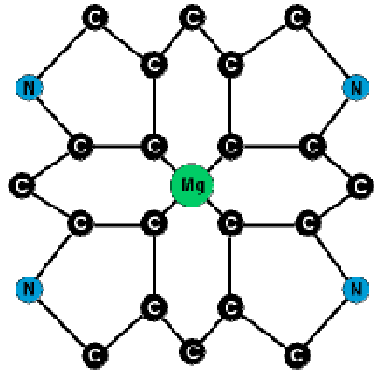


Fig. 1 CHLOROPHYLL

Let Freedom Ring

GEOLOGY INTO BIOLOGY

Carbon, Minerals & Microbes

tools to remineralize soil, sequester carbon and restore the Earth

David Yarrow

Winter 2013

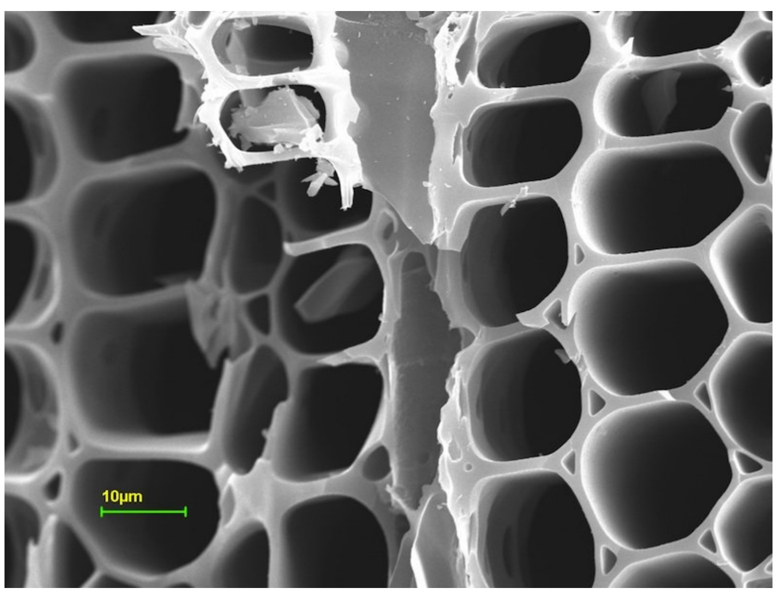
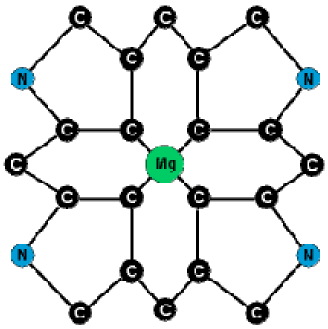


Fig. 2 **Scanning Electron Microphoto**

Cedar Chip Biochar

Juniperus virginianna

Wayne Teel, James Madison University, Harrisonburg, VA



CHLOROPHYLL

GEOLOGY INTO BIOLOGY

Let Freedom Ring

Carbon, Minerals & Microbes

tools to remineralize soil, sequester carbon and restore the Earth

David Yarrow, Winter 2013

We are the Whirled

The 20th Century saw science rise to solar prominence in western society as men analyzed the physical and chemical nature of biology, ecology, industry—of the whole cosmos. A prime paradigm of this previous century was that life is chemistry. This mindset assumed living organisms can be reduced to a menu of atoms and molecules.

Organic chemistry—the chemistry of carbon—grew, as science made rapid advances to spawn a technology revolution and give birth to new industries and global economy. Food was defined as nutritional chemistry. Food processing refined complex living organisms into pure crystals and simple chemical formulas. Farming became a chemical-dependent industry. Medical science used chemical therapy with "miracle drugs" to give birth to pharmaceutical industry.

Now, a more profound and astounding shift to a 21st Century paradigm is underway. The true nature and full scope of this sea change of consciousness isn't well recognized or understood yet. Not only is the planet's climate changing, but multiple geologic, ecologic, economic, socio-politico systems are simultaneously shifting to reach “limits.” Even theology is undergoing rebirth. Our concepts and images of the universe, physics, nature, human identity, and spiritual destiny are in accelerating transformation. Our ways and means to inhabit Earth is also in rapid reformation.

Most mystifying, not only are our ideas of space-time reality changing, our brains are evolving, too. Our very neurological process of awareness is altered, awakening, remembering.

Biological Revolution

The first phase of this revolution in evolution is to realize that life is **Biology**. Emerging insights see that life is more than a matter of physical chemistry. Atoms and molecules are organized in discrete, complex, functioning units called "cells." These tiny, fragile units aggregate into organized, specialized, unified organs and organisms. Our bodies are at least a trillion cells, sharing space inside our skin, all guided by a single, unitary identity.

Earth's diversity of living organisms use specific life cycles, architectures and inter-active functions to associate into family, community and ecology. These very orderly, functional structures of living organisms are a form of biological intelligence encoded in the dance of physical matter. The form, context and organization of nutrients is as important as their chemical formulas. To confront this complexity of biology's inter-active inter-relationships requires a higher order resource called "culture."

Thus, 21st Century farming is probiotic, not antibiotic. This reversal of relationship respects microbes as allies, not enemies. Rather than eradicate them, enlightened growers encourage population explosions of beneficial organisms, starting with micro-organisms. Biological farmers minimize disruptive practices such as tillage, herbicide, fungicide, toxic or harsh chemicals. Instead, carbon-smart farmers inoculate to spread special microbial "cultures." Rather than killing pests, the focus is to create stable environments and favorable conditions for microbes to proliferate and differentiate into stable, complex communities.

Life Energy

Second phase of this revolution is that life is **Energy**. We now understand life's bits of matter also hold and transmit energy. Life's atoms and molecules carry specific energy as polarized charge, kinetic motion, harmonic vibration, and bandwidth.

Charge: Bits of quanta-fied matter share, store and circulate energy as charge, which is fully polarized force. Beginning with pH (acid/alkaline balance), living cells and organisms are electric—and magnetic. Each biological molecule is an ion, with specific electric charges arranged in specific geometries to sustain specific shape, structure and function. The molecular motions of metabolism is this shared kinetic energy of life.

Frequency: Energy isn’t just polarity and charge. Energy is dynamic oscillation, or vibration. As energy, life is also frequency, to transmit not only power, but information as geometric order and synchronous action. Many biomolecules ring at radio frequency—they emit and react to specific frequencies. Orderly, rhythmic, kinetic movement of molecules in cells allows them to coordinate function, hold memory, carry information, transmit intelligence.

This biodynamic energy raises the quantum question: is a cell a collection of particles? or a collision of waves?

Unifying Principle

Information: Energy carries pattern and rhythm encoded as frequency—as in-FORM-ation. Cells communicate by exchanging electric charge, but also by wireless vibrational harmonics. Science has just begun to grasp the electronic functions of living cells, organisms and eco-communities.

Yet, biological cells are crystalline electromagnetic units operating at radio frequencies. Like our smart electronic devices, cells use radio frequencies to operate and communicate at specific scales and bandwidth. Contemporary scientists describing “bioplasmic body,” "solid-state biology" and "quantum coherence" have begun to hear the symphony and chorus of life.

Third phase of this paradigm shift is **Spirit**. An emerging holistic perspective implicitly understands the universe is one. This unifying view appreciates that everything is connected—a single, unitary field. All living beings form a single community. Modern culture and consciousness is evolving toward renewed respect for the Oneness of Creation, and our human responsibility as Stewards to support the planetary web of life, to protect biodiversity and the sanctity of all its participants.

But, reverting to the 20th Century paradigm of physical chemistry, life is exquisitely simple.

Life Elements

Most matter in living cells is four of the lightest, simplest elements. In organisms, 95% of the atoms are, in order of amount: **Hydrogen**, **Oxygen**, **Carbon**, **Nitrogen**. These four **Organic Elements** are most of life’s physical substance and structure..

Of these, the first two together are **Water** (**H_2O**). Most living organisms are 75% or more water. A living cell is a tiny bubble of water held inside a thin-film, oil membrane.

Water's gift to life is, as a fluid, to allow atoms, molecules, cells, and organisms to move around. Movement is life.

Water in an organism is much more orderly than in a cloud, stream, or pipe. Water inside a cell membrane is precisely organized into specific structures, yet is still a freely flowing fluid. Cell water isn't formless, shapeless or motionless, yet still a liquid. Such water is a "liquid crystal"—a dual phase state, when atoms share unifying energy fields, and move and circulate in orderly, synchronous patterns. This harmonic organic unity of discrete objects is “quantum coherent.”

Water’s mystery is this capacity to use the implosion power of vortex geometry to infold pattern through fractal scales to contain, carry and compress spin energy as information, memory and intelligence.

Organic Elements
Hydrogen
Oxygen
Carbon
Nitrogen

Major Minerals	
Cations (+)	**Anions (-)**
Sodium	Phosphorus
Potassium	Sulfur
Calcium	Chlorine
Magnesium	

Carbon: Backbone of Biochemistry

Carbon is #3 of the Organic Elements. Carbon is most of the rest of the atoms in a cell. Life on Earth consists of carbon-based organisms. Complex biological molecules such as sugar, oil, fat, and protein have a backbone of carbon atoms.

Carbon makes four bonds with tetrahedral (4-direction) symmetry. Unlike water's fluid nature, Carbon builds fixed, rigid structure. Carbon’s 4-arm common connector links to two other carbon atoms, to thus create long chains, or “hydrocarbons.” Carbon chains loop to form closed rings. Thus, a small, lightweight atom—Carbon—creates complex structures.

Carbon, thus, is the backbone atom of biochemistry. Nature builds complex biomolecules out of carbon chains and rings. Biomolecules are composed of hundreds, even thousands, of carbon atoms interlinked in chains, rings, sheets, spirals, tubes—even bubbles ("bucky balls"). Among Nature’s most complex Carbons are humus particles in **Soil Organic Matter** (**SOM**)—indigestible residue of bacterial decay.

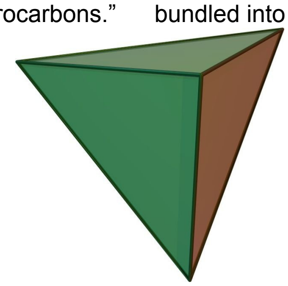


Fig. 3 **Tetrahedron**
4-arm symmetry

Supreme expression of Carbon's creative complexity is DNA—twin helix spiral stairway, with treads and risers made of Carbon—keycode to memory and instruction in every cell’s heart.

Bio-Carbon

Carbohydrate is chemistry’s name for the sweetness of life: sugar. Sweet is made with the first three Organic Elements. This **CHO Trinity** of biochemistry forms various 5- and 6-carbon ring molecules. Carbon itself holds a lot of energy. But these large loops of Carbon hold extra electrons to deliver extra energy in an organism.

But those Carbon rings are also crystals that carry an extra quality of energy. Those extra electrons vibrate at higher harmonic frequencies. Yes, carbohydrates ring in resonance!!

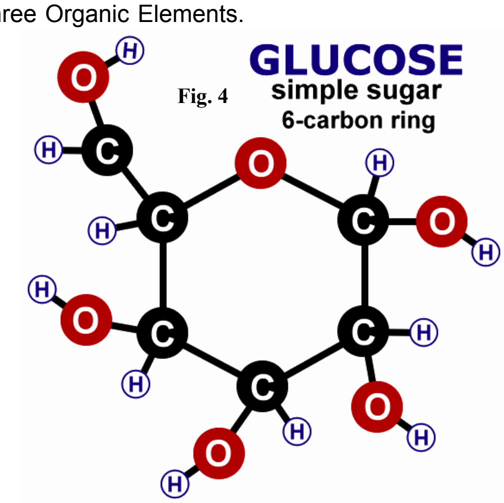


Fig. 4

Sugar is also structure. Plants build their bodies out of sugar spun in spirals. Linked one way, sugars create cellulose fiber, the primary skeletal substance of living plants. Linked another way, sugars weave pleated sheets of starch—a compact, efficient way to stack and store fuel for energy.

Bio-carbon forms complex, massive molecules. Tens of thousands of Carbon atoms interlink as cellulose fiber, cell membrane, enzyme, hormone, and nuclear DNA. Ribose, a 5-carbon sugar, sits at opposite ends of DNA's spiral stairway, linked by amino acid “treads” of each rising step in the helix. Complex bio-carbon structures are made by organisms as diverse as whisker-thin, white fungal threads deep in soil, or photosynthetic green needles 300 feet high in a redwood—as varied as mosquito or whale.

Nitrate, Ammonia, Amino Acid

Nitrogen, the odd member of the Organic Elements, makes 3 bonds to other atoms, also in tetrahedral, 4-arm symmetry.

