

The Biochar Revolution

Transforming Agriculture & Environment



Biochar:
Ancient Origins, Modern Solution
A Biochar Timeline

Author **Paul Taylor PhD**

This complete book is available at
www.TheBiocharRevolution.com

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FIRST EDITION 2010

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National Library of Australia
Cataloguing-in-Publishing entry:

Taylor, Paul, 1945--

The Biochar Revolution: Transforming Agriculture & Environment.

1st ed.

ISBN: 978 1 921630 41 5 (pbk.)

1. Ashes as fertilizer.
2. Carbon sequestration.
3. Charcoal.
4. Soil amendments

631.4

Published by NuLife Publishing
PO Box 9284 GCMC Qld 9726 Australia
Email: info@thebiocharrevolution.com

For further information about orders:
Email: info@thebiocharrevolution.com
Website: www.thebiocharrevolution.com

ACKNOWLEDGEMENTS

I am grateful for the interest, support, patience, and effort expressed consistently—yet in unique ways—by each and every author, as we went through many revisions together. They are listed in the front of the book, with their bios in the back, under contributing authors.

I owe special thanks to Hugh McLaughlin and Paul Anderson for their belief, interest, advice and support in the book as a whole. Both read, and offered valuable editing suggestions on, diverse chapters. Hugh reviewed most of the final manuscript.

Gary Levi played a crucial role as chief editor and editorial advisor. He edited every chapter numerous times, and stayed with the project as it extended from 5 weeks to 5 months, working generously and meticulously to shape and organize the book. He was especially attuned to those new to biochar, helping us strike a balance between technical science, passionate advocacy, and readability. I also appreciate the editorial assistance of John Lierman.

The book would not exist without the faith and end-to-end support of my brother, Ron Taylor. He funded the publishing and editing of the book, contributed to assembling the manuscript, and set up the back-end websites to promote the book and our goal to raise awareness about biochar systems.

I thank Global Publishing Group and their staff for accommodating the extended timeline of the book.

I am also indebted to John Seed of the Rain Forest Information Center and to Artists Project Earth (APE). My interest in biochar focused on the backyard and small-farm scale, when John applied for and received a grant from APE. This initiated “Project 540: Low-emission, low cost biochar kilns for small farms and villages”—and involved me with Geoff Moxham in researching kiln design.

In the midst of our collaboration, Geoff suffered a fatal accident in his beloved rainforest near his home. Whenever I make or demonstrate small-scale biochar, I am following Geoff’s enthusiastic, enlightened lead. His spirit has inspired this book, and I dedicate it to him (see page 348).

I am more than grateful for the unstinting support of my partner in life, Renate Kraus. She allowed me months of long days with limited distraction to focus on the book. In February 2010, seeing me immobilized by the heat and humidity of the tropical Australian summer, yet with a first deadline to finish the book by early May, she pushed me to reach out to potential authors. And behold—it worked!

The support and synchronicities for this book come from the magic of our relationship, the goodwill and enthusiasm of the biochar community, and the importance of biochar itself for the well-being of our planet.

Paul Taylor,
Mount Warning, NSW

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FOREWORD

Dr. Tim Flannery
Professor, Macquarie University
Sydney, Australia
Australian of the Year

I've often said that biochar may represent the single most important initiative for humanity's environmental future. This statement is consciously broad, and speaks to the simple truth that climate change is real and it's happening.

However, this statement may not be broad enough. Even if climate change could be arrested tomorrow, the world's population is growing faster than our capacity to feed it.

This book shows how, through small-scale individual steps through larger-scale approaches, biochar can play a key role in achieving more productive, sustainable, and environmentally beneficial agriculture. And justifies expanding my initial statement:

Biochar may represent the single most important initiative
for humanity's environmental *and agricultural* future.

Technically, biochar science is complex and evolving but its essence, as explained within these pages, is straightforward. If you heat almost any biological material to a certain temperature, and restrict or exclude oxygen, a process called pyrolysis occurs. The material changes form and you get two very useful end-products: charcoal and synthetic gas. The synthetic gas can be used in the same way as other fuels, including generating electricity.

The charcoal end-product has remarkable qualities and is the main focus of this work. When added to soil, the charcoal is called biochar. Biochar amends and improves the soil for the long term. Studies have proved that properly applied biochar improves crop yields.

At the same time, biochar in the soil sequesters carbon from the atmosphere for hundreds, perhaps thousands of years. This actively draws down atmospheric carbon and can help repair our global carbon debt.

This book articulates how producing and applying biochar can transform abundant, readily available biomass usually considered waste—the crop waste left rotting in the field after harvest, fallen limbs in a forest—into a renewable, environmentally friendly resource.

Here, we learn that these benefits are well within reach. The technologies for producing biochar already exist, and have been in use for centuries, dating back to the ancient Amazon basin. Those technologies have decidedly low-tech roots, and therefore may be globally adaptable.

For all of these reasons, biochar has profound potential. It can be a key part of the solution to the daunting, interlaced challenges we face, because above all other options offered to date, biochar represents a practical, scalable approach that can address those challenges *simultaneously*.

What about the title, *The Biochar Revolution*? The title is apt: it reflects that revolutionary change is needed—because we simply don't have time to wait for evolutionary change. In a very real sense, the predicate for the biochar solution is a biochar *revolution*.

On the other hand, despite the word "revolution," this is not a political or philosophical screed, aloof from garden and field. It is by design and execution a compendium of historical, scientific, and practical how-to information, flavored with inspiring personal histories, from a diverse community of contributors.

More pointedly, because biochar-making techniques are readily accessible to everyone, and the need is so pressing, this book shows concretely how all of us, in our own gardens and in our own communities, can contribute and help make a genuine difference *now*—"from the ground up"—without having to wait for our governments and institutions to fully mobilize. Those interested can try making their own biochar and by sharing their results, add valuable data to the worldwide knowledge base. Others can make an impact by participating in community biochar initiatives.

These messages in this book cannot be repeated enough. If it finds wide enough readership, and if enough people at the grass roots—literally and figuratively—take some of the small, easy steps outlined here, the cumulative power of the many will lever dramatic, sustainable, and *revolutionary* change for us all.

Tim Flannery
Sydney, Australia
September 2010

PREFACE

Paul Taylor, Editor

Welcome to *The Biochar Revolution*.

In this ambitious book, we offer a compendium of material designed to inform and engage the spectrum of people interested in biochar. We embrace those who have never heard of it, as well as gardeners and farmers (small and large); ardent advocates pressing for global change; researchers and scientists working toward creative solutions; government agencies and decision makers in developed and developing countries seeking viable policy pathways; and entrepreneurs intrigued by new business opportunities from the ascending biochar phenomenon.

The book works “from the ground up.” First are current global context, fundamental definitions, history, and science, much of it woven into personal stories. Those fundamentals are reiterated in context throughout the book to remind and refresh the reader. Next come more in-depth biochar science, production, and practice. The last part of the book draws on and pulls together the previous material, offering large-canvas concepts on how biochar can profoundly impact the planet.

The “ground up” progression is also followed by starting with proactive individuals on up to households, communities, and utility-scale concepts. Small-scale, low-tech biochar production precedes large-scale, high-tech production.

HOW THE BOOK IS ORGANIZED

The book consists of twenty chapters contributed by eighteen authors from various disciplines, organized into five parts.

Part I Ancient Origins, Modern Inspirations

This part contains five chapters, starting with an overview of the current and historical context for biochar and its benefits. The next four chapters offer inspiring and engaging personal stories from entrepreneurs, community builders, and farmers who discovered biochar and changed their lives.

Part II Understanding Biochar

Here are three chapters that help explain what biochar is, how it helps the soil, and how to characterize it before applying it to the soil. The last chapter contains step-by-step instructions for methods that can be applied at home to test properties of the biochar you make or purchase.

Part III Producing Biochar

Part III consists of five chapters on production that follow the previously noted progression from small-scale, low-tech, backyard production that can be done with recycled cans and drums, through modest-scale production methods applicable to the community garden or small farm, up to commercial scale.

A caveat on production: the authors provide outlines, concepts, or their own experience rather than instruction manuals. Use this as a basis to begin your

own online research to find the most suitable, cleanest method for you. Take responsibility for your own safety and adherence to local codes.

Part IV Testing, Conditioning, and Using Biochar

The three chapters in Part IV cover the important subjects of biochar testing, conditioning, and application to the soil. The last chapter offers insights on the methods for using biochar in mixtures and complexes—all relevant for your own experiments.

Part V Changing the World

Part V consists of four chapters. It begins with a chapter explaining the limitations of the synthetic fertilizer-driven “green revolution” over the last 50 years, the dire need for a greener revolution, and how biochar can be integral to the solution.

Building on these themes, the other three chapters in Part V address specific applications of biochar that could produce material benefits ranging from widespread, small-scale, low-tech application in the developing world, through the potential for medium-scale application on millions of sugar cane farms worldwide, to large-scale biomass pyrolysis for simultaneously producing biochar and generating electricity.

