respect to the many benefits of biochar technology and to listen to their suggestions and concerns. Based on this engagement, the research, economic, and policy agendas we propose here will need to be continuously updated to ensure the broadest public support for the adoption of sustainable and climate-friendly biochar technology.

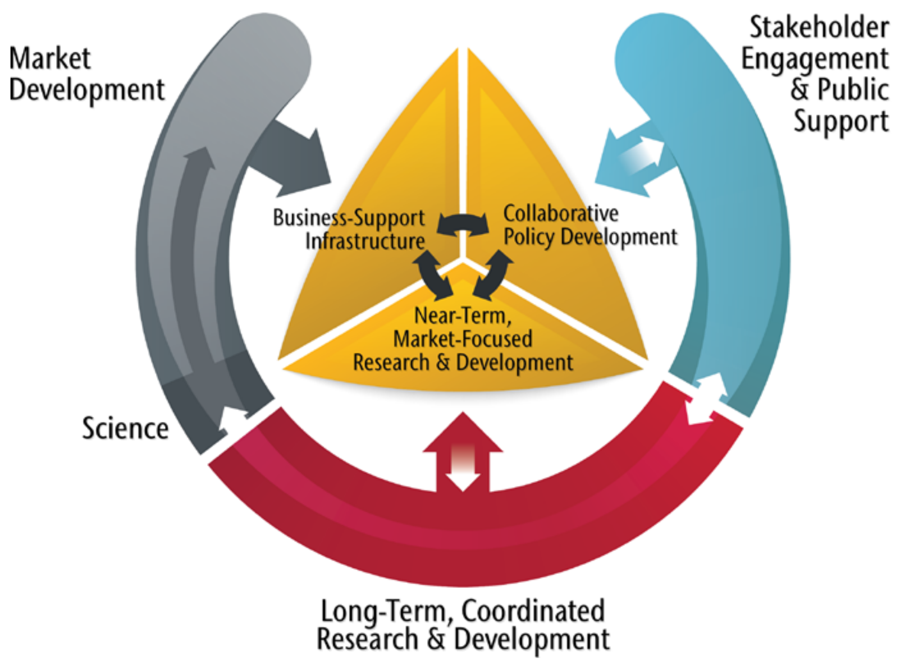

Figure 3.1. *Conceptual diagram of the relationships between the four major priority funding areas recommended by the workshop. Long-term coordinated research & development (in red) provides the foundational science and engineering needed to support development of biochar technology. Three closely related areas, shown in yellow, focus on different activities needed to develop markets for a sustainable biochar-based industry. The grey arc on the left shows the transition in focus of the proposed work from foundational science and engineering to market development. The blue arc on the right shows the level of stakeholder engagement and public support required for the proposed work to succeed. (Figure: Andrew Mack)*

Roadmap

The relationship between these four priority areas is illustrated in Figure 3.1. The **long-term (decades-scale) coordinated research program** provides the scientific and engineering foundation for biochar technology. As currently envisioned, this program could be national or international in scope and would involve coordination among a series of regional sites devoted to understanding the science and improving the climate-, energy-, labor-, and capital-efficiency of biochar technology. An advisory council composed of representatives of various stakeholder groups would help guide the program. Novel engineering approaches would be developed and tested. An improved understanding of the biophysical processes involved in biochar production and use would be developed. The fundamental knowledge generated would be used to improve models of biochar reactor designs and plant response to biochar amendments, to develop life cycle assessments of net climate impact, and to construct techno-economic pathways and macro-economic scenarios for adoption of biochar technology. A knowledge consolidation and extension effort would ensure that the new information generated by the program would be readily available to biochar technology practitioners, government agencies, and the general public.

This knowledge developed in the more fundamentally focused long-term research program would also help guide **near-term (one to three year) research efforts aimed at overcoming barriers to market development**. These efforts would 1) develop protocols and specifications to ensure product consistency and appropriate use of biochar, 2) construct and apply algorithms to assess the market value of ecosystem services provided by the application of biochar technology, and 3) measure environmental emissions factors associated with biochar production to help refine regulatory approaches. A fourth major category of near-term research would largely focus on regional market development and include pilot-scale demonstrations of biochar technology. Specific markets would include prescriptive applications of biochar to agronomic, silvicultural, horticultural, range management (Figure 3.2), and livestock systems to solve specific problems. Others would include applications of biochar technology for fire-hazard reduction, land reclamation and restoration, co-composting of municipal and agricultural waste, environmental filtration of contaminants from waterways, and the development of new high-value C-based materials.

The results of the near-term research efforts would inform, enable, and be responsive to the other two major funding priority areas shown in the center triangle of Figure 3.1. Funding to **develop and strengthen the support infrastructure for business** would focus on three areas: 1) direct assistance to businesses to develop partnerships and to provide planning tools as well as technical, regulatory, and financial aid, 2) training of a diverse workforce, and 3) engagement with potential customers (including retail nurseries and garden centers as well as potential biochar end users) through marketing research and

Figure 3.2. *Field plots to measure the influence of juniper biochar on the establishment of bunchgrass in rangeland are installed at Six Shooter Ranch in Mitchell, Oregon. (Photo: Marcus Kauffman)*

the subsequent development of customer awareness campaigns. Implementation of business-support infrastructure would involve strengthening existing biochar industry trade organizations such as the *International Biochar Initiative* and the *United States Biochar Initiative*, as well as potentially endowing an entirely new organization (analogous in many ways to the *United States Endowment for Forestry and Communities*) to promote biochar-based community development activities.

Funding for the fourth major priority, **collaborative development of policy related to biochar technology,** would focus on development of 1) robust pricing mechanisms to pay biochar practitioners for the ecosystem services they provide, and 2) appropriate environmental permitting instruments related to biochar production. As indicated in Figure 3.1, a key aspect of this funding effort would be the engagement and formation of partnerships with a wide range of potential stakeholders as well as the general public to develop specific policies.

In the remainder of this chapter, we provide further details regarding the four major investment priorities recommended by the workshop. Some of these concepts are best funded by philanthropic organizations, others by national, state, or local governmental agencies, and still others by private capital. To identify our assessment of likely funding entities we have provided one or more icons at the start of each concept description, with the first icon listed being the most applicable to a specific concept. These are:

- P Philanthropic organizations
- N National governmental agencies
- S State/Provincial governmental agencies
- L Local governmental agencies
- C Private capital

LONG-TERM MULTI-SITE COORDINATED RESEARCH PROGRAM

N S P C

Rationale

Although natural wildfires have generated charcoal for about 420 million years [26] and humans have been making charcoal from biomass for tens of millennia, either intentionally [3] or inadvertently [11], the concept that biochar could be produced deliberately for use as a tool to mitigate climate change while increasing biomass productivity has been around for less than three decades [12, 14-16, 27, 29, see supplementary note in 33]. The past two decades has seen an explosion in research devoted to this topic [34], but much of the research is of a short-term nature and significant knowledge gaps remain. If research were to continue to proceed "organically," several decades might pass before these gaps were closed given the complexity of the field (multiple sources of biomass, methods of biochar production, soil types, and potential plant systems to consider). Given the urgency of climate change and the potential contribution that biochar can make to its mitigation, the consensus of the workshop is that the organic approach is a luxury we cannot afford. Consequently, **we recommend that a decades-long coordinated multi-site research and development program implemented at a national (or even international) scale would be the fastest way to close the fundamental scientific and engineering knowledge gaps** and thereby provide the knowledge needed to address the key economic and policy challenges discussed in Chapter 2.