Nitrogen is ubiquitous on Earth. Nitrogen gas (N2) is 78 percent of Earth’s atmosphere—an inert, stable form plants can't use. Not until Nitrogen combines with Oxygen to form Nitrate (NO3)—by nitrogen-fixing bacteria, or by synthetic fertilizer industry—can crops grow productively, lushly, rapidly.

Nitrogen is a reversible ion. It binds with Oxygen to form anion **Nitrate** (NO3-). It bonds with Hydrogen to make cation **Ammonia** (NH4+).

Nitrogen bonds with two Carbons to form **Amino Acid**: C-C-N. **Amino Acids** link together in longer -C-C-N-C-C-N- chains to become **Proteins**. Some proteins are hundreds, even thousands, of Amino Acids, joined in long chains that are folded, twisted and bundled into orderly shapes and structures.

Nature uses the **Nitrogen Cycle** to change this 3-arm atom from nitrate (-) to ammonia (+), and back to nitrate (-). This Cycle is fundamental to almost all biology, especially animals, whose growth depends on Amino Acids and Proteins. Nitrogen-fixation in soil, and the entire Nitrogen Cycle, is run by bacteria. Microbes control this primary engine of biosynthesis.

These two Organic Elements must be in proper proportion. **Carbon/Nitrogen Ratio** is a key fundamental balance in any biological system, whether soil, compost, microbe, food, or tissue. This ratio also appears as Carbohydrate/Protein, the two basic nutrients in every organism’s diet.

Plants build their bodies from **Carbohydrates** that are spun into chains of **Cellulose** fibers.

Animals grow their tissues with **Protein** formed by chains of **Amino Acids**.

Geology into Biology

After Organic Elements, the 5% of atoms left in a living body are loosely labeled "minerals." These physical elements are the simplest matter—tiny bundles of protons, electrons and neutrons that are called “atoms.”

“Atom” is a physical science term. “Mineral” is a word from geological science. The two are similar, but different, often confused. In geology, “mineral” is a molecule formed when two or more physical “atoms” react, bond and associate together. In short, minerals are atoms that got married. An element atom is one of many in a mineral molecule.

These discrete bits of matter aren't synthesized by plants, animals or humans. These elements are the cold stardust of the cosmos, collected, condensed and compressed into the bedrock and basalt of a planet. We can't make or manufacture these centers of density. We get them direct from Nature.

To see majestic Rocky Mountains, or peer into deep valleys like The Grand Canyon, is a glimpse at ancient layers of the planet's bedrock of minerals. Those dense, hard rocks are source and substance of the basic building blocks of life. From crystal bedrock density, Nature dissolves, selects, organizes mineral elements to build cells and organisms—atom by atom, molecule by molecule.

Elements and minerals are fundamental for life. My analogy is building a house. First, a foundation is laid of natural or synthetic stone. Similarly, to build biology, after water, next comes the minerals—the geology. Then comes sills, walls, floors, doors, windows, rafters, roof, closets, counters, shelves, appliances. Biological molecules—carbohydrate, protein, oil, and all—are like the house framing, flooring, fittings, and furniture. Even wooden members need little metal mineral nails or screws to join together and hold their shape.

This is the mineral imperative: geology underlies biology. Minerals are the stable, solid foundation to support the biological infrastructure of cells and organisms.

This is a key insight into how Nature works—how geology becomes biology. Specific, special processes, partners and relations govern how raw, elemental minerals transform into dynamic, organic, living, cellular protoplasm. Gradually, stones and bones of the land are ground down to dust and dissolved into watery solution, to become life's elemental building blocks.

Bread from Stones

In the Christian ***New Testament***, when Jesus was fasting for 40 days, Satan tempts him to turn stones into bread. This Gospel parable of rocks and food is a profound and true teaching about minerals and grain. The miracle of life transforms bedrock into biology—turns stones into food. In eons of evolution, Nature experimented with countless ways to transform bedrock elements into edible nutrients, then into cell protoplasm in living organisms.

And of all foods, seeds are the key, source and secret of plant life—and thus, of all animals.

Plants, through their roots, take in water and minerals from soil to transform into protoplasm and cells. The mineral elements must be in the soil for plants to get them. And the minerals must be in plants for animals to get them. If any essential element isn't in soil, then it must be imported from elsewhere and added to the soil, or else biology suffers a deficit.

So, these elements and minerals are gotten from the rocks of the planet—geology of the Earth. Varied chemical and biological processes transform inert rock into living biology. Most minerals are digested by microbes, which nurse the roots of plants, which become food for animals. Thus, stone becomes bone.

Most of biology depends on this disassembly, dissolution and decay of rocks into soil. Most of all, it is bacteria that digest minerals in cellular protoplasm, and thus build the fundamental molecules of life. It begins with water, heat and cold etching and weathering the bare rocks. Eventually, lichen, moss and tiny, simple life forms encrust the stones to slowing dissolve and digest the minerals into replicas of themselves. In their death, their bodies become food for the next cycle of the soil food web that sustains most of the life on Earth.

So, soil is a living matrix to turn minerals into organisms.

Trace Elements

Cations (+) **Anions (-)**

KNOWN (proven essential)	
Iron	**Iodine**
Silicon	**Selenium**
Copper	**Fluorine**
Zinc	**Boron**
Manganese	
Chromium	
Cobalt	
Vanadium	
Germanium	
Molybdenum	
Nickel	
Tin	
Lithium	

UNCERTAIN (new data)	
Yttrium	**Bismuth**
Silver	
Gold	
Lanthanum	
Neodymium	
Platinum	

Microbes as intermediaries turning rock minerals into primary cell metabolism.

There are three kinds of rocks in the Earth's crust: Igneous, Sedimentary, Metamorphic.

Igneous bedrock generally forms from very hot, molten magma inside the Earth. Volcanic lava is magma that reaches the Earth's surface, but many igneous rocks form under the sea, or inside the Earth. Igneous rocks are very dense, highly crystalline, with heavier elements. Elements in these rocks aren't reacted or weathered into complex mineral compounds. Electrons in their outer orbits are available and ready to form bonds with other atoms to begin building complex molecules.

Primary igneous rock is weathered, worn away and washed into solution, and carried by rivers to the sea. Sediments from these eroded rocks were deposited on coastal sea floors. Other sediments formed from biological activity and bodies of living organisms. Then, over tens of millions of years, these deposits were hardened again into new bedrock—layers of Sedimentary stone—mostly shale, limestone and sandstone.

In planetary geology, certain processes periodically renew the minerals in soil. Annual spring flooding of rivers is a common way primary soil mineral are replenished, which is why many civilizations arose in river valleys. Volcanic eruptions distribute new minerals on Earth's surface as ash and lava. At longer intervals, glaciers in Ice Ages grind rocks to powder and distribute them by ice and water. Mineral springs are another process that brings deep minerals to the surface to renew soils.

In a more limited, local way, deep-rooted plants mine minerals from subsoil and scatter them on the land surface to replenish primary minerals in the root zone of soils.

Today, we face an urgent crisis of soil, water and climate. This man-made calamity begs for a man-made remedy. Or we can wait centuries for natural processes to restore minerals, renew soil, regenerate microbiology. Creating sustainable, enduring soil fertility is the foundation of any effort at Earth

Iron Fortification

Iron fortification of food is recommended when dietary iron is insufficient, or of poor bio-availability. This is reality for most developing nations and vulnerable populations in developed nations. Iron deficiency and anaemia in vegetarians and developing nations dependent on cereals or tubers is higher than in omnivore populations. Iron is present in foods in two forms:

Heme: from flesh foods (meats, poultry, fish); highly absorbed (20-30%); bio-availability relatively unaffected by dietary factors.

Non-Heme: inorganic form in plant foods: beans, grains, nuts, vegetables; lower absorption rates (2-10%); depends on balance between dietary iron absorption inhibitors (phytates, polyphenols, calcium, phosphate) and enhancers (ascorbic acid, citric acid, cysteine peptides, ethanol, fermented products).

Staple foods worldwide provide mostly non-heme iron of low bio-availability. Traditional staple foods are excellent for iron fortification: wheat flour, corn (maize) flour, rice, salt, sugar, cookies, curry powder, fish sauce, soy sauce.

Benefits of consuming iron absorption enhancers are extensively proven, and should be promoted (i.e. consume vitamin C-rich food together with non-heme iron source).

***Human Vitamin and Mineral Needs**, 2005*
United Nations World Health Organization (WHO)
Food and Agriculture Organization (FAO)

restoration and Nature regeneration.

Major Minerals

Most of this 5% of essential elements are the very lightest atoms. The seven **Major Minerals** are commonly present in organisms at parts per thousand.

Four are cations, with positive, alkaline charge:

Sodium, Potassium, Calcium, Magnesium.

Three anions have negative, acid-forming charge:

Phosphorus, Sulfur, Chlorine.

These small, simple atoms have few electrons in their outer orbitals, and their orbit diameters are very short. Thus, they easily give or take one, or two, or three electrons to become ions with a strong electric charge. Thus, they are very reactive. In cell biology, minerals are the centers of charge: negative and positive electric ions. In solutions, their electric charge exerts strong attraction on other atoms to organize their arrangement in space. This electric charge is the "fire in the water" of biological life—the spark of chemical fire that allows atoms to react and bond.

Major Elements have specific functional relationships, and exist in cells and living tissue in fundamental, broadly universal proportions. In general, these seven exist in easy-to-remember ratios—about 1-to-7.

A prime example of this proportion principle is Calcium and Phosphorus. This cation—anion pair is essential for energy exchange and transport, especially sugar synthesis and metabolism. Calcium and Phosphorus are the two main minerals in your bones, and are also essential in soil. Ideally, calcium is 65-75% of base saturation, and phosphorus is 1/7th (9-12%).

Trace Elements

Beyond four Organic Elements and seven Major Minerals, other elements are known to be necessary for life and health. But these other elements are needed at much less than parts per thousand. A few lesser elements are Minor Minerals (Iron, Boron, Silicon). The rest are **Trace Elements**, required at extremely minute amounts—commonly, a few parts per million.

Trace elements are new to science and medicine, due to ongoing research discoveries in recent decades. At present, over 20 Trace Elements are identified as essential for healthy biology. Most were discovered only in the last century, and our understanding of their roles in cell biology is a still-unfolding story.

Yet, because of solid science abut these minerals, it's public policy since 1941 that all "refined" flours are "enriched" with Iron. The medical reality of one Trace Element nutrient is so well known that all table salt (except sea salt) is "iodized."

Iodine is added to commercial salt because it is documented science that iodine deficiency results in birth defects affecting the brain, mental development and the thyroid. Inadequate iodine is a proven cause of thyroid hormone deficiency. Iodine deficiency disrupts neurologic and endocrine hormones, while excess is still a common medical disinfectant.

Cobalt is the trace element co-factor in vitamin B12 (cyano**cobal**amin), its only known use in humans. Cobalt is only needed at parts per million—a tiny speck that fits on a pinhead.

Yet, without cobalt in B12, your body can't make adequate red blood cells, and red cells it makes are swollen, enlarged, and weakly attract oxygen. Without B12, nerves have less ability to transmit energy, causing numbness. Without a microgram of cobalt, DNA replication into messenger RNA slows, and key protein synthesis can slow, even halt. Without a speck of one element, key pineal and pituitary hormones aren't made.

Without a few micrograms of cobalt, you're a corpse.

Iodine Fortification

Iodine is sparsely distributed on Earth. Foods grown in soil with little or no iodine will lack adequate amounts. Only marine-origin foods are naturally iodine-rich. Thus, iodine deficiency disorders were prevalent in many countries before salt iodization.

Salt is used by most people worldwide, so salt iodization is the best way to eliminate iodine deficiency. A well-implemented salt-iodization can eradicate iodine deficiency disorders.

Iodine must be added within safe, effective ranges, usually 25 to 50 mg/kg salt. Actual amount is set by each country's salt intake level and deficit magnitude.

Salt iodization isn't just a legislated mandate. Each nation must determine the best fortification technique, co-ordinate implementation at all salt production sites, establish monitoring and quality control, and measure iodine fortification periodically.

Difficulty implementing salt iodization arises mostly when salt industry is dispersed among many small producers. A monitoring plan must assess the amount at consumer level. United Nations agencies provide technical support to implement, monitor and evaluate to ensure sustainability.

Human Vitamin and Mineral Needs, *2005*
United Nations World Health Organization (WHO)
Food and Agriculture Organization (FAO)

The Most from the Least

The powerful systemic effects of Iodine and Cobalt illustrate the power of Trace Elements. These atoms are needed in very tiny amounts, yet have tremendous effects on biological organisms. This miracle of the micro-dose is because these least of all the elements are key co-factors in catalysts, enzymes, hormones and other biomolecules that accelerate and regulate metabolism. Iodine and Cobalt are key trace elements for endocrine hormones. Their miniscule presence is enhanced and amplified by their special uses as critical metabolic regulators.