OUR EDITING APPROACH

In editing this work, we have attempted to preserve the authors’ own voices and idioms. The authors contribute a variety of opinions and approaches, based on their experience and philosophies, in a field where the rules, methods, and science are still being defined.

The reader is encouraged to dive in and read the entire book, or to browse through chapters of interest before embarking on their own experiments. And even then, we encourage further exploration of the references given and internet research. We particularly encourage and invite visits to the book’s website, www.TheBiocharRevolution.com. The website will provide useful supplemental information and updates.

HELPING THE READER

We have used a variety of devices to help the reader:

- Each chapter begins with a brief overview of the topics you will learn about in that chapter. If you are a shotgun reader, this will help you navigate.
- Many chapters end with a bulleted list of key points to take away.
- The first time a technical word appears in a substantive portion of a chapter, it appears in **bold-face type**. This indicates that a brief definition can be found in the Glossary, except when the occasional word or phrase is bolded for emphasis rather than definition.
- For some bolded, technical words look for text boxes nearby called “Definitions for Non-Scientists.”

- Some chapters contain text boxes of various other types: quotes (highlighting an interesting or key point of the author); asides (interesting, but not quite a part of the main text flow); technical boxes (more technical material for optional reading); instructions or “@Home Biochar” (helpful instructions for a particular procedure to be used in your own workshop or yard); additional reading; and tips.
- Occasional editorial comments are inserted [in square brackets].

Author and editor pictures and brief bios, most with email addresses, are located in the back of the book.

BIOCHAR TERMINOLOGY

Because the following chapters have been written independently, it will be helpful to introduce some basic terminology. Pyrolysis of biomass to produce biochar is central to the subject of biochar, so here are some terms to get you started.

Pyrolysis refers to the breakdown of biomass when heated into solid charcoal, gases, and liquids.

Biomass refers to living or once living material. In this book it will usually mean plant material such as wood or crop wastes, although other biological materials, such as manure, can be pyrolyzed to produce biochar.

The solid residue from pyrolysis is given various names, depending on how it is produced, its components and qualities, and its intended use:

Char is a general term for the solid product arising from thermal decomposition of any organic material, such as from forest fire.

Charcoal typically refers to carbon-rich material produced in traditional or modern charcoal kilns and generally intended as a fuel.

Biochar is a new term for charcoal that is intended for application to soils as a soil amendment and/or for carbon sequestration.

Black carbon is a general term encompassing all carbon-rich solid residues from fire or heat, including char, soot, and graphite.

Sometimes an author will use the term char, black carbon, or charcoal even when the material is intended for soil (biochar) because the more general term suits the context (such as in discussing charcoal production methods for making biochar).

STYLE AND UNITS OF MEASURE

The book is written in U.S. English. With five Australian authors, and with scientists' propensity to use the metric system, both metric and U.S. units occur in the text. In order to preserve reading flow, translations are made only occasionally. Since generally the quantities cited in the text are approximate, the following on-the-fly conversions can be kept in mind, or referred to (with more accurate conversion in parentheses):

1 inch = 2.5 cm (2.54) 1 foot = 30 cm (30.5) 1 mile = 1.5 km (1.6 km)

1 hectare (ha) = 2.5 acres 1 square meter = 10 sq ft (10.8) = 1 sq yard (1.2)

1 US gal = 4 liters (3.78) 1 cu m = 35 cu ft = 1 cu yard (1.3)

1 kg = 2 pounds (lbs) (2.2)

Generally, "ton" is used as a unit of measure for large weights (of biomass, etc.). All the following units of measure should be considered interchangeable for the approximate precision intended in this book:

1 tonne = 1 metric ton = 1,000 kg = approximately 1 long ton (UK) = 2240 lbs

In the United States and Canada, 1 ton = 1 short ton = 2,000 lbs

°C = °F | 100 = 212 | 300 = 572 | 400 = 752 | 500 = 932 | 600 = 1112

FINAL THOUGHTS

The book mirrors the nascent biochar movement: a diverse, steadily growing community of home gardeners, farmers, scientists, environmentalists, and entrepreneurs, all with different lenses. As in any large community, there is a measure of disagreement about terminology, about science, about results. In the biochar community much is new—or new again—evolving, and unsettled.

While much of the book's content may not be considered scientifically rigorous or exact, pains have been taken to preserve overall scientific integrity.

This book does have an ambitious reach. We have sought to offer a representative spectrum of contributions, and to make them sufficiently readable, so that readers with many backgrounds and intentions will find something, hopefully much, within these covers that will resonate—and that they can use now and over time.

Despite the myriad voices of those contributions, a single truth comes clear: there is ample room for all in this tent. No matter the lens, and no matter the motivation, the biochar community rows toward an overarching, greater good: healing the planet, and helping it sustain and feed us.

Paul Taylor, PhD
Mount Warning, Australia
September 2010

Chapter 1

BIOCHAR Ancient Origins, Modern Solution

Paul Taylor, PhD

Biochar Consultant,
biocharbooks.org

IN THIS CHAPTER YOU WILL LEARN:

- How an intertwining host of problems—and harmful “solutions”—have compromised our planet.
- The instructive history of biochar as ancient technology, and how that technology can be adapted and used today.
- The interlinking soil-enhancing and environmental benefits of biochar.

"These problems—of our own making—are complex, proliferating, and alarming. But a surprisingly simple potential solution to a broad range of problems, a solution built on ancient knowledge, is within reach. In order to look forward to that solution, we must first look back to its origins."



WHAT IS BIOCHAR?

When I say I am involved with biochar, I usually get a blank stare and a question: "What is biochar?" This book will answer that question...and many others.

Right up front, and in the simplest terms, biochar is charcoal produced for mixing into soil. Yes, charcoal—the carbon-rich material made from heating wood or other plant material in an oxygen-deprived atmosphere. As a soil additive, biochar offers numerous potential benefits. Those benefits are detailed in this book but simply summarized, biochar increases the capacity for soil to hold nutrients, enhances crop yields, and captures and stores carbon for the long term.

This introduction will outline the promise biochar holds for rescuing our compromised planet, leaving the detailed exploration to the chapters ahead.

PAST IS PROLOGUE

As a teenager growing up in Australia in the early 1960s, I often thought of the folly and injustice of wastefully burning up our fossil carbon without a passing thought about the needs of future generations—and when other alternatives were apparent. One of my concerns, emerging from my formal training in physics, was that we would inevitably heat the planet in our rush to inefficiently and mindlessly consume energy, while in the process taking the planet's stored fossil carbon out of the ground and putting it back into the atmosphere.

Since that time, in the fifty years from 1960 to 2010, humans have consumed 280 billion tons of fossil fuel, and converted it to about 1 trillion tons of carbon dioxide (CO_2). Over 40% of that CO_2 has stayed in the atmosphere and about half of the balance has been absorbed into the oceans.¹ Excess CO_2 is a problem: in the atmosphere it acts as a **greenhouse gas**, trapping infrared radiation, inhibiting the earth from shedding solar heat, and therefore causing the planet to warm.² Excess CO_2 in the oceans changes their chemistry, making them more acidic, and threatening their living web.³

The ultimate outcome of this human-created condition will be determined by the interactions of numerous interconnecting feedbacks. However, accumulating understanding in science and planetary history indicate that most of those feedbacks are unfavorable, and will amplify the ominous repercussions.

INTERTWINING PROBLEMS

As serious as they are, climate change and ocean acidification are not the only problems generated by the human footprint on the planet. In 2002, World Bank economist Jean-François Rischard identified 20 global issues that, if not addressed and on the way to resolution by 2020 will have drastic negative effects on the fate of our planet and civilization well into the future.⁴ Rischard divided those issues into environmental (such as climate change, soil degradation and loss, and deforestation), social (such as poverty and overpopulation), and regulatory (such as taxation, international labor, and migration).

These problems are laden with unfortunate consequences—and worse yet, they intertwine and reverberate:

- Deforestation, by decreasing the uptake of carbon dioxide and increasing its release into the atmosphere, accelerates global warming. Global warming stresses forests, changes their relationship with destructive pests, and increases the incidence and extent of fires. This feeds back and further amplifies global warming in a vicious cycle.
- Organized efforts to deal with social issues (such as poverty) are undermined by food and water shortages, disasters and dislocations. Yet if people cannot meet basic subsistence needs, they will have little ability or incentive to participate in solving worldwide population and environmental problems.
- Sustainability issues cannot be resolved without a consensus among nations to reinvent their tax schemes to internalize the costs of, and thus transform, unsustainable practices. However, prospects for global regulatory agreements recede as worsening physical and fiscal environments impel political expedience—and obstruct long-term political vision.

Attempts at solutions also intertwine and undermine our attempts to extricate ourselves.