First, we discuss three broad research areas to be addressed by the proposed program: engineering, biophysical processes, and model development. We then describe a knowledge consolidation and extension effort to ensure that the information developed by the research effort is shared as widely and efficiently as possible. Finally, we describe some initial thoughts about program structure and governance.

Research Topics

Engineering

Two of the key challenges addressed by engineering are lowering the cost and improving the overall climate impact of the biomass-to-biochar conversion process.

Lower cost will be achieved by improving the efficiency of 1) biomass harvest and handling, 2) biochar production, handling, and post-production processing, 3) capture and utilization of bioenergy generated during biochar production, and 4) biochar application. The first three of these activities lend themselves well to vertical integration, that is, the design of equipment to maximize biochar/bioenergy production efficiency from biomass harvest through post-production processing of biochar. An example of how this might be done with woody biomass feedstocks is given in the sidebar *"Designing Sustainable Biochar Systems"*.

Application of biochar is another area where engineering can lower costs while ensuring proper and safe placement of the biochar. The optimum methods of application will differ for agronomic, horticultural, forested, and grassland sites (Figure 3.3). Although the nature of the application site will largely dictate the design of application equipment, the ability to accommodate biochars prepared from different biomass sources by different methods and to integrate with existing agricultural and forestry equipment will likely be important secondary design considerations.

To improve the climate impact, engineering will largely focus on optimizing the production process to increase C efficiency (the fraction of biomass C that ends up in the biochar) and decrease the amount of CH_4 and soot released to the atmosphere. The quality of the biochar produced matters also—the more stable the biochar is to oxidation once in soil, the greater the C sequestration potential and better the climate impact. Engineering is needed to develop biochar production equipment that optimize these design criteria for different scales of operation—ranging from the landscape scale encountered with small landholdings and farms, through moderate-scale production at forest landings, to large-scale production at centralized facilities. This work will require close coordination between development of theoretical pyrolysis reactor designs and the construction and testing of pilot-scale pyrolysis reactors to validate these designs.

Figure 3.3. *Broadcast application of mixed-wood biochar on the Armstrong Memorial Research and Demonstration Farm near Lewis, Iowa. (Photo: David Laird)*

Designing Sustainable Biochar Systems

In 1992, the Hannover Principles for sustainable design were first published [17]. A full example of the application of these principles is given as Scenario 1 in Chapter 5. The goals are to approach the minimum theoretical energy consumption and maximize the C content of the biochar while closing the materials and energy balance for the entire biomass to biochar system.

Scenario 1 includes the following steps: 1) gather intact biomass and transport it by baling or bundling to the production site; 2) for conversion to biochar, crush the biomass into ¼-inch diameter scrim using rollers followed by cross-shearing; use screening to remove oversized pieces (for re-crushing) and fines containing soil (for mulch); 3) locate the biochar production system at the forest landing and only move it, if at all, every few weeks to months; 4) dry the sheared scrim using exhaust gases from the pyrolyzer and condense the water vapor (after filtration to remove terpenes as a product stream) for subsequent use to quench the biochar; 5) design the pyrolyzer to run continuously at a feed rate of 1-5 tons per hour, maximize biochar-C efficiency, and to operate across a range of temperatures and feedstock sizes so that a variety of tailored biochar products can be made; 6) incorporate the ability to apply functionalizing agents to the feedstock, before pyrolysis, or to the biochar during the quench process; 7) when cool, package the biochar in supersacks for shipment to a central warehouse for final processing and distribution to customers.

Another example of these principles applied is the Biomass Utilization Campus (BUC) described in Chapter 6. Briefly, a BUC is an integrated processing facility to convert solid wood and residues to a variety of value-added products including biochar. It allows for multiple industries to share the cost of harvesting and transportation. Dimensional lumber, round timbers, post/pole, fiber logs, kiln dried firewood, beauty bark and mulches can be produced while residues from these processes can be converted to energy and biochar, all in a centralized facility. ■

Biophysical Processes

The primary focus of research into the biophysical processes that operate in managed and natural ecosystems will be to increase the understanding of the various climate-related and economic impacts that biochar has on the diverse systems in which it may be applied to the degree required to ensure successful and widespread deployment. Potential impacts to be investigated include changes in crop yield, quality, and nutrient density, native soil-C stocks (See sidebar in Chapter 2: "*Biochar's Impact on Native Soil Carbon Stocks"*), disease pressure, greenhouse gas (GHG) fluxes, compost production efficiency, fertilizer and herbicide use efficiency, and resilience of natural ecosystems. While agricultural systems, particularly in the tropics, have been studied the most, few data exist concerning these potential impacts on horticultural, silvicultural, and grassland systems and on agricultural systems in temperate climate zones. A wide variety of measurements are needed from controlled plot trials to inform and constrain models that can predict the climate-related, economic, and ecosystem service impacts of biochar amendments in these systems.

The types of biomass feedstocks (e.g., wood, straw, and manure) and biochar production methods used have an impact on the intrinsic properties of biochar, including stability of the C, ash type and content, acid/base character, porosity, and water holding capacity. While a fair amount of knowledge exists regarding these impacts, further refinement is needed to improve the efficiency of production and increase the climate benefit of the biochar.

In addition to field applications, biochar is added to municipal and agricultural composting operations where it may impact the time required (and hence cost of production) to finish the compost as well as the total quantities of GHGs emitted during the process, and potentially improve the value of the end compost product. The composting process can also impact the properties of the biochar. More information is needed about these co-composting impacts and how they change with the type of biochar, compost feedstock, and method of composting. We propose that research specifically focused on municipal and agricultural co-composting operations be conducted to answer these questions.

Model Development

Predictive computer-based models are essential tools for consolidating knowledge in a form that allows it to be used to solve problems and inform decision makers. As an integral part of this program, we propose to develop the next generation of fundamental pyrolysis models to assist in the design, engineering, and testing of the reactors that make biochar at different scales. Models to optimize the logistical factors across the biomass-to-biochar supply chain are also needed. Just as important, however, will be the development of a range of powerful response models that build on the data generated in the engineering and biophysical processes areas to predict the impacts of biochar technology.

Examples include:

- productivity and yield responses of plants to biochar applications,
- impact of biochar on agroecosystem resilience including building soil organic matter, cycling of water and nutrients and fate and transport of agrochemicals and fertilizers,
- integrated life cycle assessments of the climate benefits of various implementations of biochar technology,
- techno-economic assessments of the most favorable pathways to large-scale implementation of biochar technology,
- macro-economic scenarios of the overall impact of the integration of biochar technology into the economic mainstream and, ultimately,
- integration of the productivity response, life cycle assessment, and economic models with the general circulation models that predict global climate change, thus allowing a clearer assessment of the potential impacts that biochar technology can have under different climate-change scenarios as well as the impact of climate change on the biomass-to-biochar supply chain.