Modern electronics is based on a similar microdose miracle. Diodes, transistors and solid state electronic devices are made by growing highly purified crystals of semi-conductors such as Germanium or Silicon. These crystalline materials have their atoms arranged in orderly, prefect arrays, with precise geometry and symmetry. These super-pure, perfectly orderly crystals then have another element added at extremely low levels of a few parts per million. Adding a tiny trace of another element distort the crystal structure, and alters electron distribution, thus affecting their electric characteristics.

Such exotic electric effects of crystals carefully contaminated with parts per million of another element allow a tiny electric voltage to control a large flow of electrons. These semi-conductor crystals then become microscopic, super-fast, super-sensitive switches and gates in sensor, amplifier and logic circuits of modern electronics.

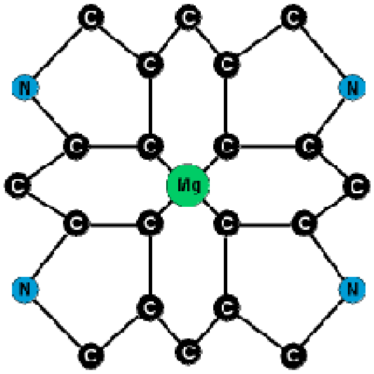
Similarly, in biology, tiny amounts of certain elements have dramatic effects on energy flow in and between living cells. A trace element at parts per million embedded in endocrine hormone molecules can turn on or off key biological systems for growth, immunity, awareness, memory, reproduction, or detoxication. And often, trace element deficits don't appear as a disease, but as less than optimum biological function.

Nano-nutrients & Pico-elements

In recent decades, accumulating evidence in biology and medicine indicates that some elements are needed by biology at "beyond trace" levels—at parts per billion, even less. These "nano-nutrients" use complex geometries and dense energies of the heavy elements to build nature's most complex biomolecules. Greater complexity stores higher intelligence.

But lab data hints that a few elements are needed at parts “beyond billionths”—parts per trillion—millionth of a millionth. These "pico-elements" are present in cells at the current threshold of detection by laboratory equipment and methods. Even if biochemical assays detect these rare elements at these beyond-micro levels, biology has little insight into their roles in cell structure and function. But clearly, they're keys and catalysts to enhance biochemical reactions and metabolic pathways.

These dense, heavy atoms are very large, with huge, complex clouds of orbiting electrons. This multitude of spinning electrons provides these elements with multiple valence energy levels to bond with other atoms. These heavy atoms use unique and complex geometries to coordinate and organize their electron bonds to other atoms—not four bonds, like light and simple Carbon, or six, like Cobalt—but twelve bonds, even as many as 20 links to other atoms.



CHLOROPHYLL

These more elaborate geometries are used to build Nature's most complex biomolecules. This molecular complexity encodes the most intelligent functions of cells and organisms: immunity, reproduction, neurology, endocrine hormones, and high-level metabolic processes. If we appreciate the critical and essential roles of Trace Elements to regulate and accelerate metabolism, we can begin to imagine the synergistic effects of pico-elements.

Taken together, a gathering mass of scientific data and detail suggests human physiology doesn't need a few elements. Our bodies don't need a mere dozen elements, or even 25, or only 33. Increasing insights from research encourage the assumption that human biology needs nearly every element in The Periodic Table—as many as 76, likely more.

Consider the Platinum series, at the very bottom of The Periodic Table of Elements. These heaviest elements have 72 to 80 electrons in orbitals organized by the geometry of 5-sided symmetry. These elements have over twelve valence electrons, allowing them to create gradual, controlled cascades of electron energy. These rare elements provide very special services to cells needed by Nature's most complex, exotic, potent, and intelligent biomolecules, including DNA, endocrine hormones and neuro-activators.

Thus, intravenous solutions for medical injection should contain—not just Sodium Chloride, or even only the Major Minerals—but nearly every water-soluble element. And these elements must be in specific ratios or ranges suited to human physiology. And the same true for fertilizers to supply primary minerals to assure optimum, healthy plant growth.

To get the best, the most growth, we must provide these least of al the elements—not just three (NPK) or merely a dozen.

Chelation: pack & stack with Carbon

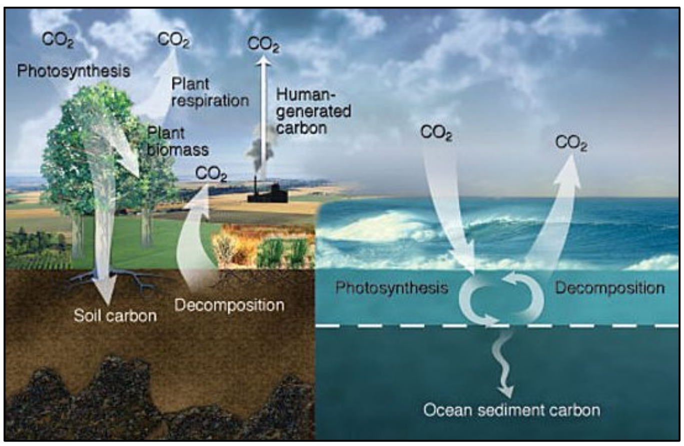
As ions, atoms deliver power to chemical reactions of cell metabolism. The strong electric charge of these mineral atoms—mostly metals and non-metals—attracts other atoms and arranges them to form orderly structures with specific geometries and symmetries. The ion charge of highly polar atoms is too strong to simply float in solution. Pure sodium, for example, is so reactive, it explodes with a "POP" when it touches water.

So, Nature separates these strong ion charges, to carefully isolate their electric power. An ion's powerful charge must be buffered, contained and controlled, lest it disrupt the careful order inside a cell. An ion's strong electric field must be organized and focused to form stable structures, and to deliver useful charge to enzymes in as cell's chemical reactions.

when I studied Basic Electricity in high school, Carbon was a "resistor" in our circuits. Carbon is neither a good conductor, nor a good insulator. It's a "semi-conductor," like Germanium and Silicon crystals in solid-state electronics. Thus, Carbon allows strong electric charges to be Isolated, separated, contained. In biology, individual ions are almost always enclosed in Carbons.

So, in a cell, Nature embeds an ion amidst Carbon atoms or other molecules to insulate and focus the charge. A cell organizes an energy field around an ion to create a structure to package and harness a strong electric charge. In biochemistry, ions are enclosed in Carbon rings or a cloud of biomolecules.

Fig. 6: **The Carbon Cycle** (simplified)

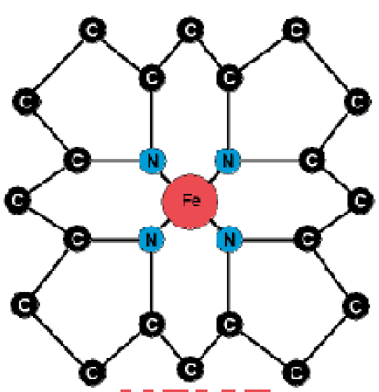


In cell protoplasm and body fluids, mineral ions are held in a matrix of Carbon atoms. Thus, a cell can hold a strong electric charge in a stable, sustaining shape. The ability to hold charge in a stable shape is what creates cellular memory. At molecular, cellular and organism scales, shape creates identity.

In biochemistry, embedding ions is called "chelation." In modern nutrition, mineral supplements are "chelated" with biomolecules to improve their absorption in intestines. Calcium, for example, as raw mineral element, is only 15 percent absorbed. But *chelation* with Carbon biomolecules can boost calcium assimilation to 80 percent. Modern medicine uses *chelation* to transfer specific minerals or biomolecules in the body, or to target specific cells.

Sunshine into Sugar: freedom rings

One key biomolecule is a perfect portrait of this marriage of Mineral with Carbon: **Chlorophyll**. This large, complex molecule gives plants their green color, and is the antenna of **Photosynthesis** to capture sunshine to create sugar. Ultimately, plants use sunshine to combine carbon dioxide (CO2) with water, converting them to carbohydrates and oxygen.



HEME

Chlorophyll is a large biomolecule formed from a few dozen atoms. A single Magnesium atom sits at the center, surrounded by rings of Carbons and four Nitrogens. When a photon of light strikes the Magnesium in the heart of this orderly Carbon array, this creates a molecular vibration to advance a 5-step cascade that converts high frequency light into electric charge.

So, photosynthesis begins when a Magnesium antenna intercepts a photon of sunlight. High frequency light transmits an impulse to the Magnesium atom. This pulse triggers ringing in Carbons around it—a molecular vibration that is transferred to other molecules in the plant's photoreaction center.

Eventually, a 5-step Water Splitting Clock will pry a Hydrogen off a Water molecule nearby, liberating an electron and a proton. Plant photosynthesis captures four photons to pry four Hydrogens off two Water molecules, yielding one Oxygen molecule, four protons and four electrons. Now the plant has the strong electric charge needed to fix Carbon into Carbohydrate.

Chlorophyll's remarkable Ion—Carbon geometry, symmetry and synergy gets evermore extra-ordinary.

Heme: flip side of photosynthesis

Animal blood is red due to cells packed with **Iron** in **Heme** molecules of **Hemoglobin** (globin=protein). Thousands of Heme molecules stack inside each red blood cell to attract Oxygen, and carry it to a cell to burn sugar and release energy for metabolism. Heme has nearly the same geometry as

Chlorophyll, except four Nitrogens flip inward, and peripheral Carbons and Oxygens are rearranged.

Besides their remarkable symmetry of structure and function, Chlorophyll and Heme illustrate how strong electric charge of ions is buffered by being embedded in Carbons, and thus organized into a functional bioenergy field. Carbon allows cells to safely acquire, move and use the electric charge of mineral ions, and harness their energy in cell metabolism.

Carbons distribute the electric charge of an ion to shape it into a focused field. Thus, electric charge can be harnessed to make or break bonds, to build specific geometry and structure, and to create energy flows, including electron cascades and radio frequency ringing.

Carbon Cycle: Complexity & Diversity

Carbon is one of Earth's most mobile, labile and facile atoms. It's in constant change, moving around the planet, making molecules in new organisms, assuming seemingly endless forms and complex structure. Carbon's most amazing disguises are as Carbohydrate and Amino Acid. As sugar and protein, Carbon forms the biological bodies of plants and animals. As living organisms, Carbon achieves its greatest complexity and diversity, from microscopic fungal mycelia to giant redwoods and whales.

In soil, diversity is as crucial as quantity and proportion.

Today, billions of extra tons of CO2 sit in the atmosphere, changing climate around the world. Global warming makes us aware of Carbon's movement as CO2 and methane into Earth's atmosphere. Carbonates (CO3) are carbon bedrock—mostly limestones—fossil skeletal shells of cells that lived in Earth's ancient sea—buried as bedrock for millions of years. Coal is fossil Carbon from the cellulose bodies of ancient trees that we mine today to burn for energy.

Soil is the largest carbon storage on land: three-quarters of land-based carbon resides in soil. Plants take in carbon during growth. When they die, this carbon enters soil. Soil carbon is like a bank: it can either remain in soil, or quickly return to the atmosphere. Modern soil management drains the soil carbon bank, and depletes our capital, rather than gaining new interest.

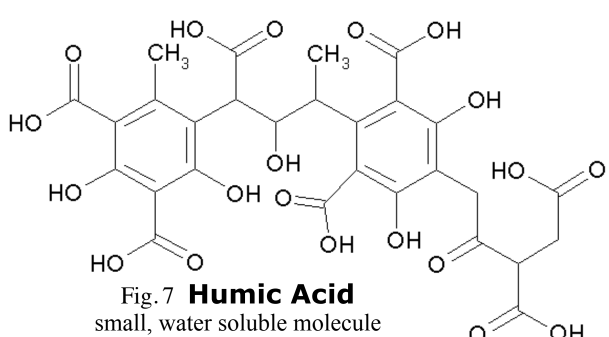


Fig. 7 **Humic Acid**
small, water soluble molecule
28 Carbons — 2 rings

Carbon is accumulating in Earth's atmosphere, fed by fossil fuels, deforestation, soil destruction, and industrialization. Carbon movement from biosphere to atmosphere is causing a thermal imbalance known as "greenhouse effect." Our Carbon emissions are now known as a pollutant that is a menace to life on Earth. The Carbon Cycle that kept the Biosphere in a remarkable state of stability is now falling out of balance, threatening rapid-onset, runaway climate change.

Food production is releases at least 30% of man-made greenhouse gas emissions. Deforestation to remove trees for farmland is 20% of Carbon emissions. Carbon and Nitrogen outgas from fields subject to routine tillage, monoculture and synthetic fertilizers. Half of US-produced hydrogen is used to make nitrogen fertilizer—most from methane, a greenhouse gas.