- Solving climate change and peak oil (declining production with increasing demand), requires us to rapidly install vast new infrastructures for energy supply, housing, transport, and food production and delivery that use less fossil fuel and cause fewer emissions. But building these new infrastructures requires massive quantities of fossil energy and capital—and the climate and financial impacts will soon be unaffordable.
- Wealthy nations resist agreements to mitigate past and future greenhouse gas emissions, which cause damaging climate change, unless developing and undeveloped nations sign on. Yet understandably, those nations want their own chance to develop and expect wealthy nations to take fair responsibility for their past emissions—which, after all, are the prime cause of the current pressures.
- Chapter 17 of this book, “The Greener Revolution,” describes the impending crisis in agriculture and the environment. That crisis, set in motion by past unsustainable practices and spiraling populations, is now magnified by a rush to biofuels (corn-based ethanol and palm oil), spawned by increased political awareness about global warming and limited petroleum. We use fossil fuel to grow our food, and now there is a headlong push to use food to make our fuel. This shortsighted “solution” is already having negative consequences on food prices and availability, as well as on the environment and species diversity.

These problems—of our own making—are complex, proliferating, and alarming. But a surprisingly simple potential solution to a broad range of problems, a solution built on ancient knowledge, is well within reach. More specifically, biochar represents a rare technological intervention into nature that, if done carefully,

could have beneficial feedbacks rather than vicious ones. In order to look forward to that solution, we must first look back to its origins.

HISTORICAL CONTEXT: ANCIENT ROOTS, BENEFICIAL TECHNOLOGY

I first became aware of biochar from the 2002 BBC documentary "The Secret of El Dorado." In 1542 the scribe of Francisco de Orellana, drifting with him down a tributary of the Amazon wrote: "...there could be seen very large cities that glistened in white...many roads that entered into the interior...and besides this, the land is as fertile...as our Spain." When the Spaniards returned 50 years later, they found only a few scattered settlements (the aboriginal people having been decimated by diseases the Spaniards introduced)—and Orellana's report was relegated to myth.

Conventional wisdom held that the typically infertile Amazon soil could never have supported large populations, and therefore these "cities" could not have existed. Betty J. Meggers, the Smithsonian archaeologist, said, "The apparent lushness of the rainforest is a sham. The soils are poor and can't hold nutrients—the jungle flora exists only because it snatches up everything worthwhile before it leaches away in the rain. Agriculture, which depends on extracting the wealth of the soil, therefore faces inherent ecological limitations in the wet desert of Amazonia."⁵

Conventional wisdom has shifted. It has become increasingly clear that the ancient peoples of the Amazon compensated for nature's limitations, leaving an enduring legacy of rich soils, known as *terra preta de Índio* (Indian black earth). In fact, their agriculture methods were adding wealth to the soil, not "extracting" it. This phenomenon may have profound impact for the future of agriculture (a concept further developed in Chapter 17). Modern awareness and understanding of *terra preta* and its remarkable traits have evolved only gradually, over centuries, but with dramatic acceleration this decade, as outlined in "A Biochar Timeline" following this chapter.

Terra preta is found in or near those sites where the Amazon Indians had established long-term villages. As such, it is a midden soil: its link to prehistoric settlement is evidenced by a liberal sprinkling of artifacts, including ceramic shards and animal bones. A less rich, brown earth, called *terra mulata*, is much more extensive; it generally surrounds the village sites where the *terra preta* is found, and contains few or no artifacts. Although the precise origins of *terra mulata* are unclear, evidence suggests that it may have resulted from relatively intensive, purposeful cultivation over extended time periods.

Both of these Amazonian dark earths, up to 2 meters deep, are darker and more fertile than the surrounding soil, which is—as Betty Meggers declared—highly weathered and poor (see Figure 1.1, left and middle photos).

Terra preta soils have generally retained their fertility to the present day, and the rich soil is even excavated and sold as potting soil (Figure 1.1, right photo). Their durable fertility is attributed to their high black carbon (biochar) content, which has been scientifically dated as far back as 450 to 8,000 B.C. (Chapter 7 details how biochar helps soil.)



Fig. 1 Carbon-rich *Terra preta* Soil (middle) and Neighboring Soil (left).

Photos: Dr. Bruno Glaser (with permission). Photo, right: Christoph Steiner

Where does the highly durable and beneficial carbon in these soils come from? From managed fires related to routine village activities such as cooking, firing of clay pots, disposing of refuse, sanitation, field burning prior to planting, and burning crop waste and forest debris. *Terra mulata* soils, in particular, appear to be the result of deliberate soil improvements. The ancient Amazonians evidently learned that somehow, their routine activities were linked to improved soil. Armed with that knowledge, they likely applied it intentionally to improve the soil—in other words, they developed a *technology*.

In present day Amazon villages, routine activities do not involve creating more *terra preta*, suggesting that past soil amendment practices were intentional, but the tradition has been lost. Low-intensity or "cool" burning, resulting in incomplete combustion, produces char that can persist in soil for thousands of years. This has been called "slash and char," as opposed to "slash and burn" fires, which are often used in the tropics as part of shifting cultivation¹ and tend to be "hot" fires set at the end of the dry season. These "hot" fires leave mostly ash, which fertilizes the soil for a season or two, but is quickly leached away by rains.

In Africa, India, and elsewhere, some native peoples still use fire management practices that purposely **carbonize** plant and animal waste to make biochar for amending the soil (see Chapters 16 and 17 for more details).

¹ An agricultural system in which people move from one spot to another as soil fertility declines.

OTHER HISTORIC SOILS AND USE OF CHARCOAL*

Christoph Steiner, PhD

SHARED TRAITS

Even though the *terra preta* phenomenon may attract the most popular attention, similarly fertile soils exist.

In many places and circumstances, humans have found ways to overcome environmental limitations. In northwest Cameroon, another tropical environment, grasses are intentionally carbonized for agricultural uses. In this simple in-field technique, dried grasses are covered with a layer of soil before burning. This reduces the oxygen availability and increases char formation relative to ash.

Plaggen were created in the Middle Ages in northern Europe by spreading cattle bedding made from peat, along with manure, to agricultural soils. Over time, plaggen soils have accumulated to over 1 meter (m) in depth.

Chernozem (in Ukrainian, "black soil") soils are not man-made, but are among the most productive. They are found in the grass steppes of Romania, Russia, and the Ukraine, in the prairies of North America (Mollisols), and in the pampas of Argentina. In all of these places, grassland fires have contributed a high content of durable carbon to the soil.

HISTORIC USE OF AGRICULTURAL CHARCOAL (BIOCHAR)

There are early descriptions of agricultural charcoal use (biochar) outside the tropics. R.L. Allen's 1846 book, *Brief Compend of American Agriculture*, mentions multiple uses of charcoal mainly for conserving nutrients. Allen also observed that the pronounced benefits of top-dressing with charcoal led to extensive use of the practice in France. Most of charcoal-related benefits described by Allen have been corroborated by recent scientific studies.

There are even older descriptions of charcoal use in non-tropical agriculture. In 1697, Yasusada Miyazaki of Japan called charcoal "fire manure"; he described roasting organic wastes and mixing them with nutrient-rich manures.

Throughout Asia rice husk biochar has been mixed with nutrient-rich materials to enhance fertilization. Crops were also fertilized with a mixture of human waste and charcoal powder called "haigoe."

*For citations and a wider perspective on what can be learned and adapted from historical soils to bring about dramatic, sustainable global benefits, see Chapter 17.

Dutch soil scientist Wim Sombroek recognized that the fertile Amazonian soils might have been created by humans because of their similarity to the rich, black, human-created Plaggen soils of his homeland (see the text box labeled "Other Historic Soils and Use of Charcoal"). That recognition triggered Sombroek's 40-year fascination with Amazonian soils. Sombroek, and other soil scientists analyzing the *terra preta*, were astonished at its ability to maintain nutrient levels over hundreds of years. Research has shown that even chemical fertilizers cannot maintain crop yields into a third consecutive growing season in cleared rainforest soils, yet *terra preta* remains fertile year after year.

In 1992, Sombroek drew attention to the potential of *terra preta* as a tool for carbon sequestration (a concept discussed below). Before his death in 2003, he rounded up like-minded colleagues into the *Terra preta Nova* group, to reinvent the ancient *terra preta* as a strategy for large-scale farming and as a carbon sink to recapture excess carbon dioxide from the atmosphere.

In 2004, New Zealand climate scientist Peter Read suggested the term "biochar" to describe charcoal made from **biomass** and intended for use in agriculture, although another term, agrichar, was already in use. The First International Agrichar Conference was held in 2007 in New South Wales, Australia, and attracted 107 participants from 13 countries. At that conference, the name of the association was changed to The International Biochar Initiative (IBI).

In 2008, the second international conference was held in Newcastle Upon Tyne, United Kingdom, right across from the university physics department where I had once worked. This time there were 225 attendees from 31 different countries.