Knowledge Consolidation and Extension

To have the desired impact, the results of this research program need to be archived, consolidated, and communicated to other researchers, biochar practitioners, stakeholders, and the general public. Conversely, communication from these same entities to the research program is needed to share concerns, help interpret results and stimulate new ideas that can guide further research. To accomplish these two functions, we propose a major three-part effort:

- Establish an online information clearinghouse (in conjunction with the biochar trade organizations) that would contain electronic versions of the experimental data, technical reports and scientific publications generated by the program, together with relevant publicly available reports from other organizations and individuals active in biochar technology research and development. This clearinghouse would provide a focal point for discussion and information exchange by interested parties from around the world.

- Compile the scientific knowledge developed by the program together with that from other organizations, businesses, and individuals active in biochar technology research and development into a series of topical reports as well as documents describing best management practices. These documents would be freely available to biochar practitioners and other interested parties, thereby helping to promote the best possible climate-mitigation and economic outcomes from the production and use of biochar.
- Set up an interactive outreach effort, involving workshops and webinars, online curricula, and field days at biochar production facilities and test plots to communicate directly with the larger community interested in biochar technology. This effort would stimulate education and discussion, sharing of concerns, and the formation of new concepts, thus further strengthening the research program and amplifying its impact.

Program Structure

We propose that the long-term research and development program would be led by a management team responsible for coordinating the three major types of activities: engineering and biophysical process research, model development, and knowledge consolidation and extension (Figure 3.4). The team would meet regularly with a moderately sized (24-36 members) advisory council consisting of representatives from the biochar technology field (50%), scientific experts in broader topical areas relevant to the research (25%), and a cross section of potential stakeholders (25%). During these meetings, program progress would be shared, and input related to program goals, research projects, and outreach activities sought from the council members.

The topical areas for the *Modeling Development* and the *Knowledge Consolidation and Extension* activities are listed in Figure 3.4 as described earlier. We propose to organize the *Engineering and Biophysical Processes* activities into five topical groups (Figure 3.4 and 3.5). The first group would focus on the use of biochar in a range of composting operations (municipal green waste, food waste, biosolids/animal manures), and on the production of biochar using municipal green waste, biosolids, and animal manures as feedstocks. Engineering for biochar production, energy, and chemicals would be conducted at two locations, one focused on municipal solid waste facilities using a variety of feedstocks (recovered wood, green waste, biosolids) and one focused on using animal manures from large-scale animal production facilities (e.g., dairy farms, feedlots, poultry production facilities) as feedstock.

The remaining topical groups would focus on geographically relevant research questions related to the production and use of biochar in agronomy, horticulture, forestry, and grassland management (Figure 3.5). The exact number of sites would need to be determined (see [2] for another example), but nominally, research would be distributed among six sites for agronomy, three sites for horticulture, four sites for forestry, and three sites for grassland management. Two of the agronomy sites, one of the horticulture sites, and all the forestry sites would include biochar production and the associated engineering development activity. In addition to biochar production, the engineering activity at the four forestry sites would include a strong focus on biomass handling and biochar application technology, as these would be expected to differ significantly among the sites. The engineering development activity at the grassland management sites would focus solely on biochar application methods. Taken as a whole, therefore, the program would produce biochar from wood, straw/stover, municipal green waste, orchard/vineyard prunings, biosolids, and animal manure, using a variety of production methods, and it would have the capability of co-composting any of these biochars.

The biochar response research conducted under the agronomy, horticulture, forestry, and grassland management areas would likely consist of 1) a core set of mechanistically focused experiments applied across all sites that would allow comparisons of the relative effects of soil, climate, and plant type to application of a common project-wide biochar at a standard set of application rates, and 2) a larger set of site-directed experiments that would focus on application of locally produced biochars and testing of different application methods, watering regimes, and fertilization strategies. Within each topical research area, testing using a common plant type (when practical) with the common biochar would further improve assessment of soil and climate effects on observed responses to biochar amendments. Results from both types of experiments would be used to drive and validate the model development efforts.

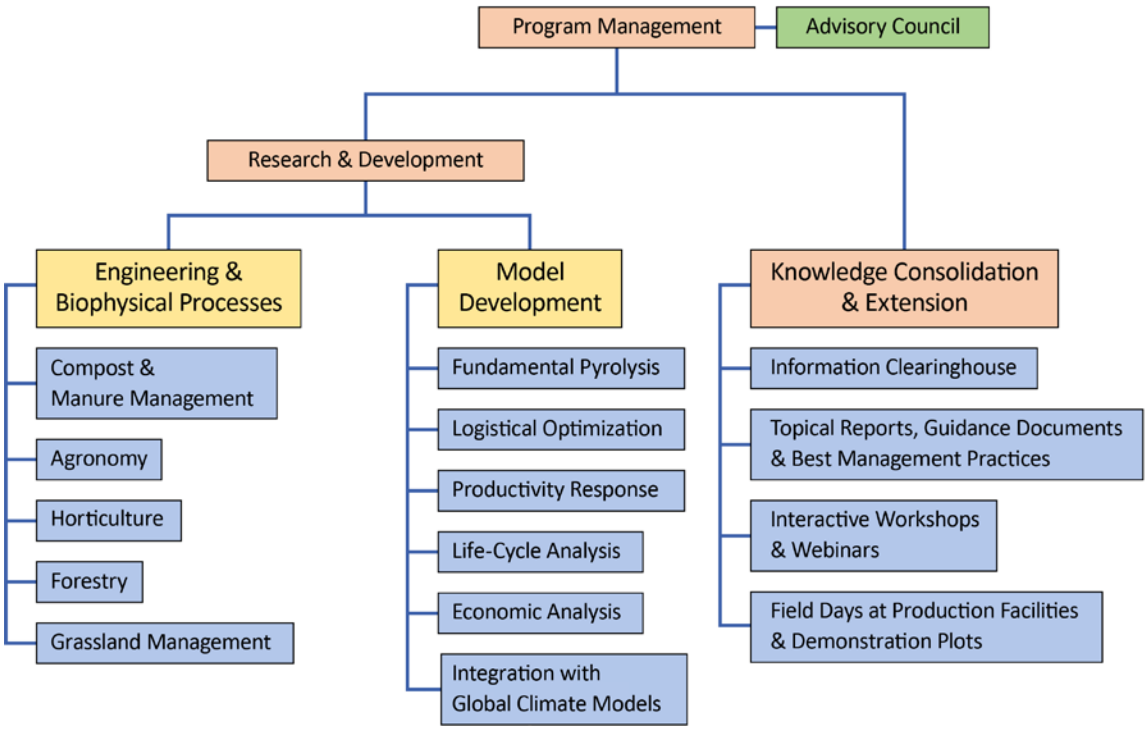

Figure 3.4. *Proposed long-term coordinated research and development program structure showing major groupings of activities.*