Carbon in soil comes in an incredible array of chemical forms. A fertile, functional soil is alive, and not only needs lots of Carbon, but Carbon in a wide variety of forms. However, until lately, soil science interest in soil Carbon was minimal. Science has just begun to recognize and sort out the diversity and complexity of soil Carbon.

Prepare to plunge into the black hole of Carbon Complexity.

A Sense of Humus

It's no joke to say 50 years ago, soil science had no sense of humus. Soil was seen as inert dirt—a structural media to support plants, and hold water and dissolved nutrients. No one investigated soil residues of dead fungal bodies. No one studied the unique roles of charred Carbon in soils. No one measured soil microbe respiration.

A consequence of this purely chemical view is that in the 20th Century, soil Carbon declined steadily, and in far too many soils, approached zero. On the Great Plains, soil organic matter has decreased from a historic 8 percent down to a current 2 percent. Similarly, biological activity in soil dropped, as soils became increasingly sterile and lifeless—inert dirt. This reduction in soil carbon and life is unhealthy for plants, but also had a big impact on human carbon emissions.

Humus, a complex organic substance, occurs naturally in soil and compost, the result of plant and animal matter that rots, decays and decomposes. Like air, humus is abundant, renewable, essential to life, but far more complex. After hundreds of years of research, no one knows exactly what humus is.

Soil science uncertainty about humus is mirrored by an ambiguous definition. "Humus" originated as a scientific word in late 18th century from Latin for "earth, or ground." Like "organic," "humus" has multiple meanings defined with varied precision. Most often, humus is a generic term for all kinds of carbon. In agriculture, humus is mature compost, or natural compost from forest or prairie soil. Humus also is a topsoil horizon that contains organic matter.

Technically, precisely, humus is the final product of decaying plant and animal residues. Scientists say if it's not stable, it's not humus. Stable humus complexes survive thousands of years. Compost is able to decompose further, and thus is classified as "active humus." "Passive" humus is humic acids and substances so tightly bound to clay and hydroxides, microbes can't penetrate them, thus they resist further decay. So, stable humus adds few available nutrients to soil, but does supply essential physical structure.

But humus is never static. It's dynamic, always changing, in constant digestion. So, it's hard to refer to it as "end product." This confusion reveals vast unknowns about humus chemistry.

Humus begins when plant and animal residues are eaten by microbes. Carbon molecules synthesized by plant and animal are now food for bacteria, fungi, algae, actinomycetes, yeasts, and all microbes of decay. Microbes dismantle sugar, starch, protein, cellulose, and other carbon-based molecules. Nutrients and energy released by this microbial digestion are used by microbes and plants. Some revert to CO2, water and other gas. Some mineralize back into plant foods. Some resist rot, and accumulate as indigestible residue.

As Nature nibbles at complex, large biomolecules, something remains. Every biomass leaves some sort of indigestible residue. This inert, inedible, black residue is true **Humus**—left-overs from microbial feasts.

This residual volume varies with type of biomass, climate and environmental conditions, but is in the range of 5 to 15%. The decay-resistant molecules have been altered by microbial digestion. They consist mostly of Carbon in the form of extremely large molecules, usually with multiple Carbon rings, embedded in long, branching Carbon chains (*see Fig. 8*).

Information on humus identifies specific chemicals and certain components. Its nature and properties are well-known. Factors that control it are common knowledge.

Yet, an accurate way to extract humus from soil has yet to be devised. This itself limits the study of humus. Further, humus in one soil differs structurally, chemically, visibly from humus in another soil. So, it's simplistic to call them all the same thing.

Until recently, humus molecules were too large and complicated to study. Only in the last decade did science acquire tools to accurately map and measure these complex Carbon structures. Now, with advanced high-tech tools such as x-ray crystallography, scanning electron microphotos (SEM), and super-computer 3D imaging, scientists can peer at these massive molecules and begin to decipher their structures and functions.

Humus, while very stable, continues to decompose at a very slow rate, dependent largely on external climate factors such as temperature and moisture, but also the character of the source biomass. The lifetime of humus in soil is variable, but easily several decades, and in some circumstance, over a century. In some environments, humus may remain for a few centuries.

SOM: Soil Organic Matter

So, plants create "Organic Matter" (OM) by photosynthesis and metabolism. In death, their Carbon-based bodies become debris and residue. Microbes eat this dead biomass, and turn it back into water, CO2, plant food—and humus.

As OM's complex biomolecules break down by weathering and digestion into simpler substances, they release energy and nutrients to feed other organisms. Easily digested residues are re-used over and over by organisms, and never become humus.

OM, then, is organic debris in the process of becoming humus. And humus is the most stable, persistent form of OM.

In the 1980s, we drafted *Certified Organic Standards* for food, not just in the US, but worldwide. Agreement was universal that organic farming's foundation is use of natural methods and materials to maintain soil fertility. Our complete consensus was that soil must have a minimum of Carbon as "Organic Matter." Certified farms must show soil tests with 4 to 5 percent soil Carbon. But Carbon's complexity was lumped under one broad, vague term: "**Soil Organic Matter**" (**SOM**).

To most minds, **SOM** is decayed and decaying biomass—rotting bodies of dead organisms—mostly plants, but also animals and their manures. SOM isn't a stable, fixed substance, but a complex concoction of biochemicals in the process of digestion and transformation. In most environments, SOM is in a state of rapid flux as it changes and degrades into simpler substances. Most SOM—85 to 95%—eventually reverts back to CO2 and water—the **CHO Trinity**.

SOM contains more than Carbon, or only Organic Elements. Dry and burn it, and a whitish powder remains: ash—the oxidized minerals. So, embedded in SOM's Carbon matrix are atoms and ions of metals and non-metals—major minerals, trace elements and all the least elements. These embedded ions support SOM structures and clusters, and create electric charges on surfaces of huge SOM molecules.

SOM holds other mineral ions on its surfaces by ***adsorption***, a weak electric attraction between atoms with opposite charge. The adsorped minerals enrich the SOM, and allow soil to acquire and hold electric charges. The ions aren't bonded, but lightly held in loose association, so they're easily available to soil organisms and plant roots. Once held by SOM, ions are less likely to dissolve and flow through soil with water from rain or irrigation. Thus, nutrients stay in soil near the top, where they're available to microbes and rootlets.

SOM improves soil structure and increases water absorption and retention. SOM's large, complex Carbon molecules insert themselves between soil particles to separate them, create open spaces, and form supra-molecular superstructures that allow soil to breathe. Looser soil structure also allows water to easily enter and pass into soil. Open spaces in and around clusters of SOM molecules store water in soil, keep it wetter.

SOM is the essence of "Recycling"—the breakdown, release and re-use of nutrients to grow new organisms. In gardens, the icon of this microbial recycling is **Compost**—a deliberate, sometimes carefully constructed, heap of OM that turns plant wastes and weeds into black, crumbly, lightweight soil ingredient. It's hardly hyperbole to say Compost is legendary to enhance fertility and renew plant growth.

SOC: Soil Organic Carbon

Unfortunately, SOM is a simplistic idea to describe one of the planet's most complex structures: **Soil Organic Carbon**. SOM isn't just dead, decaying biomass. Missing from this SOM concept are living organisms—the microbes and larger organisms—tiny life forms that actively digest and disassemble OM's massive molecules. Complex communities of microbes inhabit the biomass, converting rotting carbon skeletons into food and energy.

So, OM isn't just rotting debris. OM also includes the living organisms actively digesting the inert biomass. OM contains and shelters this microbial community—an interactive assembly of diversity of Nature's smallest, simplest, most ancient organisms.

A significant fraction of Soil Organic Carbon exists as cells and bodies of living organisms. One cup of living soil is estimated to contain a few billion bacteria, a few million fungi, a few thousand pinhead-size creatures, and a few earthworm cocoons. The interaction of these microbial communities takes our quest for Carbon's complexity into a deeper dimension of diversity.

Agriculture has just begun to assess this living biomass as a critical to sustainable soil fertility, and able to convert currently infertile land into productive soil. The new 21st Century agriculture studies this soil biology, applies probiotic methods, mimics microbial interactions, and harnesses their symbiotic functions to grow stronger, healthier crops. We need to learn much more about this living soil ecology, and employ them as primary allies in soil fertility.

Currently, the only simple, economical way to evaluate the presence of soil organisms is a Solvita respiration test. A soil sample is sealed in a jar, and the conversion of O2 to CO2 is measured. This provides a rough measure of biological activity in the soil sample. However, we need better, simpler tools to evaluate soil biology—not only quantity, but diversity.

Dozens of types organisms are the denizens of soil, each with families and species, all working together to sustain soil's fertility and stability. This world of tiny, invisible life forms is easily as complex and diverse as our large-scale realm of biology and ecology. But microbes are among Earth's oldest communities of life—among Earth's earliest inhabitants. Soil isn't just inert geological matter, but a living tissue—Gaia's thin skin, covering the surfaces of the planet.

Soil Food Web

In recent years, science began to study the complex biochemistry and ecology of soil biology, and thus SOC. My own encounters with USDA and NRCS directors and board members convinced me this new biological paradigm is firmly in the minds of most agricultural leaders, and they are receptive to new probiotics strategies to work with soil life.

Dr. Elaine Ingham at Oregon State University, a leader in this research, developed the concept of the **Soil Food Web** to identify and describe this complexity of cooperating organisms. Dr. Ingham created ways to assay and quantitatively evaluate the many different categories of soil organisms. Dr. Ingham trained hundreds in Soil Food Web technology, who are now soil consultants all over the world. Dr. Ingham also developed ways to propagate and promote this living soil biology, most notably, by the technique of Compost Tea.

So, peering into Carbon's roles in soil opens windows into a tremendous complex biochemistry of tiny cells, microbiology and molecular life. We're still learning about these invisible-to-the-eye soil communities. Science is discovering Nature has used nanotechnology and quantum physics for millions of millennia.

The Humus Society, a new international association of scientists and researchers, meets every year to review new scientific papers on the complexities of soil Carbon. In 2010, for the first time, the Society was addressed by a biocarbon expert on "biochar," Dr. Hugh McLaughlin.

Charred Carbon

SOC's newest, most intriguing disguise is as charcoal, made by charring biomass in a smoldering fire. Charcoal is a common, well-known substance worldwide—preferred fuel for cookout and barbeque, preferred media for water filtration. Yet, ten years ago, adding charcoal to soil was nearly unknown in western agriculture and ecology.

But, a 2009 international conference in Birmingham, England adopted the term **biochar** to describe special charcoal made to add to soil. And since that soil will grow food to feed humans, special, higher standards must apply to this charcoal.

Biochar is a carbon-rich solid made by ***carbonization***, when biomass is heated with little or no oxygen (O_2) at low temperatures (<700°C). Instead of complete combustion to ash, an oxygen-starved fire smolders by **gasification**—releasing gas, vapors and smoke, leaving behind charred Carbon, or charcoal. Biomass can be wood, manure, leaves, straw, cornstalks, rice hulls, or any burnable organic waste.

Biochar added to soil improves soil fertility and health, filters nutrients, keeps them from leaching, provides Carbon storage, cuts greenhouse gas emissions, and a host of other services. Biochar's promise and promotion is a way to sequester Carbon that is measurable and verifiable for Carbon offset protocols.

A side effect of adding biochar to soil is it's then easy to grow nutrient-dense crops.

In 2010, USDA Sustainable Agriculture Research and Education (SARE) funded Iowa farmer John Topic to build charcoal kilns and add biochar to his heavy clay soils (FNC10-807). In fall, he tilled a few tons per acre into a test plot, with cow manure compost. Next spring, he wrote in his report:

> *"Untreated soil was gooey and waterlogged. Soil with only composted manure was also sticky. Soil with char only was more friable, less gooey. But the char and manure mix was like potting soil, requiring only a twist of the wrist to loosen the surface."*

Yet, until very recently, hardly anyone in agriculture, botany or soil science ever thought to use charred Carbon in soil. But what's new to science and farming has 6000-years of success in South America.

The Uniqueness of Charcoal

Charcoal is the most unique adsorbent known to man because of variable size and shape micropores COMBINED with constant electric surface charges. Far beyond empty space, the walls of char maintain many surface charge sites to trap and hold much smaller "stuff" than pore size and configuration would indicate.

Plants know how to go into the char and de-energize or reverse polarize the plates to overpower attractive forces. Root hairs and gels coordinate to become a microscopic organic ion vacuum cleaner.

Charcoal is a catalyst, releasing its goodies as conditions dictate. The analogy that works for me is electrostatic filters. Relatively open flow, but catching the small stuff by using surface attraction.