THE ENVIRONMENTAL CONNECTION IS MADE

About the time of these conferences, my own long-term concern about emissions-induced climate change convinced me that in addition to mitigating emissions, the land's ability to absorb and store carbon *must* be maintained and improved. The marine and terrestrial **ecosystems** take up around three billion tons of the eight billion tons of carbon we emit each year globally (as carbon dioxide). But as the forests become stressed by warming and succumb to pests and forest fires, as deserts expand and more carbon is lost from the soil, and as the oceans warm and acidify (among many unfortunate feedbacks), the ability of the land and oceans to capture and hold carbon will continue to deteriorate.

I was struck by the idea that biochar could be used to improve the land's carbon uptake capability (see Figure 1.2). Here is the reasoning behind the potential:

- Planet Earth is bathed in sunshine, which delivers to its surface 10,000 times more energy than humans consume globally each year.
- Photosynthesis in living plants uses this solar energy to extract carbon dioxide from the atmosphere and synthesize it into carbon-based compounds that make up biomass. The amount of energy trapped by photosynthesis is immense—annually, about 5 times total human energy consumption. In all, photosynthetic

organisms convert around 100 billion tons of carbon into biomass each year. Humans use an alarming 30% of this biomass productivity as crops, forest products and fuel, but whether consumed as food, burned, or left to rot, virtually all biomass is broken down again so that nearly all of its carbon ends up back in the atmosphere as CO₂.

- When waste biomass is thermally decomposed (a process called **pyrolysis**), it breaks down into gases and residual charcoal. In a modern biochar system, the gases produced by **pyrolysis** are collected and cleanly combusted, which not only provides heat to sustain the pyrolysis but also provides energy for external use—renewable energy! The gases can also be condensed into liquid fuels and other valuable products. When intended as a soil additive, the residual charcoal is called biochar.
- The carbon remaining in biochar resists decomposition in the soil for centuries to millennia, effectively locking it out of the atmosphere. At the same time, the fertility of the soil is increased—thus enhancing food yield and augmenting biomass supply for making even more biochar, energy, and sequestered carbon.

A beneficial feedback at last! Just when we need one!

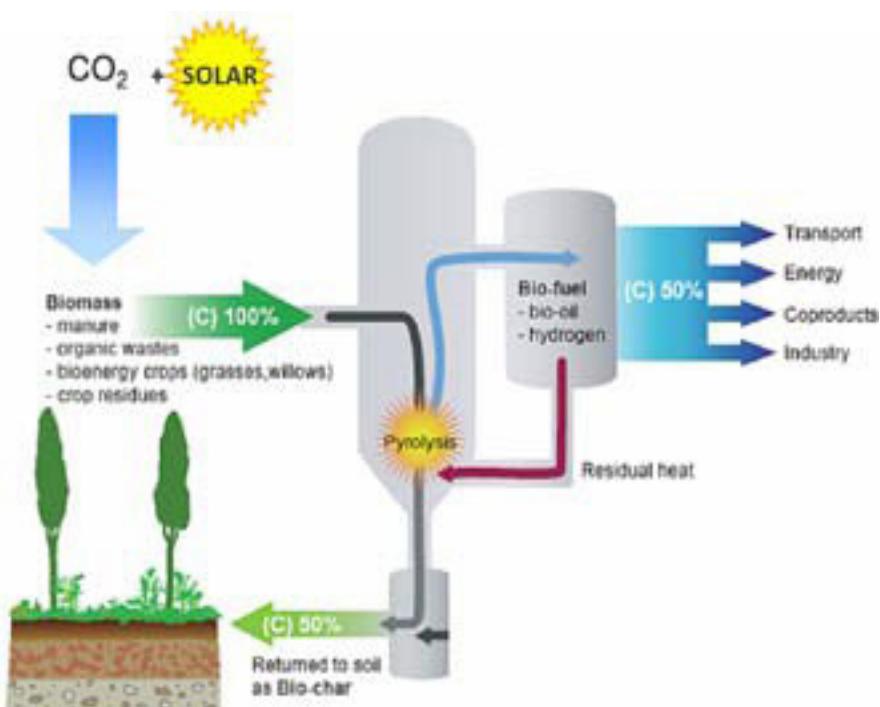


Fig. 1.2 Modern Biochar System

Source: Adapted from J. Lehmann *Frontiers in Ecology and the Environment*. 2007; 7: 381-387.

As illustrated in Figure 1.2, solar energy enables plants to synthesize carbon dioxide into biomass, which is transformed by a pyrolysis system into biochar, while producing energy and other co-products. Approximately fifty percent of the carbon in the biomass is retained in the biochar, which is stored in the soil, contributing to enhanced plant growth. As already mentioned, most of the carbon in biochar is resistant to breakdown, and will be kept out of the atmosphere for hundreds or thousands of years. Without the biochar system, nearly all of the carbon would cycle back to the atmosphere in just years, as fallen plant material decomposes. Thus, biochar accelerates the part of the carbon cycle that takes up carbon dioxide from the atmosphere (photosynthesis) and slows—by a large factor—the part that returns it to the atmosphere (decomposition). Thought of in another way, the biochar system is a solar-driven carbon pump, which rather than requiring energy to run, throws off valuable, renewable energy.

Here we have a carbon-capture technology, which appears to have the potential to play a major role in restoring our soils and our climate, while providing renewable energy and avoiding use of fossil fuels. In addition to the environmental benefits, the economic opportunity related to the scale of the coming changes is worth contemplating: sustaining civilization in the face of environmental imperative will require replacing most of the present fossil fuel industry and most of current fossil fuel-driven, unsustainable agriculture. The interlinking benefits of biochar systems are depicted in Figure 1.3.

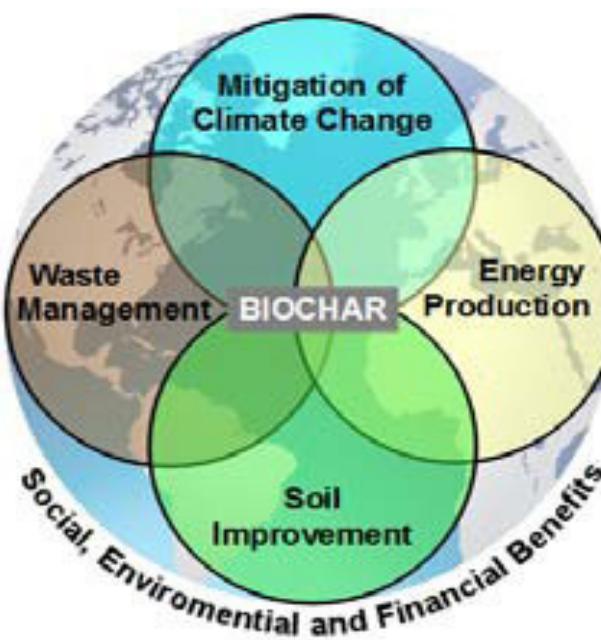


Fig. 1.3 Interlinking Benefits of Biochar

Modern biochar systems can transform waste into valuable soil improvement, which sequesters carbon and mitigates climate change, while at the same time producing renewable energy. Social, environmental and economic benefits flow from optimum implementation of the system.

Source: Adapted and modified from J. Lehmann, Biochar for Environmental Management: Science and Technology, 5

Biochar is not the only carbon-capture technology that will be part of the mix in the coming greener revolution², but pyrolysis technologies seem destined to play a substantial role, and biochar's array of potential environmental, economic, and social benefits stand apart.

BIOCHAR AND POLICY

Policy around energy security and climate mitigation will play a vital role in promoting the development of biochar systems. However, given that biochar is but one arrow in a quiver of required solutions, the sweet spot in the above diagram for making biochar most sustainable and beneficial, and to influence if not drive policy, is to first focus on how it can improve soil and food production. The remainder of this book does just that—but first, a little more about how biochar might fit into the big picture.

CARBON CAPTURE AND ETHICAL CARBON POLICY

In a world dependent on fossil energy, it is easy to be seduced into considering the carbon capture benefits of biochar as offsets against current and future fossil fuel emissions. However, biochar is a better—and more ethical—match to recapture the *past* accumulated carbon dioxide emissions that are causing *present* climate change. In fact, many scientists now believe there is already an unsafe excess of carbon dioxide in the atmosphere; arguably, this obligates the nations that caused the excess to abate it. Only a carbon capture technology, such as biochar, can draw down this excess and repay the debt.

It is notable that from 1850 to 2000, 34% of carbon dioxide emissions have been attributed to land clearing.⁶ Therefore, in a sense, the first goal of biochar is to restore the carbon lost from the soil due to the past 150 years of agricultural practice. After that, the particular durability of biochar will enable the build-up of more carbon in soils, with further fertility benefits (as the *terra preta* example has shown us). This will recapture some of the released fossil carbon back into the ground.

² Other carbon capture methods range from reforestation, no-till agriculture, pasture management, prairie regeneration, and use of biomass for long-term building products, on through “green” cement production, to new biological processes. Carbon capture technologies must be complemented by emissions reduction from efficient use of renewable energy.