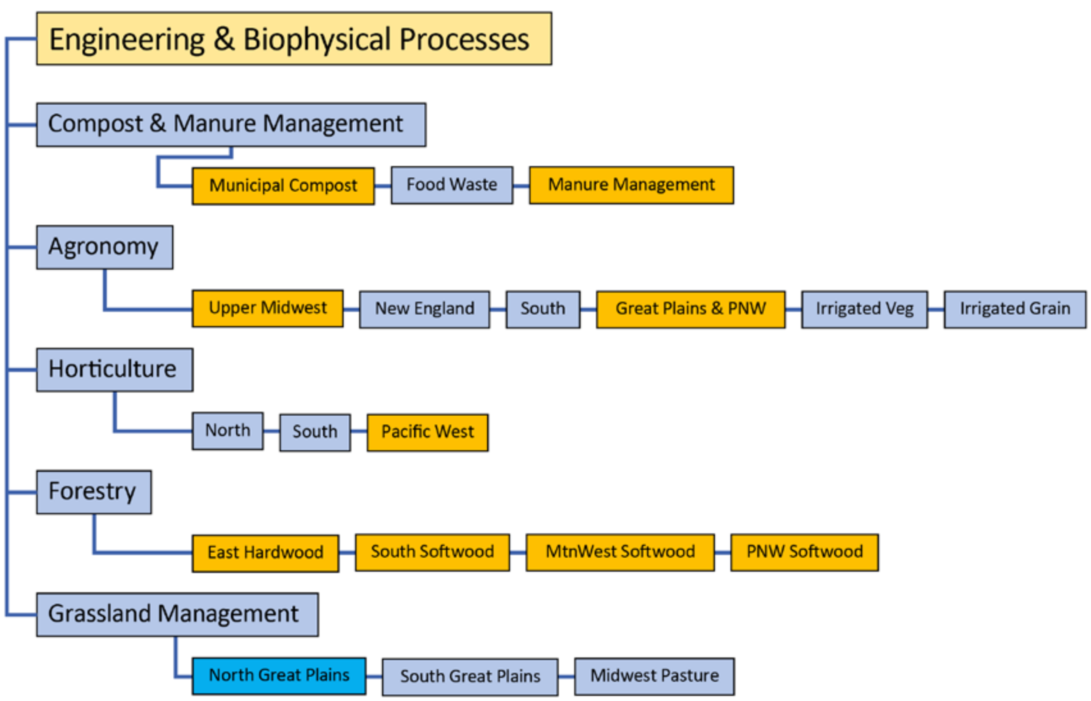

Figure 3.5. *Proposed topical/geographic sites for Engineering & Biophysical Processes efforts in long-term coordinated research and development program. All sites would conduct research on impacts of biochar amendments to soils. Orange-colored sites include biochar production and engineering capabilities; the brilliant blue site includes engineering capability only for biochar application technology.*

Program Sponsorship

At face value, the geographic complexity and long-term nature of this proposed research and development program would require a substantial level of funding, possibly on the order of $150-200 million per year for the first decade [2]. Smaller levels of funding to maintain the long-term experiments would be envisioned for the decades to follow. Significant cost savings could be achieved by leveraging existing USDA agronomic and forestry research infrastructure, and developing collaborations with universities, state agencies, private foundations, farm organizations, environmental groups, and private venture capital. Formation of a formal consortium for this purpose might be the best path forward.

An international version of this program with a proportionally larger geographic footprint can also be envisioned, with support to come from a variety of national and international funding sources. In this instance, the model provided by the Consortium of International Agricultural Research Centers (*CGIAR*) is a good example that also leverages the available existing research infrastructure.

Whether national or international in scope, we think that the promise of biochar technology to address climate change, food security, and the need to stabilize/revitalize rural communities is most readily met by a coordinated program like the one we have described here.

Assessing Biochar Quality

Currently, in the U.S., biochar quality is ascertained following the International Biochar Initiative (IBI) protocol [9]. Typically, producers conduct the laboratory testing and report the results but do not pay to certify their product with the IBI (only three biochar producers are listed as being certified on the IBI website as of 20 July 2020). A less-restrictive “organic-origin” protocol is also available through the Organic Materials Review Institute [22], which certifies compliance with the USDA’s National Organic Program regulations. Five companies have certified 24 biochar-containing products in the U.S. through OMRI (as of 20 July 2020). In Europe, the European Biochar Certificate [6] is a voluntary standard for wood biochar developed by the Ithaka Institute and used by several countries to ensure product quality. Currently, 18 biochar manufacturers or resellers have obtained the EBC, which costs approximately $2,500 for extensive government-accredited on-site sustainability and safety inspection, laboratory testing, and labeling [25]. The EBC can be issued for four classes of biochar depending on end-use: feed (animal feed), agro, agro-organic, and material (various industrial uses). A “C-sink” certification option was recently added to the EBC to address the need for ensuring sustainable, climate-friendly biochar production. In addition to these standards, the IBI has proposed a biochar classification and labeling scheme [4]. This classification scheme organizes detailed information about a biochar’s properties and ranks its suitability to provide different benefits. ■

NEAR-TERM MARKET-FOCUSED RESEARCH AND DEVELOPMENT

Bringing sustainable biochar to market requires near-term actions such as the development of **characterization and labeling protocols** as well as **guidelines for successful application and use**. It also requires market-focused research and development that, in some instances, builds on data collected during the long-term coordinated research program. Critical needs include 1) measurements of **environmental emissions factors** for biochar production systems and development of algorithms suitable for regulatory purposes, 2) development of scientifically defensible algorithms to **estimate the contribution and market value of biochar technology to ecosystem services** including climate change mitigation, soil health, air quality and human health, and water storage. In addition, **regional market development efforts** require conduct of near-term research and pilot-scale demonstrations of biochar technology to **demonstrate how biochar can generate direct value** when used to address problems as diverse as soil acidity, low water-holding capacity, fire hazard reduction, abandoned mine land reclamation, composting odors and efficiencies, and stormwater filtration, as well as the development of new high-value C-based materials. In the sections that follow, we present proposals for work in these areas.

Develop Protocols and Specifications

Ensuring sustainable production, product consistency and appropriate use is essential to market development of climate-friendly biochar. Sustainable production requires appropriate biomass sourcing and production with minimal emissions of environmental concern. Product consistency depends on the development and widespread adoption of biochar characterization and classification protocols (see sidebar *“Assessing Biochar Quality”*), coupled with simplified product labeling for retail sales of biochar-containing products. Appropriate use at the industrial scale is enabled by development and adoption of contract specifications based on best management practices. At the retail scale, publicizing the availability of guidance documents and promoting the use of best management practices can help users achieve a consistent outcome.

Despite having a larger market [36] and a smaller certification fee ($500 vs. $2,500, [25]), the adoption of the IBI biochar certificate in the U.S. lags that of the EBC in Europe. The European consumers of biochar products value the EBC highly enough that the price of biochar marketed without an EBC is roughly half of that with an EBC [25]. This fundamentally changes the market and explains, in part, the much higher adoption of biochar certification in Europe than in the U.S., even with the higher cost. Also, the higher population density and cost of energy in Europe support a mature district-heating and cogeneration infrastructure and make bioenergy more competitive with other sources of energy. European producers benefit financially by having a strong market for the energy co-generated during biochar production and thus are better positioned to absorb the costs associated with biochar certification. When the Organic Materials Review Institute (OMRI) organic-origin certification is considered, however, there is a rough parity in adoption rate between the U.S. and European systems. The U.S. lacks a "C-sink" type of certification that considers the sustainability and climate-footprint of the biochar production process. Perhaps because of this fragmented certification system in the U.S., frequent calls for developing/enhancing standards for biochar characterization and quality are heard in market surveys (e.g., [8]) even though many of those standards already exist.