Black powder makers use very specific charcoal recipes to tailor powders for fast or slow "pop". To this day, biomass-based char from distilled mountain alder consistently provides the best "pop"—highest instant energy release of any char available.

—**Doug Brethower**, Freedom Biomass Resilience Movement, Missouri

Terra Preta: Amazon Dark Earths

While putting charcoal in soil is new to western science, this method began 6000 years ago, in western Amazon rainforests, where indigenous tribes used charcoal to convert heavy, acid clays into fertile, stable topsoil. In 2000 years, this spread east to the mouth of the Amazon. By the time of Christ, enough land was converted to feed millions of people.

The first Spanish conquistadores to travel the Amazon saw tens of thousand of living densely along the river, with larger settlements further in the forest. Yet, 70 years later, when more Europeans visited the Amazon interior, no sign of huge populations was evident. The indigenous tribes vanished without a trace, leaving only a few scattered villages. Reports of densely populated Amazon cities became a myth named "El Dorado."

Early Portuguese settlers, surprised by these remarkable, productive soils, named them "*terra preta*," meaning "dark earth," due to their near-black color. They were preferred for agriculture, especially to grow sugar cane, so highly prized, they were dug to sell as potting soil. Even in intensive cultivation, *terra preta* sustained strong, healthy plant growth. In contrast, surrounding rainforest clays are poor, acidic, weak, with virtually no carbon, low ion storage capacity, and grow inferior, stunted crops.

At first, explorers assumed these desirable, dark soils were unusual geologic deposits, or river sediments.

Then, in 1966, Dutch soil scientist Wim Sombroek published ***Amazon Soils***, in which he made a case *terra preta* soils were man-made by indigenous tribes, and are black due to large amounts of added charcoal. At first, his idea was rated preposterous, but Wim made a solid scientific case.

Since then, further studies documented that *terra preta* is man-made. Archeologists from several countries made dozens of digs to document *terra preta*, verify their human origin, and assay

What is Biochar?

International Biochar Initiative
www.biochar-international.org

Biochar is fine-grained charcoal, high in organic carbon, largely resistant to decomposition, produced from pyrolysis of plant and waste feedstocks. As soil amendment, **biochar** creates a recalcitrant soil carbon pool that's *carbon-negative*—a net withdrawal of atmospheric carbon. The enhanced nutrient retention capacity of biochar-amended soil reduces total fertilizer requirements, and also the climate and environmental impact of croplands.

their characteristics. Aerial surveys with canopy-penetrating radar detected thousands more hectares of Carbon-rich soils. We now know indigenous tribes created enough *terra preta* to feed a population of five million, perhaps 25 million.

Carbon Sequestration

In 1992, Wim Sombroek published a new soils book that suggested *terra preta* may be a way to sequester Carbon, reduce greenhouse gas levels, thus reverse global warming and mitigate climate change. If we convert plant biomass to char and add it to soil, significant CO2 can be moved out of the atmosphere into a safe, solid form. If done globally on farmland, using crop and forestry wastes, perhaps enough Carbon can be sucked out of air to make a difference for our planetary future.

So, plants are our primary allies in this sequestration strategy. By photosynthesis, plants fix CO2 into carbohydrates, and build their cellulose skeletons from this sweetness. By pyrolysis, we then convert carbohydrate into char—a super-stable kind of Carbon that remains for centuries. Thus, we sequester Carbon, to reduce the impact of climate change—perhaps reverse the excess greenhouse gas in Earth's atmosphere.

Once biochar is properly put in soil, it stays for centuries. USDA soil scientist David Laird believes char's half-life in soil is over 1600 years. Controlled biochar decomposition experiments reveal a mean residence time in soil between 1,300 to 4,000 years. Thus, farmers who add biochar to soil invest in several lifetimes of sustained fertility. To sequester Carbon, science calculates it must be removed from the atmosphere 100 years. Thus, biochar sequesters Carbon 16 times longer than this minimum.

By comparison, raw organic matter has a lifetime in soil measured in years. In healthy, living soil, grasses, weeds and leaves decay and disappear within a few years. Large woody limbs rot away in a decade or two. Even stable humus has a soil life cycle of a century. But biochar is super-stable in soil, resists microbial digestion, and persists with barely measurable annual decay.

This, then, is our best, most natural strategy to quickly, remove Carbon from Earth's atmosphere. The potent advantage is that the biochar isn't a new form of waste, but a resource that boosts soil fertility so it grows even more biomass each year to sequester more carbon as plants and soil biology. Thus, soil regeneration sets in motion multiple positive feedback loops that accelerate carbon capture and sequestration.

Currently, Australia and Japan are the only nations to officially admit soil can be a carbon sink! This needs to be more widely known, and more importantly, followed.

However, while sequestering Carbon in soil is a significant way to remove Carbon from Earth's atmosphere, this is a simple, superficial, single element view of a far greater reality. It is crucial to realize that it was micro-organisms in seas and soils that—by their respiration of breathing out—created Earth's atmosphere. And the continuing activities of these least of all life forms has sustained and stabilized the gases composing Earth's air so that larger, more complex organisms could survive, thrive and evolve.

Today, we know from scientific studies and news reports that the microbial life in the sea is not faring well. Dead zones, red tides and coral bleaching are serious signs warning that single celled life in the ocean is under stress and declining. But little attention is given to the reality that soils are becoming sterile due to deforestation, acid rains, harsh agricultural fertilizers, and toxic treatments. These ancient microbial communities are collapsing due to effects of industrial civilization.

Ten years after Wim Sombroek published his sequestration suggestion, an international association formed to advance his idea. By 2012, networks and associations had formed in countries worldwide involving thousands of scientists, investigators, experimenters, inventors, and enthusiasts, guided by the International Biochar Initiative, headed by Dr. Johannes Lehmann at Cornell University. Already, in America, thousands of backyard burners have made biochar to test in gardens, farms and greenhouses.

Thus, in a single decade, biochar rapidly went from unknown idea to mainstream strategy in global efforts to mitigate climate change, restore depleted soils, create new arable land, jumpstart a new Green Revolution to transform agriculture into carbon-smart farming, and restore a solvent foundation to community economies.

And we can grow high quality, nutrient-dense foods to restore human health.

Is Biochar A Fertilizer?

In a word, "no." Biochar is not a nutrient. Nor is it a food source. Bacteria and fungi don't eat it. Neither will earthworms. Water won't dissolve it. It doesn't chemically degrade or weather. In fact, archaeology commonly does radio-carbon dating with charcoal because it resists decay so well.

Fresh char added to soil loses 3 to 5% of its mass in five years. After that, annual mass loss drops to a fraction of a percent. Most of this loss is tar and resin residues held in micropores—tiny drops and thin films of oily hydrocarbons left from cooked cellular substances. They are eaten by bacteria and simple organisms. As char ages, a tiny fraction of lightweight, water-soluble Carbon molecules are also lost. A smaller fraction of Carbon escapes as volatile gas, such as ethylene, a plant growth stimulant.

But over 95% of well-made char is super-stable, and stays in soil for centuries—truly an inert ingredient. Biochar continues to

Benefits of Biochar

Replenish soil depleted by over-farming
Crops grow larger & more bountiful
Improve soil structure and tilth
Improve water penetration & absorption
Increase water holding capacity of soil
Reduce and prevent run-off & erosion
Decrease mineral leaching
Retain nutrients in soil better
Increase soil pH / Lower soil pH
Aid roots to adsorp nutrients
Boost Cation Exchange Capacity (CEC)
Create Anion Exchange Capacity (AEC)
Greater Ca, Mg, K bioavailability
Greater micronutrient bioavailability
Greater P retention & bioavailability
Greater Nitrogen bioavailability
Increase Nitrogen fixation
Increase Nitrogen retention & cycling
Accelerate compost processes
Reduce greenhouse gas emission
Absorb gas & odor of compost & manure
Lessen aluminum toxicity
Proliferation of beneficial microbes
Increase activity of mycorrhizal fungi
Promote earthworm activity
Dissolved SOM energy for microbes
Shelter beneficial microbes from predators
Higher sorption of microorganisms
Better formations of biofilms
Sorption of inhibitory compounds
Sequester carbon for 1500+ years

Carbon Sequestration

global atmosphere
Carbon Dioxide
Greenhouse Gas

↓ **Photosynthesis**

Carbon Dioxide + Water
Carbohydrate
Plant Biomass

↓ **Pyrolysis**

controlled combustion
Biochar
Super-stable Carbon

↓ **Inoculation**

minerals & microbes
Living Soil
Soil Food Web Biology

sustain soil fertility in the Amazon, apparently for centuries.

So, if biochar isn't a fertilizer, what does it do?

Micropores: Nature's Nano-technology

Plants are mostly water. Thus, their physical structure is mostly plumbing. Seen in a microscope, plant biomass looks like bundles of pipes, tubes and tunnels to move water around. Amid all these stacks of water channels are larger cavities, each occupied by a plant cell.

Thus, char is hollow inside. Charcoal is lightweight because it's empty. It floats because air is trapped in those tiny tubes and pipes. Those bundles are like a sponge, and have a huge capacity to soak up water and other substances. And even as char is empty, open and porous inside, it causes soil to become lighter, looser, more open to air and water.

A bit of char has limited external surface area, but this is tiny compared to char's vastly greater inner surfaces. The walls of all the inner chambers are many times greater than outer surfaces. The added internal capacity of char is estimated between a few thousand, to maybe a million, times more than external surface.

Nature makes multiple uses of this emptiness. Char's profusion of microscopic pores is Nature's nano-technology. Water, oil, sugars, proteins, and other substances are drawn in and stretched into thin films that support biological organisms. Char's empty inner spaces give it tremendous storage capacity for water, ions, electrons, nutrients—even whole organisms take up residence in the char.

So, in soil, biochar's first service is to soak up and hold water, and thereby keep soil wetter. Like a dry sponge, char's micropores draw in water by capillary suction. Then, gradually, micropores meter moisture back out into soil for microbes and roots. Thus, a small amount of char greatly increases soil's water holding capacity, improves its moisture management ability.

Micropores in Biochar

Biochar pores are great refuges for microbes, but none will live–not even microbes–in the most beautiful palace without a nicely filled fridge, well-stocked pantry and fresh water. Thus, a key condition for microbes to colonize biochar is nutrients available on and in the char. Micropores must contain nutrients, and be recharged continually.

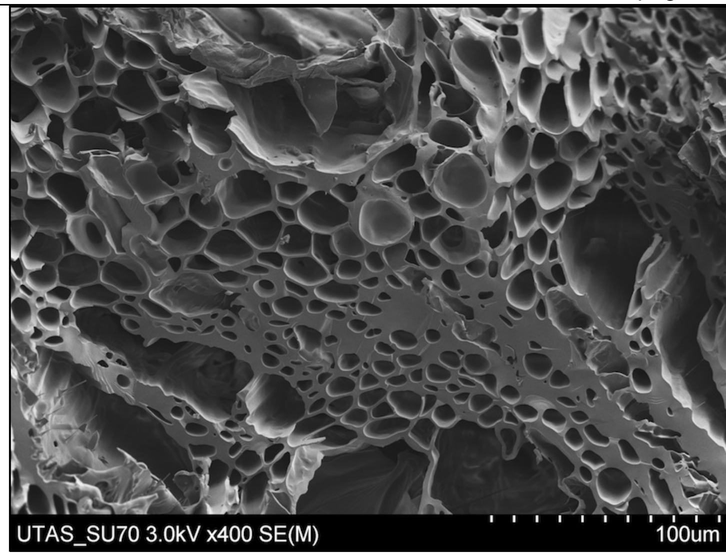
Char can be inoculated by blending with compost. Another approach is feeding it to livestock. But once in soil, nutrients of SOM go to equilibrium with biochar, and recharge them continually. Nutrient flows must be steady to keep microbes active in pores and surfaces. Biochar enables more efficient nutrient flow between soil, root and microbe. Biochar decreases nutrient leaching from soil, as the biochar matrix becomes a nutrient reservoir and relay.

The combination of micropore sponge with soil microbiology in active symbiosis with roots enhances drought tolerance of plants, from annual crops to trees. In 2011, the US Forest Service released preliminary results of adding char to soils after forest fires in the West. Clearly, soils with char stay wetter, so soil biology, including shrubs and trees, regenerate faster.

Adsorption: Why Carbon is Black

Carbon's valence electrons make four covalent bonds in tetrahedral symmetry, Nature's simplest 3-dimension geometry. This 4-arm arrangement attracts and holds many kinds of energy and chemistry, from photons of light, to neutrons in nuclear reaction. Carbon's perfect symmetry captures photons, atoms and ions, and thus is black, the color of complete absorption and zero radiation.