ALLOCATING RESPONSIBILITY, PROMOTING DEVELOPMENT

How should the responsibility for dealing with these past emissions be apportioned? Of those trillion tons of carbon dioxide emitted since I worried about it in 1960, over 25% are associated with the U.S. (which has 5% of the global population), and another 20% with the European Union (7% of population), and about 1.3% with Australia (0.3% of population). China has 19% of the world's population but, even as a leading developing country, has so far contributed only about 10% to the accumulated emissions, and therefore to current climate change. (Climate change actually lags decades behind the emissions due to inertia in the geo-climatic system—tables have been published that account for this.⁷)

In fact, only a small number of countries have released far more carbon dioxide into the atmosphere than their per capita sustainable share. If only those countries would agree to use biochar and other carbon capture methods to withdraw those emissions, it would take pressure off the futile attempt to enroll 192 divergent nations into a carbon emissions reduction scheme as a solution to a problem caused predominantly by affluent, developed nations—a problem that now requires not just reducing emissions, but also withdrawing carbon from the atmosphere.

A carbon recapture agreement among the major responsible nations could include a trading scheme for carbon capture credits. Other nations that wanted to enter the trade could join in the agreement. Affluent nations could reduce the expense of meeting their obligations by transferring technology and funding to allow and employ poorer nations, often located in the tropics with poorer soils, to concurrently sequester carbon and remediate their soils. This would help give poorer nations their fair chance to develop, and help their people satisfy subsistence needs, thereby applying direct salve to those pressing issues.

Ultimately, a carbon emissions agreement would require all nations that exceed their sustainable per capita share of current emissions to reduce them over time to that sustainability benchmark, and allow all nations to converge on a common sustainable target (contraction and convergence). However, a carbon recapture agreement does not need to wait on this. The more rapidly the responsible nations recapture their excess emissions, the more time will be available for nations to contract and converge within the physical constraints imposed by nature.

Best of all, this kind of agreement is not as much an economic burden as a viable pathway to a solid, sustainable, and socially just future. For example, Australia's national accumulated carbon debt comes out at about 3 billion tons of carbon, which, distributed over Australia's 445 million hectares⁸ of agricultural land, amounts to 6.7 tons/hectare. While numerous other agro-forestry practices could and should also contribute to carbon restoration, this scenario is actually a good match for biochar. It corresponds with a manageable rate of biochar application spread out over say 30–40 years, and also corresponds with application rates that produce soil improvement benefits (see, for example, Chapter 14).

If responsible affluent countries followed this path (either in their own land or by financially supporting the activity elsewhere), they would improve the soil's productivity, and its resilience against climate change impacts, while radically improving their ethical standing at the negotiating table for emissions reductions.

THE GROWTH OF A MOVEMENT

Researchers around the globe are now scrambling to verify and understand all of these potential benefits of biochar, so that modern biochar systems can be applied effectively and sustainably. The original *terra preta* sites are being studied, and soils with similar traits are being sought, and found. Field studies are under way on every continent, with particular enthusiasm in Brazil, Asia and Australia. In the United States, Cornell University is conducting biochar research, led by Dr. Johannes Lehmann, who co-founded the IBI. Several other U.S. universities have strong programs, with even more work occurring in Australia and Europe. Much of that work to date on the scientific, social and economic aspects of biochar is reported in what I call the Biochar Bible: *Biochar for Environmental Management: Science and Technology* (Earthscan, 2009), edited by Dr. Lehmann and another founder of IBI, Stephen Joseph (University of New South Wales). Other review articles are listed among the references at the end of this chapter.⁹

All over the world, research labs and new corporations are working to develop modern, clean, and efficient pyrolysis processes. Japan, where biochar has been used for centuries, is a leader in commercializing biochar, developing varied biochar-related production kilns, products, and applications. The mission of the IBI is to promote the development of biochar systems that follow "Cradle-to-Cradle" sustainability guidelines.

The ease of electronic communication has pushed the biochar cause beyond the ivory towers, infusing both knowledge and momentum. Home gardeners, farmers, activists, and entrepreneurs have found a community of interest and are sharing ideas, designs, and results online. The IBI keeps the biochar community updated through its website and international conferences it organizes, and as well there are regional biochar organizations around the world, and numerous individuals championing the cause online.

In May 2009, I attended The Asia Pacific Biochar Conference, in my local area of Gold Coast, NSW, Australia. The conference brought home to me the diversity in the biochar community. There was no shortage of strictly scientific presentations, yet I found myself sitting next to and chatting with farmers, waste management consultants, economists, entrepreneurs, and even a building demolisher, all keen to see what biochar could do for them. This community concept is reprised throughout the following chapters.

That diversity is significant, and so is the opportunity for individual contribution. There are many qualities of biochar, and they depend on the type of biomass, process, and conditions used to create it.

There are yet more combinations of soils, crops, and climate zones. All of these variables and combinations need to be tested to promote rapid learning and effective application. Thus, "backyard" research can be as useful and important as formal institutional study. The following chapters provide some inspiring examples, and Chapter 14 is a guide to testing and applying biochar in your own garden or farm, with suggestions on how to gather and share data on your results.

LOCAL DEPLOYMENT, COLLECTIVE GLOBAL IMPACT

One of the encouraging aspects of biochar is that it can be applied widely, yet needs to be localized. There are economic and environmental costs to transporting the bulky biomass material used to make biochar (the **feedstock**) over any considerable distance from its origin. The feedstock is best processed locally and the biochar incorporated into local soils, utilizing particularized local knowledge about conditions relating to climate, soil, crops, and species diversity.

Abundant feedstock biomass is widely available—without deforesting, and without competing with food. At present, vast amounts of biomass are left to rot or burned in field and forest, and even in landfills, or are used inefficiently in primitive and polluting stoves. (For a discussion about mitigating climate change by using "thinly distributed" feedstock and low-tech biochar devices, see Chapter 18.) Furthermore, biomass can be cultivated by **coppicing** (a woodlands management practice recalled from the early charcoal industry—see Chapter 4), or as a strategy to restore marginal lands (Chapters 19 and 20).

Granted, it does require care to gather and use this biomass harvest sustainably, and there are competing needs for it. However, biochar does not have to compete with compost, because biochar can still carry the nutrients in the biomass to the soil, and works best in *combination* with compost (see Chapter 15). Furthermore, biochar does not compete with food; rather, biochar shows great promise for enhancing food production and reducing fossil fertilizer use. Biochar also has the promise of increasing the supply of biomass over time, as soils improve and productivity increases.

Marginal and degraded soils exist in countless locales throughout the world, and must be improved as soon as possible in order to restore soils, increase food production to feed expanding populations—and recapture our historic emissions. This vital topic is expanded in Chapter 17, "The Greener Revolution," and also in the other chapters in Part V, "Changing the World."

THE PIECES FIT TOGETHER

My own exposure to small-scale biochar came via a project to develop low-emission, low-cost biochar kilns for small farms and villages.¹⁰ Project 540's focus is to prove that emissions from small biochar kilns can be controlled to best-practice standards, while still using simple designs, accessible materials, simple cues for checking emissions, and basic or no instrumentation. This, in fact, is a work in progress for many authors of this book, and numerous others reporting online.

Invited to present at an environment day in my local community, I was prepared to carefully explain the science on climate change in order to position and justify biochar, and then demonstrate a small low-tech, backyard biochar kiln (see Chapter 9). Everybody clamored to see only the demonstration, so they could go home and try it!

That real-world, grass-roots experience, coupled with the troubling global context, inspired this book. It aims to support gardeners, enthusiasts, small property owners, farmers, communities, and municipalities who wish to explore making biochar and using biochar to do so via techniques that are safe, low-emitting, resource-efficient, and effective for their local soil and crop. That way, we will do the most good and the least harm as we learn to achieve the local and global outcomes we sorely need.

In doing so, we revive legacies left to us by the ancient Amazonians and others, while being informed by modern science—and reaping the benefits of our own modern ingenuity.

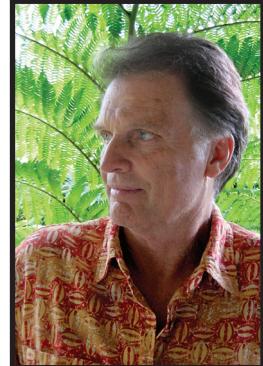
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ABOUT THE AUTHOR

Paul Taylor PhD:

With an enduring interest in environmental issues and solutions Paul has intensely researched biochar, global warming and climate since 2006. He developed presentations on these subjects, which have been lauded for not just raising the problems but bringing solutions. Paul graduated with the University medal in physics from University of NSW, received a PhD from University of Colorado, and worked at Harvard Smithsonian Astrophysical Observatory and MIT.



If you enjoyed this book and found the subject matter interesting then you may wish to read more on biochar from other authors that have written about this subject.