To repair this fragmented certification approach, we recommend that funding be directed towards the development of a new unified certification standard, at least for the U.S. This standard would combine:

- a C-sink-type estimate (e.g., a "climate star" rating of production footprint in carbon dioxide equivalent [CO_2e] per unit weight biochar, patterned after the "energy star" rating given to appliances by the U.S. EPA) with
- categories of certification based on end use of the biochar similar to those in the EBC, and
- a classification/labeling system (probably a combination of the climate star rating and the system proposed by Camps-Arbestain et al. [4]).

The classification system of Camps-Arbestain et al. [4] provides more detail than either the IBI or the EBC system. Biochars are classified on the basis of their chemical and physical properties (such as particle size) and for their ability to provide different benefits including C storage, fertilizer value, liming, and as a medium for soil-less agriculture. These suitability ratings can be displayed concisely in a simple label (Figure 3.6) and could be combined with a climate star rating (Figure 3.7) that includes both production emissions and C-storage offsets per unit of biomass feedstock for a specified period.

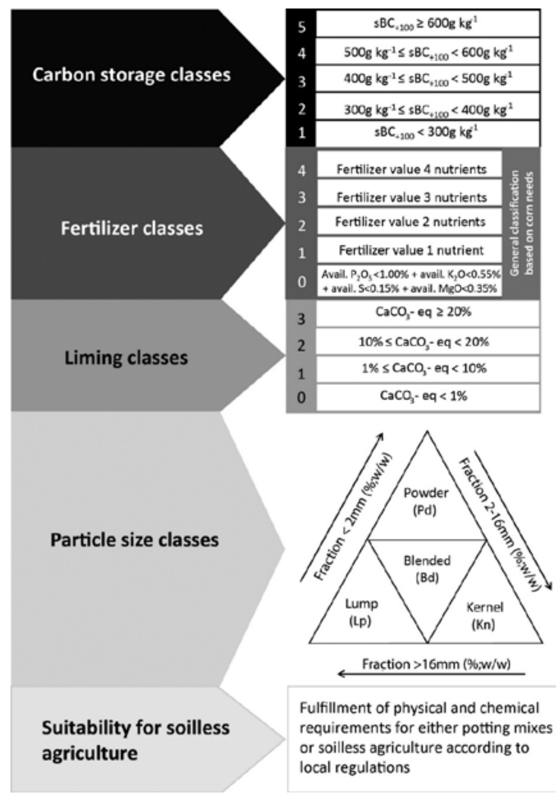

Figure 3.6. *A classification system of biochar based on its potential benefits. The C storage value (sBC+100) stands for stock BC+100 and is obtained by multiplying the organic C content of the biochar (Corg) by the estimated fraction of Corg in the biochar that remains stable in soil for more than 100 years (BC+100). Minimum levels for available P_2O_5, K_2O, S and MgO are based on the needs to fulfill the demand of an average corn crop (grain) considering a biochar application of 10 tonnes per hectare. Units of available nutrients, $CaCO_3$ equivalence ($CaCO_3$-eq) and particle fractions are on % mass basis of biochar. Copyright 2015 From Biochar for Environmental Management: Science, Technology and Implementation by Lehmann & Joseph (Eds.) Reproduced by permission of Taylor and Francis Group, LLC, a division of Informa plc.*

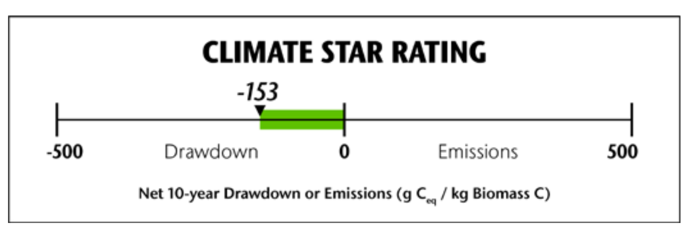

Figure 3.7. *Example of a C-sink type of rating system that could be used to certify biochars for their net climate impact including C storage and production emissions (J.E. Amonette)*

Provided that an "organic-origin" option could be added to each of the end-use categories (as appropriate), a single certification program could then cover all the important aspects of biochar production. Additional certification categories, such as for use in animal feed (currently not legal in the U.S. except for medicinal purposes), or even a combined U.S.-European standard with adjustments for specific national environmental regulations, could be added as new markets develop.

With respect to specifying and promoting appropriate use, we recommend that the best management practices developed (and periodically updated) in the long-term coordinated research and development program be prominently displayed on the website of the certifying organization (e.g., IBI) as well as form a strong part of the customer discovery process outlined under the Infrastructure to Support Business Development priority area, described below. We also recommend that funding be directed to help develop contractual language for appropriate use, and that this language could then form the basis for actions in our fourth major priority area, Collaborative Policy Development.

Measure Environmental Emissions Factors

Because biochar production has the potential to alter air quality (from emissions associated with biomass conversion processes) as well as water quality (from releases of water used to quench the biochar), it is subject to local, state, and federal environmental regulations. In many instances, these regulations were developed for other processes, such as incineration and, in the absence of relevant emission data, regulators are restricted in their ability to treat biochar production as a distinct process. (See *Chapter 12: Air Pollutant Emissions and Air Emissions Permitting for Biochar Production Systems*.)

To change this situation, we recommend funding a three-year near-term project that focuses on compilation and measurement of high-quality air (and where appropriate, water) emissions factor data for the suite of existing biochar-production methods. This would include portable flame-cap kilns used for small landholdings, mobile units used at forest landings (gasifiers, auger-driven slow pyrolysis units, air curtain burners modified to enhance biochar production), large-scale gasifiers typical of biomass boilers, and both conventional and conservation pile burning methods used in forestry operations. Emission data would be collected for appropriate feedstocks (e.g., softwood, hardwood, straw, manure) when dry, and at relevant moisture contents to simulate situations where pre-drying of biomass is not feasible. Emissions data would also be collected across a range of production temperatures (low, typical, and high) to give good coverage of potential operating conditions. Finally, to aid estimates of climate impacts, the C efficiency of each process would be determined by weighing the initial biomass and final biochar on an oven-dry basis and measuring their total C contents, and the emissions of GHGs (i.e., CH_4 and nitrous oxide) would be measured directly (in addition to the usual measurements of priority pollutants such as CO_2, oxides of sulfur and nitrogen, volatile organic compounds (VOCs), and particulate matter smaller than 2.5 microns [$PM_{2.5}$]).

In situations where water is used to quench the biochar, the amounts of water used and that are not volatilized during the quenching process would be measured, and samples taken of any runoff that might occur. Analysis of these samples for priority pollutants, together with biomass and biochar mass data, would be used to determine aqueous emissions factors per unit of biomass converted.

The results of these emissions factor measurements would be compiled along with those reported by others and used to construct/refine simple emission models for each biochar production method. These models would form the core of a scientifically defensible approach to recognize production methods with better performance, drive ongoing technology development, and assist in work with regulatory agencies to develop a regulatory framework that is more appropriate for biochar production.

Develop Algorithms and Assess Market Values for Ecosystem Services

Finding ways to monetize the ecosystem services provided by biochar technology involves the development of algorithms, based on scientific understanding and data, that quantify the size and value of these benefits relative to various alternatives (e.g., wildfires, decay in place). Once the algorithms have been developed, mechanisms of funding to compensate producers and users can be established.