But char isn't just Carbon. Held in the Carbons are minerals. If you burn charcoal, the final product is whitish ash—mostly metal oxide minerals. These embedded mineral ions create sites in the char with electric charge. Also, char has numerous Oxygen



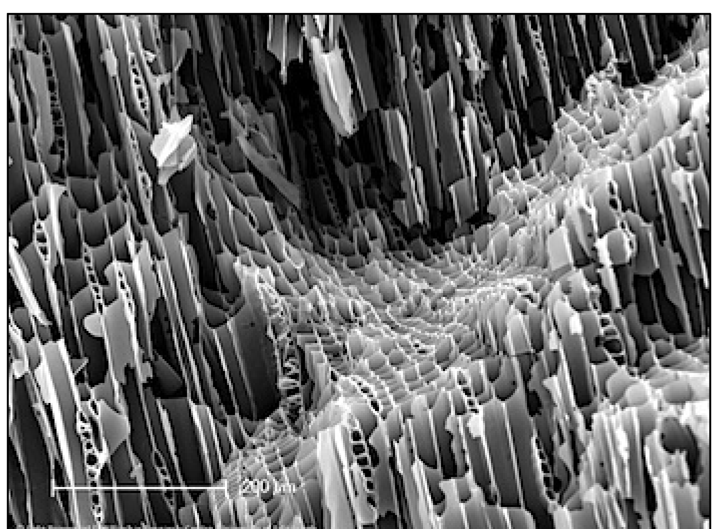
atoms (O, OH, OOH, etc.) that create other electric charge sites.

These embedded electric charges attract atoms and ions in molecules of opposite polarity. This charge isn't strong enough to form bonds in which atoms exchange or share electrons, but able to draw and hold atoms near the char. This loose association is based on a subtle mutual attraction, like a hydrogen bond in water. Nature makes many uses of these subtle electric fields.

"**Adsorption**" is a technical term for this electric attraction between atoms and molecules. Char's "absorption" of water operates largely by capillary action from differential pressures. But "adsorption" occurs due to electric charges that cause atoms and molecules to be attracted, form clusters and align in groups.

Charcoal has abundant charged sites that give it tremendous capacity to pull molecules out of solution, and hold onto atoms on—and even in—the char. Charcoal's very high adsorption potential is what makes it an ideal media for water filtration. In water purification, ions in solution are considered "pollutants." But in soil, the important ions are "nutrients." Biochar is a sponge that also soaks up and holds ions of elements and biomolecules.

Biochar has an added adsorption capacity, far beyond other soil particles like sand and clay. Like any particle, a bit of biochar has a fixed, measurable external surface area to attract and adsorp ions. But biochar's limited external surface is augmented by complex internal surfaces of its micropores. Those hollow, inner chambers provide a far greater ion adsorption capacity than almost all other natural materials. Calculations vary, as do biomass characteristics, but biochar easily has a few thousand to



over a million times more internal than external surfaces.

Char draws ions to itself, separates them from solution, and holds them tightly at char surfaces by weak electric attraction, not fixed atom-to-atom bond. This loose association is easy to affect or alter, so adsorped ions can become mobile, or jump around, such as from char to root, or microbial membrane. This easy access ion exchange makes adsorped nutrients bioavailable.

Adsorped charges can also stack up in thin layers, and form rudimentary thin films—a special structural strategy of cells and microbes. Thin films allow nutrients and electrons to move around a cell in remarkable ways that are orderly and efficient.

Like most soil particles, char has negative charge sites that attract and adsorp positive ions—the cations. Adding char to almost any soil will boost **Cation Exchange Capacity** (**CEC**). Since metal cations are soil's primary electron donors and charge sources, CEC is a valuable numerical measure of soil's potential energy to support and sustain growth. The higher the CEC, the faster and better plants are likely to grow. Typically, biochar added to clay or sandy soils sees CEC rise by ten or more points.

After char was accepted as a soil additive, scientists began a global search to re-examine other soils. Ecologists discovered ancient prairie soils had significant fractions of charred carbon—something no one had studied before. Apparently, significant charred Carbon was created by slow-moving, low temperature prairie fires, especially fires with green, moist biomass. Centuries of recurring fires accumulated charred Carbon in soils, and changed those soils to improve their fertility.

In July 2012, American Chemical Society's ***Environmental Science and Technology*** journal published six scientists' paper that the Midwest's highly productive, grassland-derived soils (Mollisols) contain char from pre-settlement fires that structurally compare to *terra preta*. These soils are much more abundant than previously thought (40—50% organic C). Oxidized char residues are particularly stable, abundant, fertility-enhancing forms of SOM. Further, if just 40% of SOC is char (low estimate for Mollisols), essentially the entire soil CEC is attributed to char.

What was good for Amazon forest soils found a natural use in North American prairies.

Fertilizer Efficiency & Water Quality

However, biochar has a further feature to dramatically boost its ion adsorption properties. Amazon studies of *terra preta* document that char also has positive charges embedded in the Carbon matrix. This positive polarity attracts negative ions and molecules: the anions. These atoms are electron acceptors that serve in cells as charge carriers to move energy around. So, unlike most soil particles, char has **Anion Exchange Capacity** (**AEC**). The two most critical soil anions are Nitrogen and Phosphorus—N and P of NPK fertilizers.

Anion adsorption is a potent tool in soil fertility. By gathering and holding anions out of the soil solution, biochar immediately curbs leaching and loss of these nutrients. Instead of washing out with rain or irrigation, Nitrogen, Phosphorus, and other anions are held on and in the bits of char. On the supply side, this holds critical nutrients in the root zone, and delivers more fertilizer to the plants, sharply increasing overall useful fertilizer efficiency.

Multiple research studies in Japan, Australia, US, and other countries found that biochar added to soil cuts nitrate migration out of the root zone into groundwater by 50 to 80 percent. Since nitrate and phosphate from farm fertilizers is a primary source of non-point water pollution, this facility of biochar has great significance for watershed management. Biochar's adsorption power is also useful in stormwater purification and management.

Federal-funded research at University of Vermont is testing biochar use as a phosphorus trap on dairy farms. Phosphorus pollution is a recurring problem fouling water in the Great Lakes. Protecting Lake Champlain, the sixth Great Lake, from phosphorus pollution from farmland runoff is an environmental priority for two states and two nations. Early efforts at Shelburne Farms near Burlington VT documented over 50 percent reduction in phosphorus leaving the farm to enter the lake.

Research in Japan, Australia, America, and Germany has documented that biochar added to soils curtails outgassing of greenhouse gases by 37 to 90 percent. Biochar seems to alter microbial activity in soil, reducing soil respiration (CO_2) and conversion of Nitrogen fertilizer to nitrous oxide (NOx) that otherwise goes into the air. Nitrous oxides have a greenhouse gas effect over 300 times that of CO2. This is partly biochar's adsorption power and capacity, but also microbial activity to manage the Nitrogen Cycle and keep these volatile molecules in soil. Methane emissions are also reduced.

The ability of biochar to curtail leaching, outgassing and pollution, and improve fertilizer effectiveness occurs at two levels. First is the physical chemistry of adsorption—char's immense capacity to capture and hold nutrient ions. The second level is biological, involving soil microbes that process nutrients into biomolecules and protoplasm.

Habitat, Housing & Shopping Malls

The final step is for biochar to be colonized by microbes. With water and nutrients stored in char micropores, bacteria, fungi and other soil biology move into the char, and claim its empty chambers as residences. We don't eat our houses, and microbes don't eat char. They live in it.

Studies of Amazonian *terra preta* describe char-enriched soils as full of microbial life—so much so, the term "soil reef" was used to highlight how the soils are bursting with microflora. Even as coral reefs provide calcium structures to house simple cellular organisms on shallow sea floors, char provides cellulosic shelters for communities of soil organisms.

Bacteria are the tiniest life forms, with diameters of 0.2 to 70 microns—average, three microns—so tiny, over a million fit on a pinhead. Bacteria have no trouble populating biochar. In fact,

Biochar and Climate Change

Biochar is produced by pyrolysis or gasification—processes that heat biomass in absence or shortage of oxygen. Biochar resists decay to stay in soil hundreds of years, likely thousands. So, buried in soil, biochar is "carbon negative"—permanently removes carbon from air into super-stable soil. This simple, yet powerful process can store 2.2 gigatons of carbon annually.

Biochar production can co-produce liquid and gas byproducts to process into biofuels, providing clean, renewable energy. This twin win of biochar and biofuel confronts global climate change, replaces fossil fuels, sequesters carbon in stable soil, improves fertilizer efficiency, and reduces nitrous oxide emissions.

It's inexpensive, widely applicable, fully scalable—a strategy we can't afford not to implement worldwide.

Global Warming Turn Around

Replacing slash-and-burn agriculture with slash-and-char, and use of agricultural and forestry wastes for biochar production could provide CO_2 drawdown of about 8ppm or more in half a century. Carbon sequestration in soil has significant potential. Biochar, produced in pyrolysis of crop residues, forestry and animal wastes, can restore soil fertility while storing carbon for centuries to millennia. Biochar helps soil retain nutrients and fertilizers, reducing emissions of greenhouse gases such as nitrous oxides.

—Dr. James Hansen, Director
NASA Goddard Institute for Space Studies
America's leading climate scientist

bacteria and creatures their size build the basic structures of all higher organisms. Their natural home is spaces like biochar micropores—skeletons of structures built by their own kind—like squatters living in abandoned buildings.

Fungi are hundreds to thousands of times larger than bacteria. While bacteria are small, independent cells, fungi form extensive networks by growing long, thin threads—*mycelium*—that scavenge their neighborhood for food and water. We have all seen the dense, whitish mats of fungal mycelium that grow like fuzzy fur on moldy food or leafy letter. These threads can travel ten or hundred of feet through searching out nutrients.

Rice-grain-size char has enough micropore capacity to easily house a million bacteria and a thousand fungi. A grain of char is a micro-condominium to provide residences for complex communities of soft-body microbes. And with water and nutrients stored in micropores, char also provides microbial shopping malls and supermarkets.

Char is a refuge for soil organisms. Walled chambers and tunnels are safe shelter from predators roaming the soil solution. Char's inner recesses are safe space to germinate spores and nurse new bacteria, fungi and their helper networks. Living in char provides microbes protection to survive, thrive, interact, and evolve to optimum density and diversity.

And because biochar is super-stable for centuries, microbes don't get short-term leases for a few months. Instead, microbial communities can become established in full-scale symbiosis.

Substrate for Microbes

In 25 years of research, Japanese charcoal scientist Dr. Makoto Ogawa showed repeatedly that *mycorrhizae* fungi have a distinct preference for char. Their rate of spore formation is greater with biochar, and a greater percent of spores germinate. From cozy quarters in char, these fungi more rapidly grow their feeding networks of *hyphae*.

These symbiotic fungi in char micropores grow dense mats of whisker-thin white fungal threads that extend throughout surrounding soil. Each thread is a tiny tube with an acid-secreting mouth at its far end to scavenge water and nutrients. The "mouth" dissolves ions such as Phosphorus from soil and rock to pipe to fungi living in char. Thus, mycorrhizal networks actively, efficiently gather and concentrate water and nutrients in bits of char. In this adsorped state, nutrient ions are readily bioavailable to microbes and rootlets. Thus, *mycorrhizae*'s networks of hyphae become extensions of a plant root system, improving the uptake of nutrients and thus tolerance for drought and other stresses. Recognition of these benefits has quickly made inoculation with *mycorrhizae* a standard practice in production agriculture, both conventional and organic.

I've seen plants quickly become intimate friends with char. The very finest roothairs easily penetrate biochar's micropores in search of water and nutrient ions that are "sorbed" inside. Roots will grow into bits of char, and tenaciously hold onto the biochar, even after being pulled from soil. Char and fungi thus become extensions of plant roots, upgrading its ability to find and get water and minerals from soil, even in dry or deficit conditions.

Growth and proliferation of *mycorrhiaze* sets the stage for a further transformation of soil structure and function. Dense mats of fungal hyphae scavenging through the soil eventually die and wither, leaving behind a tiny trace of sticky protein. These fungal residues accumulate over months to become a significant SOM fraction. In 1996, in a quest to find the "missing Carbon" in soils, USDA research scientist Sara F. Wright discovered Glomalin, named for the *Glomales* order of fungi.

Missing Carbon

Glomalin glycoprotein produced by arbuscular *mycorrhizae* in soil and roots accounts for 27% of soil Carbon, a major component of SOM. Humic acid is only about 8% of soil Carbon. Glomalin is 30 to 40 percent Carbon, stored as both protein and carbohydrate. Fungi use Carbon from plants to grow glomalin as hair-like filaments, called "hyphae", that function as pipes to funnel water and nutrients—particularly phosphorus—to plants.