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- Policy makers in Australia, NZ, US, UK, and other developed and undeveloped countries

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www.TheBiocharRevolution.com

A BIOCHAR TIMELINE - Albert Bates

- 8000 BP Earliest radiocarbon dates for Amazonian Dark Earths
- 1542 Francisco de Orellana descends the Amazon River. His scribe, Gaspar de Carvajal, writes, "Inland from the river at a distance of 2 leagues [6 miles] more or less, there could be seen some very large cities that glistened in white. This, the land, is as good, as fertile, and as normal in appearance as our Spain."
- 1670 German Jesuit missionary John Phillip Bettendorff provides the earliest known use of the term "*terra preta*."
- 1866 After surveys by Landsford Hastings, "Confederado" settlements established on *terra preta* sites in the lower Amazon, relocating Southern plantation culture to Brazil following the American Civil War.
- 1867 Ex-Confederate Admiral John Randolph Tucker charts the Amazon River for the government of Peru. In Brazil: Home for Southerners, Ballard S. Dunn writes "... for about twenty miles ... are lands of the best quality, producing every description of crops ... in the greatest perfection and abundance."
- 1868 Geologist and explorer James Orton writes of the Confederado settlements that "the soil is very black and fertile. It beats South Carolina, yielding without culture thirty bushels of rice per acre."
- 1874 Charles Frederick Hartt, first Dean of Geology at Cornell University, conducts a geological survey of Brazil, collecting 500,000 samples.
- 1876 British geologists C. Barrington Brown and William Lidstone observe deep black soils mixed with broken pottery in Guyana and later in the lower Amazon, concluding soils were "undoubtedly of artificial origin."
- 1879 Hartt's assistant, Herbert H. Smith, describes for Scribners Magazine "the rich *terra preta*, 'black land,' the best on the Amazons. It is a fine, dark loam, a foot, and often two feet thick."
- 1895 Friederick Katzer studies the "Schwarze Erde" [black earth] and concludes that the lower Amazon region's "more distinguished wealth lies in its soil."
- 1903 In Sarajevo, Katzer subjects his *terra preta* samples to loss-on-ignition, chemical leaching, and other tests and concludes that these soils were not formed by nature, but were cultivated in ancient times when Brazil was more densely populated.
- 1921-1974 Hypotheses of origins of dark earths by U.S. anthropologist William Farabee (1921), Brazilian agronomist Felisberto Camargo (1941), French geographer Pierre Gourou (1949), and Brazilian pedologist Italo Falesi (1967).
- 1925 Percy Harrison Fawcett vanishes looking for the fabled "City Z."

- 1923-1945 Brazilian anthropologist Curt Nimuendajú systematically maps and samples the *terra preta* sites in the lower Tapajós region.
- 1927 Henry Ford establishes his large rubber-growing community, Fordlândia, along the Tapajós River.
- 1934 Fordlândia is moved upstream to the much more fertile setting at Belterra, a former Confederado *terra preta* site.
- 1960 Brazilian-American geographer Hilgard Sternberg carbon-dates ceramic fragments in *terra preta* soils to 100 BP.
- 1966 Dutch soil scientist Wim Sombroek performs laboratory analysis of Belterra samples and distinguishes *terra preta* from *terra mulata*.
- 1970 Katzer's tests are repeated by Wim Sombroek.
- 1979 Bayreuth University in Germany launches research on black carbon, organic matter stability, micromorphology, chemical and mineralogical analysis, and microbiology, beginning with Wolfgang Zech and continuing with Bruno Glaser, Johannes Lehmann, Christoph Steiner, and others.
- 1980s Interdisciplinary programs are begun at institutions in Brazil, Colombia, the United States, Japan, Australia, and elsewhere to study soil carbon processes and *terra preta* formation.
- 1980 U.S. geographer Nigel Smith publishes "Anthrosols and Human Carrying Capacity in Amazonia," compiling dark earth research to date.
- 1987 Thousand-year-old dark earth sites located in Africa by Brooks and Smith.
- 1990s Archaeologists Michael Heckenberger, James Petersen, and Eduardo Neves excavate large, long-term villages on dark earths in the Upper Xingu and along the lower Rio Negro, including likely site of "City Z."
- 1992 Charcoal carbon sequestration proposed by German energy researcher Walter Seifritz as sink for anthropogenic carbon dioxide in the atmosphere.
- 1997 Japanese researchers Ogawa, Okimori and Takahashi propose carbon sequestration and forest conservation under U.N. Clean Development Mechanism, using pyrolyzed biomass residue and forestry waste.
- 2001 A *Terra preta* Symposium at the Conference of the Latin American Geographers in Benicassim, Spain brings together Geographers, archaeologists, and soil scientists from Europe and Latin America.
- 2001 U.S. Department of Energy report by Spath, et al., shows that pyrolytic conversion of biomass provides best path for hydrogen production because of co-products.

- 2001 British Museum opens display, "The Unknown Amazon."
- 2002 First International Conference on Anthropogenic *Terra preta* Soils in Manaus, Brazil. Sombroek and others propose "*Terra preta Nova*" as a global carbon sink initiative.
- 2002 "The Secret of El Dorado," a BBC Horizon television documentary, furthers global awareness of *terra preta* soils.
- 2003 Lehmann, Kern, Glaser and Woods publish *Amazonian Dark Earths: Origin, Properties, Management*, the first comprehensive anthology of *terra preta* soils.
- 2003 Findings by Heckenberger, Erickson and others show that the prehistoric civilization of the Amazon was more populous and complex than previously assumed, attributable to soil management.
- 2004 Small-scale pyrolytic kilns such as the Adam-Retort® are produced in India and Africa. Many backyard stove experiments are begun.
- 2004 New Zealand climate scientist Peter Read coins the term "bio-char" to describe biomass-derived charred carbon used in agriculture.
- 2004 At Conference on Energy and Carbon Utilization at University of Georgia, Danny Day introduces plan for integrated energy, forestry, and agricultural carbon cycle to combat climate change.
- 2006 The International Agrichar Initiative is formed at a side meeting of the World Soil Science Congress in Philadelphia.
- 2007 Tom Miles launches *terra preta* list and website in support of the Agrichar Initiative.
- 2007 First International Agrichar Conference is held in New South Wales, with 107 attendees from 13 countries, and the International Biochar Initiative (IBI) is established. "Agrichar" is trademarked by an Australian company.
- 2008 Second IBI conference held in Newcastle, United Kingdom with over 225 attendees from 31 different countries.
- 2009 Lehmann and Joseph publish *Biochar for Environmental Management*.
- 2009 Woods, Texeira, Lehmann, Steiner, WinklerPrins and Rebellato publish *Amazonian Dark Earths: Wim Sombroek's Vision*.
- 2009 Biochar is proposed as a climate mitigation strategy at the United Nations Conference of Parties to the Framework Convention on Climate Change in Copenhagen.
- 2009 "Cool Vegetable" campaign to market biochar-grown produce is launched by Japanese grocery store chain.
- 2010 Third IBI conference is held in Rio de Janeiro, Brazil.

GLOSSARY

absorb. "To soak up or drink in," like a sponge. Used when one substance takes into its volume another substance or radiation (e.g., absorbs light). Compare to the more specialized word **adsorb**.

Acacia. A genus of shrubs and trees belonging to the subfamily *Mimosoideae* of the family *Fabaceae*. The plants tend to be thorny and pod-bearing, with sap and leaves typically bearing large amounts of tannins. An important form of **mallee**.

acetic acid. A colorless, pungent, water-soluble liquid, chemical formula CH_3COOH ; the essential ingredient of vinegar, and the source of its sour taste and pungent smell.

acid sulfate soils. Soils rendered acidic through containing large amounts of dissolved sulfur in the form of sulfates, which in the presence of water give rise to sulfuric acid.

activated carbon. A very adsorbent (see **adsorb**) form of carbon, used in purifying water and gases.

adsorb. "To stick," similar to "adhere." A material adsorbs water when water sticks to it. Biochar is adsorbent, and since its structure is cellular with a lot of surface area for water to stick to, it can hold a lot of water. Compare **absorb**, **desorb**, **adsorption**, and **adsorption capacity**.

adsorption. The process of attraction of atoms or molecules from an adjacent gas or liquid to an exposed solid surface. Many chemical reactions can go a lot faster when the reacting molecules are adsorbed.

adsorption capacity. The capacity of a material to store liquid, especially water. The capacity is proportional to the material's surface area. See **adsorb**.

agri-char. Another name for biochar, emphasizing its role in fertilizing crops.

agroecosystem. A conceptual model consisting of (1) land used for crops, pasture, and livestock; (2) adjacent uncultivated land that supports other vegetation and wildlife; and (3) associated atmosphere, underlying soils, groundwater, and drainage networks.

agroforestry. The application of agricultural aims and principles to the management of woodlands. Tree farming. Also, a system of land use in which harvestable trees are grown, as a crop, among traditional crops or on pastureland.

aliphatic. A class of carbon compounds in which the carbon atoms form open chains.

anion. A negatively-charged ion (attracted to a positive-charged anode).

anthropogenic. Man-made.