We recommend that near-term funding be directed towards the development of algorithms for quantification and valuation of four major classes of ecosystem service provided by biochar technology:

- Climate change mitigation,
- Soil health,

- Air quality and human health, and
- Water storage

We estimate that useful algorithms for each of these services could be developed, based on the existing science, over the course of a one-year project. The algorithms would be reviewed after three to five years and updated as scientific knowledge progresses. The work for each ecosystem service would be performed by a team having expertise in biochar production and use, economics, and the ecological/business/legal aspects of the service in question. Thus, for climate change mitigation, expertise in life cycle assessment and C marketing would be needed; for water storage, expertise in surface and groundwater hydrology, wildlife habitat, and water rights would be needed (in addition to biochar production/use and economics). Each team would review the relevant technical literature and adapt/develop a simple model that captures the ability of biochar technology to deliver an ecosystem service. For example, with climate change mitigation that ability would likely be measured in tons of avoided CO_2e emissions, whereas for water storage, the units would be acre-feet of water storage. The team would then develop a way of valuing that service in a manner that enables the development of mechanisms to provide economic resources to pay the providers of that service.

Sponsorship of this work could come from state or federal government agencies, private foundations, or even private capital seeking to facilitate the monetization of these services. We also think this would be an excellent activity for funding by the proposed Endowment for Biochar-Based Community Development, which we describe later in this chapter.

Conduct Pilot Studies and Demonstrations for Regional Market Development

The fourth major component in the near-term research and development priority area targets pilot studies and demonstrations of biochar in applications that have strong economic potential. In most instances, these technologies have been shown to work under a particular set of circumstances but need further development and demonstration to cement their utility for other applications or regions, thus clearing the way for market growth. We recommend funding of focused two- to three-year projects in the following categories:

1. **Prescriptive applications in agronomy, horticulture, forestry, and grassland management with potential to yield high near-term returns.** An example in agronomy could be development and testing of a designer biochar to be applied to potato fields that would increase the efficiency of nitrogen fertilizer use thereby saving input costs and decreasing environmental impacts from leaching of nitrate and emissions of nitrous oxide. Another example, in the ornamental horticulture and forestry areas could be field testing of biochar/compost/soil mixtures to help establish young trees and minimize the use of unsustainable sphagnum peat moss. A third example, in grassland management, could be applications of biochar/compost mixtures on rangelands to strengthen biological diversity and increase water-holding capacity while simulating the eventual application of biochar in animal mineral supplements once Food and Drug Administration (FDA) approval is obtained. Work to test the impact of biochar in animal mineral supplements and provide data needed for FDA approval might also come under this type of project.
2. **Fire hazard reduction.** The need to thin small-diameter trees and brush in the wildland-urban interface areas of the arid and semi-arid west offers many economically promising opportunities for demonstrating the utility of biochar production as a way to offset some of the costs associated with the thinning while sequestering some of the C that would otherwise be lost to the atmosphere. When compared to the alternative of wildfire, portable gasifiers and slow-pyrolysis kilns (including flame-cap kilns) seem to offer immediate benefits. The feedstocks would come from local fire-hazard reduction operations or non-bid timber sales. As part of this effort, we propose assessing the level of progress made by fire-mitigation stewardship projects in the National Forest system. These "shelf-ready" projects would be identified through the NEPA Environmental Impact Statement process. An understanding of the outcomes of these projects would provide valuable insights into the most effective actions to take when proposing biochar-related fire-hazard reduction projects.
3. **Land reclamation and restoration.** Many abandoned mine-land sites are located in forested regions that either are actively harvested for timber or would benefit from thinning activities to suppress fire danger. Restoration of these sites using designer biochars to capture toxic metals, treat acidic soils, and increase water holding capacity to stimulate plant growth (see Project Example and Abandoned Mine Lands discussion in Chapter 5) is a prime example of the type of demonstration project we recommend funding. Another example is tied to removal of invasive

species such as conifers in oak forests of southern Oregon (Chapter 4) and Russian olive trees in the cottonwood riparian zones of the mountain states. In these instances, production of biochar could replace the dominant practice of pile burning thereby improving air quality, sequestering C in soils and stimulating growth of desirable species.

4. **Co-composting of municipal and agricultural waste.** Although much remains to be learned about the science of co-composting biochar with municipal organic wastes and with byproducts of agricultural processing facilities and animal containment operations, enough information exists to suggest that some demonstration projects can be implemented now for the purpose of eliminating odors and accelerating the composting process. These near-term projects can provide complementary information to that gained by the focused long-term coordinated research effort on this topic described earlier in this chapter.
5. **Environmental filtration.** In many instances, biochar can provide a low-cost substitute for conventional activated charcoal products. Two pioneering demonstration projects have already been conducted or are underway exploring removal of zinc from the rainwater shed by galvanized roofing to prevent its introduction to sensitive aquatic habitats [23] and removal of dissolved phosphate and nitrate from ponds to prevent algae overgrowth [18, 20]. More projects of this nature are needed to address specific regional issues and demonstrate the value added by biochar technology. One example, based on the well-known ability of biochar to sorb herbicides and pesticides[5, 10, 28, 30, 31, 32], would explore the use of filter strips containing biochar at the edges of agricultural fields as a way of minimizing runoff into surface waterways.
6. **Production of high-value C-based materials.** In contrast to the use of biochar as a high-volume, low-cost substitute for activated-charcoal filtration, we also recommend funding of projects that design and demonstrate the production of low-volume, high-value C-based products used as catalysts, battery electrodes, and reductants in specialty metallurgical operations. (See Chapter 6: Centralized Biochar Production Facilities). These projects would likely require special attention to feedstock purity, moisture content, and particle size, as well as to the design and operation of reactors that provide precise, reproducible pyrolysis conditions. Post-pyrolysis activation of these C-products by a variety of methods can further enhance their value.

As in the previous section, sponsorship of this work could come from state or federal government agencies, private foundations, and private capital seeking to develop new markets. These projects would also be ideal for funding by the proposed Endowment for Biochar-Based Community Development, which we describe in the next section.

INFRASTRUCTURE TO SUPPORT BUSINESS DEVELOPMENT

P C S L N

The third major priority area we recommend for funding involves the creation and strengthening of the infrastructure needed to support the development of community-based biochar businesses. We organize our proposed efforts into three parts that focus on business formation, training a diverse workforce, and developing customer awareness.

1. **Foster business formation.** A number of actions can facilitate the formation of new biochar-based businesses. First, **providing a forum where entrepreneurs can make connections** with researchers, practitioners, and other businesses can lead to new partnerships and business ideas. This forum can also promote public-private partnerships, such as those where government agencies with intellectual property or specific policy mandates might co-fund projects with small businesses to develop new markets. Second, **providing guidance with respect to technical and regulatory issues** can help new businesses avoid expensive situations that lead to environmental contamination or economic failure. Third, the **development and sharing of business tools** such as planning templates and cost estimators specific to biochar production and application projects can help new businesses get established. Finally, **providing new and existing businesses with financial support** through direct access to capital, as well as creative financial instruments such as financing of purchase-orders and long-term sales agreements can make a big difference in the ultimate success of particular businesses, and of the industry as a whole.
2. **Train a diverse workforce.** The biochar industry has the potential to employ people with a wide range of skills and is well-suited to the economic development needs of rural and other underserved communities. Nevertheless, because biochar

technology is relatively new, some training is required and will help create a better environment for new businesses. This training can take the form of **student and summer internships, on-the-job training, and formal education from high school through to college undergraduate and post-graduate levels**. Funding to develop curricula and to support interns, employees, and students at all levels is needed to ensure that a well-prepared and diverse workforce is available to assist in the growth of the biochar industry (Figure 3.8).