Fig. 8 **Fungal mycelium** cover leaves, searching for food

Glomalin permeates SOM, binding to silt, sand and clay particles. Because it's sticky, Glomalin glues soil granules into clumps called "aggregates" that enhance soil structure and give soil "tilth"—a texture growers judge by flowing granules through their fingers—stable, to resist wind and water erosion, but porous, to let air, water and roots flow through, harbor beneficial microbes, hold more water, resist soil surface crusting.

Glomalin is causing a rethinking of SOM, including strategies for carbon storage and soil quality. Glomalin weighs up to 24 times more than humic acids, once believed to be the main source of stable soil carbon. Glomalin also keeps other soil Carbon from escaping, thus boosting Carbon stores.

Glomalin is unique among soil components for its strength and stability. Other soil components with carbon and nitrogen don't last long. Microbes quickly break them into by-products, and plant proteins are degraded quickly in soil. Research estimates hyphae have a life of days to weeks, but glomalin lasts up to 50 years, depending on conditions, longer than most soil Carbon.

Science has only begun to peer into the microscopic world of Earth's smallest organisms and most ancient communities. The sodium hydroxide used to separate humic acids from soil misses most glomalin, and it was thrown away with insoluble humus and minerals—soil's "missing Carbon." Glomalin and other benefits of mycorrhizae in soil are just early glimpses into the intelligence and function of these least of all life forms.

Soil Reef: Microbial Communities

Microbes aren't solitary creatures. They prefer to live in communities with other microbe species and larger organisms. Microbial associations are inter-dependent, inter-active, sharing and recycle nutrients, providing mutual services. They collaborate to build infrastructures to gather resources, distribute nutrients, share information. These microbial communities can adapt to changing environments to sustain a stable habitat.

Many organisms provide special services that benefit the larger community. Super-stable biochar offers microbes long-term residence to develop full diversity and supporting services. Fully functional cultures of microbes with enough diversity adapt and respond to changing food sources, climate, geology, and other symbiotic organisms.

Consider the lowly earthworm—plowman of native soil. Recent research discovered earthworms are farmers. They eat raw plant wastes, then regurgitate partially digested pulp to line their tunnels. Fungal spores sprout, encase the plant biomass, further digest starch, cellulose and protein. Earthworms return later to graze on the fungi.

Studies of infertile Amazon clays show that adding tons of raw biochar to poor soil actually retards plant growth for one or two years. But after that, plants grow remarkably better each year, with less fertilizer. It seems biochar must undergo a gradual transformation before it is able to sustain strong plant growth.

The primary reason it takes several months for new char to boost fertility is because first, microbes must colonize the char. This microbial population explosion consumes most immediately available nutrients. But after microbial communities and networks are established, they gather and make available surplus nutrients directed to roots and plant growth.

Microbial Nitrogen Cycle

Of special interest to soil science are Nitrogen-fixing bacteria that use a *nitrogenase* enzyme to create nitrate from Nitrogen and Oxygen gas in the air. In the 1800s, French chemist Louis Pasteur, the father of microbiology, discovered the *Rhizobium* bacteria that live in pink nodules on legume roots, where they covert Nitrogen into nitrate. These microbes are well-known and widely used by farmers and gardeners as seed inoculants. But over 200 other bacteria convert Nitrogen gas into plant food. Each species adapts to specialized environments, often using unique enzymes and metabolic strategy. Most are symbiotic with particular plant species. All depend on certain “helper” bacteria.

High nitrate levels in *terra preta* suggest that certain Nitrogen-fixing bacteria take up residence in char. Ongoing research is peering into biochar’s microbial ecology to learn which microbes prefer char as a host environment. If biochar hosts special nitrate-producing microbes, farmers have added pathways to add natural nitrate to soils, and decrease their dependence on buying imported synthetic, fossil-fueled Nitrogen.

Not just Nitrogen-fixing bacteria, but all the organisms that the drive The Nitrogen Cycle seem to reside in char, and work together to support full function fertility in a stable, balanced soil. Some bacteria convert nitrate to ammonia. Other organisms flip ammonia back to nitrate. They seem to co-exist in char, and keep the form of Nitrogen in soil balanced. Research must identify microbial strains, understand their interactions, and culture colonies for specific soils, crops and climates.

Feedstocks: Weedy or Woody?

Photos at lower left show microscopic slices of eight hardwoods. It’s obvious the microscopic structure of each wood is different, unique and complex. Each type of biomass is so specialized, wood species can be identified by their different cell and cellulose structures in a microscope. Similarly, each biomass type has different chemical composition. This feedstock variability adds another confounding layer of complexity to this carbon sequestration strategy.

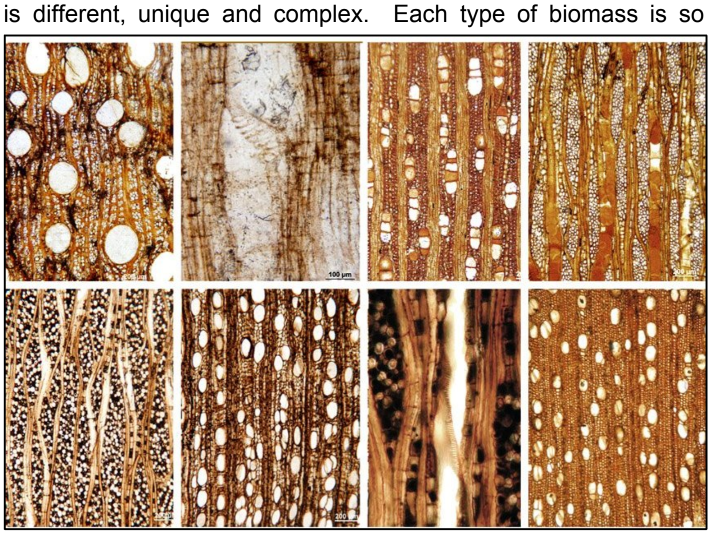


Fig. 9 **Microscopic cross-section slices of wood**

Thus, biochar characteristics vary greatly with each biomass type. Even given the same species, many factors alter biochar quality: growing conditions, soil minerals, harvest method, post-harvest processing, and more. Thus, biochars differ in particle size, porosity, surface area, pH, and biologically available compounds. Most biochar pores are at least 5 microns in diameter, and some are 20 microns. Production methods vary temperature during pyrolysis, time of heating, pressures, oxygen content, moisture content, and other parameters that affect the final char. Because of structural and chemical differences, some biochars break down more quickly in soil than others.

To understand and assess this complexity, and develop uniform, reliable standards, is an immediate technical challenge. IBI has invested three years to address this complexity and draft professional, universal standards to characterize biochar for commercial certification.

A fundamental question is: “woody or weedy?” By reflex, we believe char is made from wood—in particular, dense hardwood, such as oak—to burn for fuel. Like charcoal and campfires, we expect biochar to be made from woody trees, maybe brush.

But for soil use, farm biomass is very likely more desirable than forestry wastes. Annual plant biomass such as straw, hay, cornstalks, seed husks, weeds, and other grassy, weedy debris may prove more suitable in soil than dense, tough, chunky wood.

Global Cooling & Forest Regeneration

Europe’s Little Ice Age triggered by Amazon forest regrowth

September 2010, six scientists in ***Annals of the Association of American Geographers*** reported that Europe’s Little Ice Age was due largely to post-Columbian collapse of Amazon population.

Pre-Columbian farmers in Amazon lowlands—estimated at 25 million by 1492, 80+ percent living in forests—burned and cleared forests for agriculture. Population pressure on forest resources increased steadily, peaking after European arrival. European diseases caused epidemics, resulting in a population crash in the Amazon. An estimated 95 percent of indigenous inhabitants perished by 1650.

Fire history, high-resolution charcoal records and demographic estimates show Amazon lowlands went from being CO2 source before Columbus, to carbon sink for centuries after Columbus. Amazon forest regrowth after Columbus led to carbon sequestration of up to 5 Pg, contributing to well-documented CO2 decreases seen in Antarctic ice cores from 1500 to 1750.

Post-Columbian carbon sequestration was a global cooling process that caused Europe’s Little Ice Age. This was previously attributed entirely to decreased solar irradiance and increased global volcanism. But new evidence supports the theory that depopulation of the Amazon resulted in rapid forest regeneration, particularly on *terra preta* and *terra mulatta*. Added carbon fixed from Earth’s atmosphere by this tropical forest regeneration was sufficient to lower Earth’s thermostat.

Thus, the evidence of Earth history, read to us by science, confirms that global cooling is not only possible, but is achievable.

Tragically, in 2013, man-made carbon emissions are still climbing, and the rate of rainforest loss is still increasing. Humans not only are making climate change troubles greater, but have yet to resolve to take the actions required to turn around our direction and certain destination.

The Columbian Encounter and The Little Ice Age:
Abrupt Land Use Change, Fire and Greenhouse Forcing
Robert A. Dull, Richard J. Nevle, William I. Woods,
Dennis K. Bird, Shiri Avnery, William M. Denevan

Oak exemplifies this principle. It's very mineralized, and char from this dense hardwood is lumpy, and hard as rocks. Much energy and machinery is needed to crush oak char to soil particle sizes. Even as dust, oak char is dense, heavy, with smaller micropores and tighter internal spaces.

On the other hand, char made from weedy biomass is quite light—as fluffy as downy feathers. Weedy char will crush in your hand to a fine powder that will disperse and vanish into soil. Such soft, fluffy, fine textured char has better effects on soil structure and adsorption capacity.

Preparing Biochar for Soil

In November 2007, scientists at USDA National Laboratory for Agriculture and the Environment (NLAE) in Ames, Iowa, began multi-year field trials to assess biochar effects on crop productivity and soil quality. Scientists amended almost eight acres with biochar made from hardwood. Twelve plots got four tons per acre; twelve got eight tons per acre.

They found no significant difference in the 3-year average grain yield from either treatment. Other USDA field and laboratory studies in Idaho, Kentucky, Minnesota, South Carolina, and Texas showed hardwood biochar can improve soil structure and increase sandy soils ability to retain water. But soil fertility response was more variable.

USDA scientists violated four key principles for biochar use:

1) bulk char, in one large load,
2) raw, uncharged char,
3) sterile, uninoculated char, with only a tad of microbial life,
4) synthetic salt fertilizer, tillage and other antibiotic practices.

After all, soil may get 25 or more inches of rain a year, but not all at once in a single event. Biochar, like water, is best added in a series of small doses so soil has adequate time to distribute and digest it. We already know from Amazon research that dumping five, ten, even 20 tons of raw char all at once into poor soil retards plant growth for one year, maybe two. But after that, plants erupt in impressive, vigorous growth.

But a dip in yield isn't acceptable for production agriculture. Farmers can't wait a year or two to harvest a profitable crop. Professional growers need fast response and strong stimulus to growth. Economics and handling logistics require convenience and low cost, with vigorous growth from minimal applied material.

Terra preta wasn't made with just char, or created in a single fortnight. Clearly, char initiates a process that transforms soil, and this requires an extended period of months. Other ingredients are needed to create *terra preta*. Scientists studying Amazon village "middens know indigenous people added all kinds of "cultural debris" to soil, including garden debris, kitchen wastes, building material, clothing—even urine, feces and kid toys. In a culture with no metal, plastic or synthetic substances, everything is organic, and fully composts.

Ultimately, *terra preta* is highly fertile, not due to Carbon, but microbes. So, while microbial populations initially grow, diversify and become well-established in fresh char, nutrients are delivered to microbes, and aren't available to plant roots. But once char is fully inhabited and soil biology is fully alive, productivity rises each year to soon surpass chemical fertilizers. Multitudes of symbiosis in fully functional microbial culture take over the feeding of plants

Fortunately, we are learning how to prepare char for optimum effects in soil and on crops. Biochar research in America is hardly ten years old, but solid research shows that properly prepared, intelligently applied biochar has dramatic effects on soil structure and plant growth at as little as 500 pounds an acre.

To prepare biochar for optimum effective use in soil, there are four fundamental steps—**The 4 M's**:

Moisten, **M**ineralize, **M**icronize, **M**icrobial inoculation.

Moisten: first ingredient of life

First step is to add enough water to moisten char without becoming waterlogged.

Fresh from a production burner, char is bone dry. It's heated to over 500 degrees C, and hardly has a molecule of water in it.

But water is the first ingredient to cook up biological life. Without water, even earthworms avoid char. But properly moist, worms like char mixed with their food, and microbes rapidly move in to colonize the char.

Fresh char isn't just dry, It's hydrophobic. It actually resists water penetration. Residues of tar and resin left in the char are oily hydrocarbons, and repel water. Until thin films and beads of tar are etched out of char, it won't accept water.