Anthrosols. Soils formed or heavily modified through long-term human activity, such as from irrigation or adding organic waste. *Terra preta* is an Anthrosol.

aromatic. A class of carbon compounds containing an unsaturated ring of carbon atoms, and usually having an agreeable odor. Aromatic molecules are generally very stable and able to form planes or "sheets." Biochar contains many of these, and this trait is at the core of biochar's durability.

ash. The portion of moisture-free biochar that is not organic.

ASTM. The American Society for Testing and Materials.

autopyrolysis. Combustion (burning) that is self-initiated or self-sustained without input of energy.

bagasse. The dry, dusty, fibrous pulp that remains after sugar cane is crushed and its juice extracted.

beetle, mountain pine or bark. Beetle of western North America whose larvae feed on the inner bark of conifer trees.

BET. Brunauer-Emmett-Teller, the three scientists who published the most commonly used measure of surface area; the BET method measures the adsorption (see **adsorb**) of nitrogen vapor in a partial vacuum at liquid nitrogen temperatures (minus 196°C).

biodiesel. Diesel fuel derived from plant materials (often soybeans), not from a fossil source.

biofuels. Fuels derived from renewable plant materials, not fossil sources; examples include grain and switchgrass ethanol and **biodiesel**.

biomass. Biological material derived from living, or recently living, plants.

bio-oils. Oils derived from plant materials, not from fossil sources.

bokashi (Japanese, "fermented organic matter"). Fermented wheat bran used to pickle kitchen waste, in order to hasten decomposition and reduce odors by preventing putrefaction.

bokashi system. A composting system that uses a mixture of microorganisms to inoculate compost and hasten decomposition.

carbonize. Conversion of an organic substance to a residue richer in carbon by heating and partial burning (that is, by **pyrolysis**).

carbon to nitrogen ratio (C:N). The ratio of carbon atoms to nitrogen atoms in a given material.

Casuarina. Genus of 17 species of evergreen shrubs and trees in the family Casuarinaceae; native to Australasia, southeastern Asia, and islands of the western Pacific Ocean. An important **mallee** genus.

cation. A positively charged ion (attracted to a cathode or negative pole)

Cation Exchange Capacity (CEC). A measure of a material's capacity to retain positive ions, such as ammonium and potassium, in an exchangeable form that is available to plants.

cellulose. An inert carbohydrate, the chief constituent of plant cell walls.

chernozems. (Ukrainian, "black soil"). A type of very fertile, naturally occurring soil that contains high percentages of humus, phosphoric acids, phosphorous, and ammonia and produces a high agricultural yield.

cogeneration. Simultaneous generation of two or more forms of usable energy, such as electricity and heat.

communities-mentoring-communities (CMC) program. A development program whose governing principle is that communities learn a practice from another community that has successfully adopted the practice.

compost tea. A nutrient-containing liquid made by steeping compost in water. Used as fertilizer and to help prevent plant diseases.

collier. A miner or seller of coal. Also a maker of charcoal.

coppice. The ability to grow rapidly from burned or cut stumps. As a verb, the practice of **coppicing**.

coppicing. Forest management practice in which trees are harvested without removing the stumps, so that the cut trees re-grow, enabling further wood harvests from the same stump.

CO₂e. **Equivalent of carbon dioxide** (CO₂). To compare the expected greenhouse effect of a given gas with carbon dioxide, its greenhouse potential may be expressed in CO₂ equivalents.

db. Abbreviation of **dry basis**.

desorb. To release a substance that has previously soaked into or stuck to a material. Opposite of **absorb** and **adsorb**.

dry basis. The dry-basis moisture content of a material expresses the ratio of the moisture mass present in the material to the mass of the dry matter. A standardized dry basis is determined by weighing a volume of the material after heating to some standard temperature high enough and for long enough to drive most moisture off the material (see also **wet basis**).

dunder. The yeast-rich foam leftovers from one batch of rum that is used to start the yeast culture of a second batch. Also, the lees from boiled sugarcane juice, used in the distillation of rum.

ecosystem. A community consisting of all organisms living in that particular area and the nonliving, physical components of the environment the organisms interact with, such as air, soil, water, and sunlight.

ecotone. A transition area between two adjacent but different plant communities, such as forest and grassland. Coined from a combination of eco(logy) plus -tone, from the Greek *tonos* or tension—in other words, a place where ecologies are in tension.

endothermic. Heat-absorbing. Refers to processes or reactions that consume more energy than they release.

exothermic. Heat-releasing. Refers to processes or reactions that release more energy than they consume.

eutrophication. The natural or artificial addition of nutrients to bodies of water and the effects of the added nutrient, which can include dense growth and decay of aquatic plant life, resulting in increased demand for oxygen, contributing to death of other organisms.

fast pyrolysis. A process in which organic materials are very rapidly heated (in a few seconds) to 450–600°C in absence of air. Under these conditions, the organic vapors produced have too little time to condense in the solid char also produced, and are emitted. The vapors are condensed externally into pyrolysis oil. Typically, 50–75% of the feedstock weight is converted into pyrolysis oil. See **pyrolysis, slow pyrolysis**.

feedstock/feedstock material. Raw material. In the case of biochar, the raw material for producing biochar is some form of **biomass**.

fermentation. Conversion of sugar to alcohol brought about by enzymes secreted by certain yeasts, molds, and bacteria. The basis of many commercial fermentation offerings such as the **bokashi system**.

forage rape (*Brassica napus*). A quick-growing, short-season, leafy member of the *Brassicaceae* (mustard or cabbage) family. It is tolerant of cold, drought and heat, and is used to feed grazing deer and livestock.

gasify, gasifier. To convert a material into gas is to gasify. Any apparatus designed to gasify is a gasifier.

gasification. See **gasify**.

global warming. Sustained increase in average temperature of the earth. Popular alternative to term "climate change."

graphene. Graphite's major structural element, it is an isolated sheet of joined, hexagonal carbon rings. Graphite consists of many graphene sheets stacked together.

graphite. One of the forms of elemental carbon; used for pencil leads.

graphitic. All substances that consist of carbon in its form as graphite.

green cane harvesting (GCH). The practice of harvesting sugar cane without previously burning the crop (to remove its foliage).

greenhouse effect. The capacity of certain atmospheric gases to trap heat, after the manner of a greenhouse.

greenhouse gas (GHG). A gas believed to contribute to the **greenhouse effect**.

greenwaste. Biodegradable waste.

heat treatment temperature (HTT). The highest temperature that a biomass experiences while being modified by heat. HTT dictates char properties.

hectare (ha). A unit of surface area equal to 10,000 square meters. One hectare equals 2.471 acres.

hemicellulose. Any of a group of gummy polysaccharides intermediate in complexity between sugar and **cellulose**.

humose. The usually dark brown or black fraction of soil organic matter that forms as a result biological decomposition of organic material.

hydrophilic. "Water-loving." Describes any material that dissolves easily in water. An example is alcohol.

hydrophobic. "Water-fearing." Having little or no ability to mix with water or water-soluble liquids; the most well-known example is oil.

hygroscopic. Having the ability readily to attract and hold moisture from the environment, by absorption or adsorption. Most biochars are hygroscopic. See **absorb** and **adsorb**.

hypha (plural, **hyphae**). The thread-like processes of a fungal mycelium, through which a fungus absorbs nutrients. In layman's terms, tiny fungus roots.

infective. Able to cause infections; able to spread disease.

inoculation. In the context of biochar applications, the addition of living organisms and nutrients to biochar in order to generate a conditioned biochar, which will get a better response from the crop.

inorganic. Not derived from living organisms; in chemistry, not composed of hydrocarbons.

intercalated. In chemistry, the reversible inclusion of a molecule (or group) between two other molecules (or groups). Examples include DNA intercalations and "graphite intercalation compounds" where molecules are inserted between graphite layers.

ironmonger. Originally, referred to a person who made tools from iron, as well as the place where his wares were sold. The term is still widely used in the UK, and is the US equivalent of a hardware store.

joule. A unit of energy equal to the work done when a current of 1 ampere passes through a resistance of 1 ohm for 1 second. In layman's terms, 1 joule is the energy required to lift a small apple one meter against the Earth's gravity.

Kyoto requirements. The restrictions on carbon emissions and carbon sequestration targets set in the Kyoto accords.

labile. Unstable.

labile matter. See **mobile matter**.

leach. To remove soluble constituents from soil, char, or other material with water.

leachable. Susceptible to being leached.

lignin. An **organic** substance that, with **cellulose**, forms the chief part of wood.

lignocellulosic. Comprised of **lignin** and **cellulose**, the two primary substances that make up wood.

lodgepole pine. Conifer of western North America. Lodgepole pine is the common name for *Pinus contorta*.

mallee. Scrubland vegetation found in southern Australia, composed primarily of woody shrubs and trees of the genus *Eucalyptus*; more broadly, any short tree with a large underground stem fused with the main root, called a lignotuber.

methanol. Colorless, toxic, flammable alcohol, formula CH₃OH; also known as wood alcohol.

microbes. Microorganisms, especially bacteria.

micro-gasification. This simply denotes gasification on a small, but not microscopic, scale. See **gasify**.

mineralization. The process that converts an organic substance into an inorganic substance.

mobile matter. The organic portion of biochar that disperses into the soil and becomes food for soil microbes. Sometimes called "**labile matter**."

moisture. Wetness. The water content of biochar.

mountain pine beetle. *Dendroctonus ponderosae*, is native to the forests of western North America. Outbreaks of the insect, also called the bark beetle, the Rocky Mountain pine beetle, or the Black Hills beetle, can result in losses of millions of trees.

mycorrhiza. A symbiotic association of a fungus with the roots of certain plants, in which the **hyphae** form a woven mass around the plants roots or penetrate the cells of the roots; the colonization of fungus on or in plant roots. See **hypha**.