3. **Develop customer awareness.** Any successful business endeavor builds on an intimate understanding of the needs of potential customers, develops a product that meets those needs, and builds demand for the product through a targeted marketing campaign that grows the customer base. We recommend continued funding to **survey stakeholders regarding current barriers to more widespread biochar production and use.** Examples of this sort of survey include recent reports funded by the USDA Forest Service Wood Innovation Grants Program [7,8]. Information gathered from these surveys can be used to align priorities for long-term research projects as well as near-term research and development projects and public policy campaigns. Once the product needed by the customer has been identified and developed, we recommend that the **design and conduct of marketing campaigns** targeted at both wholesale (e.g., nurseries and garden centers) and retail customers (biochar product end-users) be funded.

Implementation of these infrastructure-building actions follows two complementary pathways. First, we recommend direct funding to **support and strengthen the two primary trade organizations** that promote the biochar industry (IBI and USBI). However, we think that a new type of organization is also needed to focus on the financial aspects of the development effort. We propose creation of an **Endowment for Biochar-Based Community Development (EBBCD)** whose purpose would be to provide financial support for the infrastructure-building activities outlined in this section as well as some of the near-term research and development activities discussed previously. With respect to direct financial assistance to businesses the EBBCD would maintain a revolving fund to loan capital and finance purchase orders and short-term operating loans. However, a substantial portion of the EBBCD's mandate would be to catalyze funding for the near-term research and development projects needed to advance the biochar industry as a whole. The EBBCD would serve as a conduit for philanthropic funding and use this funding to identify and partner with stakeholders who need matching funds for federal and state grant programs as well as to provide seed money for promising new concepts. The primary emphasis of the EBBCD's program (and part of its appeal to large philanthropic donors) would be the development of small biochar-based businesses in rural communities.

Figure 3.8. *A California Conservation Corps crew makes biochar in the Usal Redwood Forest. A McCleod tool is used to level the biochar in the kiln (left) so workers can measure the height of the pile. The CCC crew reacts to the information about how much carbon they sequestered that day (right). (Photos: Wilson Biochar Associates)*

COLLABORATIVE POLICY DEVELOPMENT

P C N S L

The fourth major priority area is the collaborative development of policies that support the goals of mitigating climate change, addressing wildfire risk, improving soil health, and revitalizing rural communities through the growth of a sustainable biochar industry. Collaboration with a broad range of stakeholders is an essential part of this process and will help ensure that the policies will be both effective and durable. We recommend that funding be prioritized to develop policies that enable price support for ecosystem services (with a near-term target on monetizing climate benefits) and that create appropriate environmental permitting instruments. Progress on policy issues will rely heavily on the development of scientific knowledge and its consolidation into Best Management Practices for regulated activities such as stormwater management, compost emission control, and nutrient management as part of the long-term and short-term research proposed previously.

Price Support for Ecosystem Services

Policies that enable biochar producers, practitioners, and consumers to receive monetary benefit for the ecosystem services their actions support fall into two categories—direct price support through subsidies and tax credits and indirect support through policies that tax or otherwise raise the cost of undesirable alternative economic decisions. In the following, we give examples of each type of policy for the four ecosystem services provided by biochar technology.

1. **Climate change mitigation.** Direct price support would come in the form of C-storage and greenhouse-gas offset credits to biochar producers, landowners who incorporate biochar into their soil, and companies that substitute biochar C for fossil-based C in the products they manufacture. These credits are enabled by two market types: voluntary markets such as Climate Action Reserve, Puro.earth, or Carbon Future, and obligated markets such as the government-supported Cap and Trade mechanisms that collect funds from fossil fuel producers and redirect them in support of biochar technology. A current example of an obligated market is the California low-C fuel standard [13]. Indirect price support would come in the form of a tax or fee levied on the CO_2e content of fossil-fuel thus making bio-based and other low-C sources of energy more price competitive. Bio-based electricity production cannot compete economically with that produced by wind and solar, but it could compete in the production of heat energy. Indirect price support thus would benefit applications where the heat released by pyrolysis could be captured and utilized in applications such as warming of greenhouses, drying operations, or manufacturing processes.
2. **Soil health.** The level of non-pyrogenic soil C, which can be increased by biochar amendments, is one of the primary indicators of soil health. Direct price support for adoption of practices like this that improve soil health would be similar in many ways to C-storage credits. A few such soil health programs already exist, including the NRCS EQIP program, which has an interim conservation practice standard for soil carbon amendment that will allow funding to be used for biochar application (code 808). States also have a variety of soil-health policies either active or in development to which biochar could be integrated (Figure 3.9). As one example, California's Healthy Soils Program, which utilizes funds from the California Cap and Trade program to support a variety of soil health practices on agricultural lands, does not currently have a management practice for biochar, but could incorporate this in the future. Governments and other organizations (such as the Soil Health Institute) interested in promoting these practices could raise funds to subsidize changes in farming and ranching practices that improve soil health. Indirect price support could come from the adoption of voluntary standards similar to those in place for organic food production that, in combination with public education, would allow producers who are certified as implementing soil health practices to charge more for their products.
3. **Air quality and human health.** Poor air quality stemming from wildfires and biomass open-burning practices harms human health, disproportionately impacts vulnerable populations, and burdens the healthcare system. Policies that provide direct price support to biochar producers and practitioners could be tied to publicly funded fuel reduction contracts in which the adoption of biochar production technologies would receive additional credits for the improved air quality resulting from less frequent wildfire. (See sidebar *"Valuing the Unvalued."*) It should be noted that clean combustion of biomass with minimal production of biochar (using air curtain burners, for example) also would improve air quality compared to burning and thus both of these approaches would provide benefit compared to open