N₂O. Nitrous oxide (laughing gas). A greenhouse gas with global warming potential about 300 times that of carbon dioxide, and a long residence time in the atmosphere of 150 years. Agriculture is the main contributor to increasing N₂O in the atmosphere through widespread use of nitrogen-based fertilizers.

NGO. Non-governmental organization. A voluntary association, pursuing a particular cause or interest, which is not created by a government, but may work cooperatively with government.

oil mallee. Mallee grown as a crop, for its oil.

open burn. Burning that is open to the air—an ordinary fire.

organic. Derived from living organisms; in chemistry, composed of hydrocarbons.

PAHs. See **polycyclic aromatic hydrocarbons**.

pathogen. A disease-producing agent, especially a virus or bacterium or other microorganism.

pathogenic. Disease-causing.

photovoltaic (PV). Converting solar energy to electric energy.

pH. Potential hydrogen. A measure of the concentration of hydrogen in a solution, which is a standard measurement of acidity or alkalinity (basicity). The pH scale runs from 0 to 14, with lower numbers indicating increasing acidity and higher numbers indicating increasing alkalinity. The neutral pH, that of distilled water, is 7. Plants are very sensitive to soil pH.

pit burn. A method of charcoal production in which biomass is set alight in a pit, then covered with dirt to smolder into char.

Plaggen. A type of soil created in the Middle Ages in northern Europe as a result of intentional "plaggen cultivation." **Turves** of peat were collected from areas with low agricultural productivity and used as cattle bedding. The bedding material, together with manure, was later applied to agricultural fields, creating rich top-soils on top of sandy soils. Like *terra preta* soils, Plaggen have thick man-made surface horizons.

polycyclic aromatic hydrocarbons. Hydrocarbon compounds that consist of linked **aromatic** rings. They are a by-product of fuel (fossil or biomass) combustion, but also occur naturally and are linked to numerous ill health effects.

prill. To aggregate material from a molten state into small spheres, granules or pellets. Solid fertilizers are commonly manufactured and applied as prills.

proximate analysis. Test used to gauge the heating value of coal. The test measures moisture content, volatile content, fixed and free carbon remaining after heating, and ash (mineral) content. An adaptation of the same test can be used to assess biochar.

putrefaction. Decomposition of **organic** matter by bacteria and fungi, resulting in strongly odorous products; rotting. Putrefaction provides nutrients for plants, but also creates a **pathogenic** condition within the soil.

pyroligneous. Produced by the distillation of wood.

pyroligneous acids. Also referred to as **smoke water** or **wood vinegar**. A by-product of producing biochar through pyrolysis, made by condensing smoke emitted by kilns. Long used in China and Japan as a bio-pesticide and to increase seed germination rates.

pyrolysis. Use of heat to break down complex chemical substances into simpler substances.

pyrophoric. Prone to self-heating and combustion—spontaneous combustion. **recalcitrant.** Term applied to organic matter or nutrients that are stable and not subject to release into soluble form. Strong resistance against mineralization. See **resident matter**.

reductant. Reducing agent, a substance that brings about reduction in another substance, being itself oxidized. The class of reactions known as oxidation is familiar to most people; examples include fire and rust. Reduction may be conceptualized as the chemical opposite of oxidation. Among its older and easier to grasp definitions is that reduction is the loss of oxygen or the gain of hydrogen. Modern chemists, however, define reduction more precisely.

refractory. Heat-resistant; used especially to describe materials that have the ability to retain their shape and chemical identity when subjected to high temperatures and that are used for lining furnaces.

resident matter. The **organic** portion of biochar that remains stable in the soil for a very long time. Also known as **recalcitrant** matter.

residence time. The average amount of time that a representative particle spends within a particular space or system. Residence time is a function of the speed with which material is fed into the system and speed at which the system processes material. Any given particle may exit the system faster or slower than average, but the overall average is the residence time for that system.

retort. A closed vessel with an outlet tube used for distilling, separating, or decomposing substances that are placed inside and subjected to heat.

rhizome. A root-like, horizontal stem, commonly horizontal in position, which usually sends shoots upward and roots downward along its length. Also called creeping rootstalks, or rootstocks.

rhizosphere. The few centimeters (sometimes meters) of soil that immediately surround the plant roots and are affected by chemical secretions from them.

rick. A stack or pile, usually of wood or straw. In the southern United States, a unit of firewood (half a cord, or a cube measuring 4 feet on a side).

sesquiterpenes. A common group of plant poisons found naturally in plants and insects, that act as defensive agents.

slow pyrolysis. Characterized by gradual heating, which produces a purer and more uniform char product than **fast pyrolysis**. See also **pyrolysis**.

silviculture. The cultivation and management of woodlands.

smoke water. Also known as **wood vinegar**. See **pyroligneous acids**.

sustainable. Maintainable. Among environmentalists, describes any activity depending only on non-exhaustible or naturally renewable resources.

syngas. Abbreviation for "synthesis gas"; loosely, any artificially created gas that contains mostly hydrogen and carbon monoxide.

terra preta de Indio (Portuguese, "black earth of the Indian"). Fertile, black, biochar-rich soil found in scattered tracts throughout the Amazon basin; also, the pre-Columbian civilization responsible for creating that soil.

thermo-gravimetric analyzer (TGA). Custom-built, modified apparatus used for chemical analysis of a material. Only ten such machines exist in the world.

thinly distributed. Describing crop residue, manure, or other **biomass**, indicates that the volume of biomass is not concentrated in any single place.

TLUD ("TEE-lud"). Stands for top-lit updraft. A gasifier stove in which the fuel burns from the top down in a self-sustained burn, while air flows through from the bottom up. Efficiently produces biochar.

top-lit updraft. This denotes the combination of two **pyrolysis** technologies: The fire of pyrolysis is lit at the top of the fuel column and burns downward. The fire is fed by an updraft of air, moved by the heat of pyrolysis, through the fuel column.

torrefied, torrified. Scorched, charred, **carbonized**.

torefy, horrify. To subject to fire or intense heat; roast or scorch.

total dissolved solids (TDS). A measure of the combined content of all substances contained in water apart from the water itself; what remains of a water sample after all H₂O has evaporated or been distilled away. An indicator of water quality.

transpire. To emit or give off gases, through the surface, as for example leaves giving off water vapor and oxygen.

trench burn. See **pit burn**.

vermicomposting. Composting using worms. Vermicelli is pasta that looks like worms.

vinasse. The residue left in a still after distillation. In the sugar industry, the residue left after molasses is fermented.

wb. Abbreviation of **wet basis**.

wet basis. The wet basis is simply the mass of the material before drying. The wet-basis moisture content expresses the ratio of the moisture mass present in the material to the mass of the wet matter. The moisture content is the difference between wet basis and the mass of the dried material (see also **dry basis**).

wood vinegar. Also known as **smoke water**. See **pyroligneous acids**.

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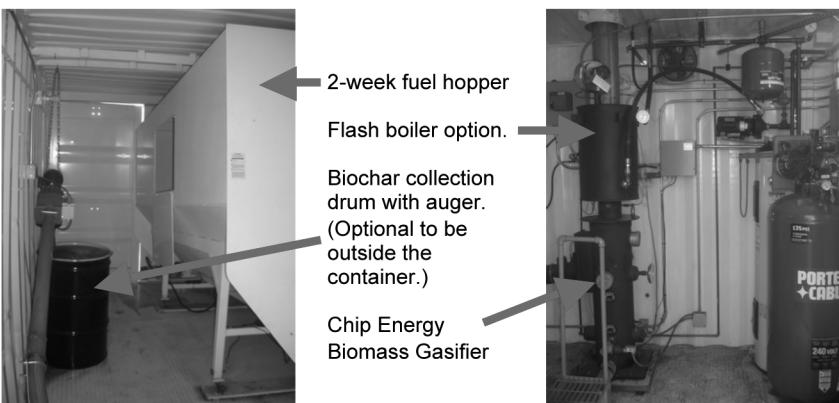
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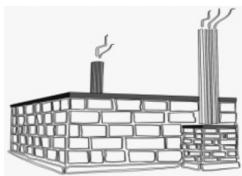
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GLOBAL PUBLISHING
ISBN 978-1-921630-41-5



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