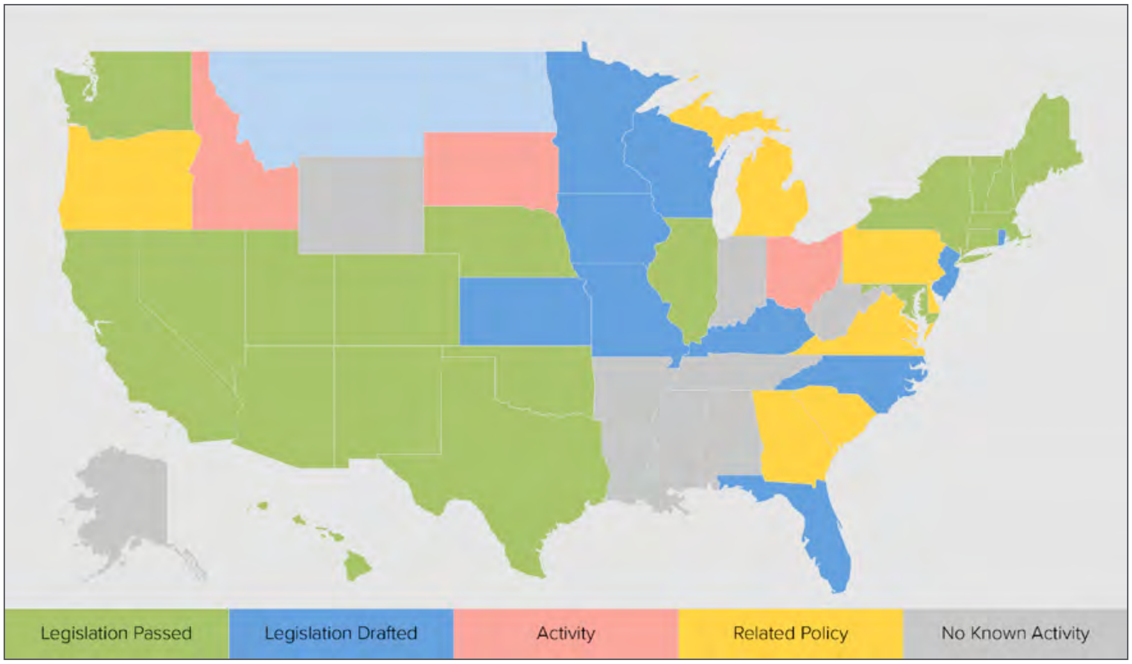

Figure 3.9. *Status of state-level soil health supporting legislation in the United States, as of July 2021. (US State Soil Health Policy Map provided by Steven Keleti, Healthy Soils Advocate, on https://nerdsforearth.com/state-healthy-soils-policy/. This crowd-sourced policy tracker is hosted by Nerds for Earth, a volunteer group that provides technical support for rebalancing the earth's climate.)*

Valuing the Unvalued

There's potential to change the way that some publicly funded contracts are written to encourage recovery of biomass for biochar production, or even to provide additional credits for those employing biochar technology. For example, currently the U.S. Forest Service (USFS) writes some timber sales contracts to require the purchaser to consume "unmerchantable slash." If the USFS were to restructure sales to allow unmerchantable slash, the sale purchaser might work with those who have firewood, posts/poles, or biochar production needs; more of the wood already handled will avoid the burn pile and open burning of biomass concentrations. Meanwhile, USFS fuel reduction contracts often involve several treatment steps including mulching, "lop and scatter," and controlled underburn. In some cases, however, it may be possible to make a merchantable product, such as biochar, from some of the materials resulting from fuel reduction activities, which could be specified in the contracts with a policy change.

The USFS represents one major example of a public land management agency that could implement future policy changes to encourage the production of biochar. However, if other public agencies managing forests (e.g., federal, state, tribal) were to enact similar policies, the collective impact would be significant. Because both supply and demand are required for a robust industry, policies encouraging application of biochar, particularly in promising agricultural contexts are also important for growing the emerging industry and reaping the benefits of biochar. ■

burning practices. Other factors associated with biochar production (e.g., climate, soil health, water holding capacity) could help tip the balance towards implementation of biochar in many situations. Indirect pricing support would largely come from the implementation of regulatory or economic (e.g., taxation) policies that discourage open burning of brush piles and that mandate wildfire hazard-reduction practices. For example, a civil penalty or tax on private land where a wildfire hazard exists would indirectly stimulate efforts to remove the risk, especially if some public funds were also available to help landowners deal with the problem.

4. **Water storage.** Aside from the direct economic benefits that water storage brings by enhancing plant productivity on lands where biochar is applied, the enhancement of water storage capacity by biochar (see sidebar *"Soil Water Storage with Biochar"*) can help minimize the size of flooding events. As a consequence, in specific areas where flooding is an issue, a policy by which national, state, and local flood-control districts would directly pay particular upstream landowners to apply biochar to their soils could make sense. After implementation, flood control payments could continue provided that the available evidence supported the maintenance of the improved water holding capacity.

Appropriate Environmental Permitting Instruments

To be successful, biochar businesses need to obtain a range of permits, of which air quality permits can be particularly challenging. To address this issue, a range of strategies may be needed to smooth the regulatory pathway, and in some cases, to successfully develop new regulatory instruments that protect the environment without penalizing pyrolysis-based conversion of biomass to biochar. This will require a collaborative approach that is based on the appropriate use of biochar technology and the collection of high-quality scientific data to support development of the new policy instruments. We have recommended funding to develop and consolidate the scientific understanding needed to create these new regulatory instruments associated with environmental protection of air and water quality. Here, we simply recommend that funding be provided to the biochar industry trade organizations (IBI and USBI) to engage and work collaboratively with federal, state, and local regulatory agencies in the creation of these instruments.

Implementation

We envision a four-stage collaborative process to implement recommended policy changes, led by the biochar industry trade organizations. Funding to support this process would come in part from the industry itself, but also from non-governmental entities (e.g., foundations, private venture capital) interested in seeing biochar technology implemented to help meet their goals related to climate change mitigation and rural community development.

The first stage of implementation is to engage a diverse range of potential stakeholders in a conversation about what needs they see, the types of policies they prefer to address these needs, and their ideas of how best to proceed. These stakeholders should include landowners, land managers (private, state, federal), environmental regulatory agencies, C-marketing organizations, private foundations focused on climate action and community development, tribes and indigenous practitioners, economic development organizations, and climate-oriented private capital. The results of this conversation may impact decisions made to develop and prioritize specific near-term research and development projects as well as policy recommendations.

The second stage, which overlaps in part with the first stage, involves the sharing of relevant research results with this group of interested stakeholders.

Soil Water Storage with Biochar

Biochar can hold as much as twice its own weight in water when saturated. Like water retention by native soil organic matter [19], much of the water retained by biochar is held in large pores that drain readily after a few days (i.e., field capacity). This short-term buffering effect can serve to blunt some of the impact of large rain events on the runoff that leads to flooding. When added to soil, the effect of biochar is strongest in sandier soils and weakest in soils that are high in clay [21, 24]. For example, working in the laboratory with Washington soils and a wood biochar prepared by gasification, Zhang et al. [35] showed a relative increase of more than 72% in the retention of water by a sandy soil at field capacity when the soil was amended with 2.4% biochar by weight; a silt-loam soil showed a 29% increase and a high clay soil only an 8% increase. In absolute terms, these increases were about 3.9%, 7.9%, and 3.5% by weight for the three soils, respectively. A back-of-the-envelope calculation for a 5-cm rain event onto the dry sandy soil without biochar shows that the top 15 cm of the soil could absorb about 1.4 cm of the rain, leaving 3.6 cm to run off. When amended by 2.4% dry biochar, about 2.4 cm are retained, and only 2.6 cm would run off (a 28% decrease). ■

In the third stage, stakeholder coalitions would be formed to address and promote specific policy changes. Working groups would develop support documentation for the policy changes and draft specific policy language.

The final stage would involve promotional activity to implement and enable the new policy. This activity would likely involve developing general public support through media channels, and direct lobbying (by the members of each partnership) of governmental agencies and local, state, and federal legislators to enact any legislation needed to enable policy. In comparison to the first three stages, the final stage may take the longest to complete given the slow speed at which political change often proceeds in the U.S. However, with enough public support, change can happen quite rapidly particularly if the political ground is well-prepared by the process we have just outlined.

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