However, char left lying on soil a few months loses those black beads of resin, and its color shifts from sparkly black to lusterless gray. Microbes inhabiting char see those hydrocarbon residues as food. Carbon chains and rings contain electrons and energy, so bacteria and other organisms eat it like candy.

Without water, char is very dusty. Fresh char is weak, brittle and shatters easily. So, dry char easily sheds fine black dust that hovers around like a dark cloud. This dust is hard to handle, easily airborne, not healthy to inhale, and blows away in a wind. And yet, that very fine dust is the most precious portion to add to soil and transform its structure because it most widely and intimately inserts itself between soil particles.

In normal production, water is used to kill the fire that makes the char—to cool it down and stop the charcoal fire. People beginning to make char are surprised how much water is needed to extinguish a charcoal fire. A lot of heat is held in char, and char's micropores soak up lots of water. Often engineers quench fresh, hot char by dumping it in water. However, too much water yields char that is soggy, sticky and heavy, which makes handling messy, and screening for particle size difficult. And water-logged char is anaerobic, and poor habitat for beneficial microbes.

But, with careful attention and proper protocol, a minimum of water will put out a fire, yielding lightweight char that's easy to

Blending Biochar with Compost

We have no hard numbers on biochar-to-compost ratio. Farmers I work with use 5 parts compost to one part biochar (crushed, average size 3mm, like coarse sand) by volume with good anecdotal results. We don't have replicated, statistically valid trials at this point.

—**Wayne S. Teel**, James Madison University

Most compost we see is done with wood char, but biochar from grass and manure will work. We don't see much char from grass except energy crops like switchgrass. In Germany, bio-activation is done primarily by wood char with manure.

Two operations find poultry litter char composted with dairy manure is a great combination. Carbonized poultry litter provides compost with nutrients removed in the dairy flush.

Pyrolysis is in the absence air. Gasifiers are slightly oxidizing, as is staged combustion (e.g. high carbon boiler ash).

Particle size is highly variable. Lots of theories; no rules. Depends on porosity of other material in compost, and what is the bulking agent. Aeration is an important attribute of char in compost.

In Germany, Spain and Japan, compost is up to 50% by weight (w/w), mostly 5%-25% by volume (v/v). We blend 1:2 (v/v) biochar:organics (municipal yard waste) to end with 1:1 compost-biochar blend to use in stormwater bioretention trials.

When composting grasses, your hands get black at 15% biochar: 85% organics by volume (1:6 v/v). If organics lose half their volume, the end is 1:3, 25% v/v (about 12% biochar by weight). That works well for tree nursery growing media.

As little as 5% biochar by volume is beneficial in compost. We put that much in kitchen compost (food scraps), and worms love it!

— **Tom Miles**

process. With the right moisture, char isn't dusty, but cohesive enough to hold together in soft clumps that are easy and safe to handle, and don't disappear in a wind. And with just enough water, char is suitable media for strong colonies of microbes, and earthworms are attracted to it.

Micronize: intimate relations

Second step is to reduce particle size.

Smaller particles disappear into soil quicker, mixing more thoroughly and intimately with soil particles and organisms. Thus, crushing, grinding and screening char are valuable to increase char's dispersal throughout soil, and optimize its effects on soil structure, ion adsorption and microbial colonization.

The first benefit of smaller particle size is increased surface area. For water, ions and microbes to penetrate char, they must enter at an exterior surface. Smaller bits have more total surface available for absorption and adsorption. A one-inch chunk has a surface area of—at best—six square inches. The same chunk shattered in a thousand fragments has thousands times more surface area. Due to extremely fine microporosity, one gram of biochar has over 4000 square feet of surface area, and 12,000 is achievable. Water, nutrients and microbes quickly get inside smaller particles, and access interior spaces.

Smaller particle sizes also distribute in soil more widely, more intimately. Dust—the smallest particles—smaller than most soil particles—inserts itself between soil particles. Carbon isolates soil granules, insulating their electric charges. Thus, clay is less sticky, while sand has more cohesive body.

Smaller particles hold water better, because water penetrates more easily and quickly into char's sponge-like micropores. Large chunk of char have difficulty drawing water into its deepest recesses, and do so slowly.

Similarly, smaller particles allow ions better penetration into the char's sponge-like internal micropore matrix. A large chunk of char has difficulty drawing ions into its deepest interior spaces.

Ultimately, think like a microbe. What size micropores are fit for bacteria? What size will satisfy a fungi? Rice grain kernels of char are large enough to house thousands of microbes. A 1-inch chunk of char is a microbial metropolis—millions of denizens inhabit and share such a charred Carbon matrix.

Because char performs an assortment of services to soil, a variety of particle sizes seem best. Rice grain size char is large enough for large microbial communities. Powdered char provides condominiums for microbes. Fine dust is most effective to separate soil particles and shift soil structure and tilth.

One advantage of weedy biomass is its char easily crushes to dust in your hand. Minimal effort and machinery is needed to create extra fine, fluffy char, and such char seems to further enhance soil structure and boost its CEC and AEC. After a few years of field trials, we may decide weedy char is better than woody for many agricultural soils and crops.

One fascinating facet is water-soluble complex Carbons. Tiny bits of char—the finest dust, with up to 100 Carbons—are small and light enough to suspend in water. These extremely small Carbon molecules can be harvested by rinsing fresh, dusty char with water. They disappear in water, making it slightly dark. The micro-particles are useful in foliar and other sprays, where minerals ions and nutrients are packaged in these ultra-light Carbons. Such nutrients are more easily and efficiently assimilated through leaf pores. And inside a plant, the Carbons strengthen plant structure and energy.

Mineralize: charge the soil battery

Third step is to add minerals to biochar.

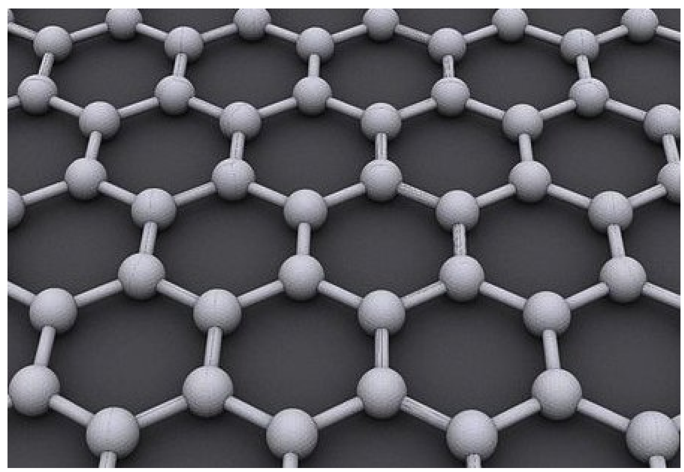
Soil is a battery that stores electric charge. Electrons and ions are electric charges that adsorp onto soil particles, especially SOM and biochar. The ability of soils to capture and hold these charges—both positive (CEC) and negative (AEC)—creates a fundamental electric storage capacity—like the electric potential, or ampere-hours, of a battery. Beyond simple quantity, it's important to also examine how soils can easily and quickly make these electric charges available to organisms.

Both SOM and biochar have remarkable capacity to gather and store both negative (electron) and positive (proton = H+) charges, and are highly efficient to hold and deliver ionized minerals and their electrons to cells. Soil Carbon's large, complex molecules, with their embedded minerals and multiple surface charges, are especially effective to capture and hold free electrons. The more electric charges char can store, the more energy soil has to deliver to growing microbes and plants.

Charging this biological battery begins by adding ionized and ionizing minerals. Cations, although they have a positive charge, contribute electrons to the soil battery by giving up their valence electrons, and thus deliver these fundamental mobile charges to power cell biology. Meanwhile, anions are electron receptors (or acceptors) that hold and safely transport electrons around soil or inside a cell, and deliver them to metabolic reaction sites.

Biochar's high adsorption capacity makes it an ideal delivery system for minerals and their electric charges. Electrons and ions adsorped onto and into biochar are safely, efficiently placed in the root zone, and kept there, ready for ion exchanges with plant roots. Char-adsorped minerals are removed from the soil solution, and thus have minimal mobility to leach and outgas. So, any electrons in char are kept in the root zone, in locations that attract plant roots.

Micronized minerals that are finely powdered are more able to blend into intimate contact with bits of char, and thus deliver electric charges where they are needed. Like micronized char,



Carbon Super-battery

In 1962, science discovered "graphene"—pure Carbon atoms in a regular hexagonal pattern as a one-atom thick monolayer sheet. Atoms are densely packed in flat honeycomb lattice, best visualized as atom-scale chicken wire. Graphene is very light; a one-square-meter sheet weighs only 0.77 milligrams.

Research now makes graphene batteries to charge 100 to 1000 times faster, are inexpensive, non-toxic, and surpass current battery technology in efficiency and performance. Graphene nano-technology deposits an atom-thin layer of carbon on an electrode. This super-thin coating quickly adsorps huge numbers of electrons, stores that charge, slowly meters electrons out for use.

An iPhone graphene battery can charge in five seconds. MacBook graphene battery can charge in 30 seconds. Electric cars with a graphene battery can charge as quickly as filling a car with gas. Besides super fast charging, the battery has few negative environmental impacts, and is biodegradable, even compostable.

smaller particles mean greater surface area, and faster, easier digestion by microbes. Stone meal or rock dusts are natural, insoluble forms of minerals that can be mixed with char to charge the soil battery. Synthetic, soluble commercial fertilizers can also be micronized to blend into char to supply electric charge.

Most farm soils have deficits and/or imbalances of major minerals, and thus require amendments. Similarly, char made from biomass grown in mineral-deficient soil will be short of essential elements. Any soil test quickly, cheaply reveals what minerals are needed by soil, and in what amounts. Adding these minerals to soil directly can create losses, and lower effective use of the minerals. But blending these minerals with biochar adds needed nutrients in a high efficiency, targeted delivery system.

Full Spectrum Fertility

Nature's best source for trace elements is sea minerals. For over a billion years, minerals from the land washed into the sea. Every element that dissolves in water is in the sea—including nano- and pico-elements. Sea water is a full spectrum source for every and all elements that are essential for life.

And sea minerals are in ratios that are ideal to sustain cells and organisms. This mix of minerals was blended, sorted, stirred, precipitated, titrated, and energized by geological and biological processes of Earth evolution. For example, early in planetary history, bacteria in the sea ate Iron, and precipitated this magnetic mineral out of solution. Later, cells evolved that fixed Calcium and Phosphorus to create crystal shells to shield their soft bodies. Many biological and geological processes have created the mix of minerals in the sea. Thus, this mix is no accident, but a full menu of all minerals needed by biology in a deliberate, balanced blend, created by intelligent evolution.

Given the weak, depleted, deficit state of most farm soils, I recommend charging biochar with sea minerals as a way to deliver the full spectrum menu of elements needed by biology. Immediately after making char, douse the char with sea minerals dissolved in water. Adding this solution to fresh, hot char accomplishes five tasks in one operation:

1) **Extinguish**: sea mineral solution puts out the charcoal fire by cooling and by steam;
2) **Moisten**: hot char flushed with water generates steam with enough pressure to force itself into char micropores;
3) **Fracture**: steam pressure strong enough cracks open char to expose inner area as external surface, boosting adsorption;
4) **Scour**: alkali ions of sea minerals loosen and remove tar and resin residues from char's micropores;
5) **Mineralize**: sea mineral ions adsorped onto char's electric charge sites load Carbon matrix with a full menu of elements.

Then, when microbes and roots invade char micropores, they find fundamental food all cells require, already in solution, ready to feed them. This elemental feast assures soil a foundation of essential nutrients to support rapid, vigorous, healthy growth.

Biochar's AEC also allows it to adsorp and supply negative ions, mostly nitrates and phosphates. Nitrogen and Phosphorus were #1 and #2 fertilizers in 20th Century farming. Sea minerals don't supply much of either, so N and P must be added in various forms. Biochar is a high efficiency delivery system for anions, with high bioavailability and minimal loss by leaching. In properly prepared biochar, N and P are not only present as nutrients, but also as organic biomolecules of living soil biology. Microbes living in biochar are an ideal medium to retain and recycle these anions.

Microbial Inoculation

Fourth step to prepare biochar for soil is to add life to it. With water, nutrient ions, and vast, empty micropores in the char, microbes move in. We don't eat our houses, and microbes don't eat char. They live in it.

In the paradigm shift from 20th Century chemistry to 21st Century biology, the culture and care of symbiotic organisms is crucial for soil fertility. For endless eons of geological evolution, microbes managed and improved soil to sustain fertility. Creating fertile soil is a fundamental job description for these "no-see-ums" of soil. These least and smallest of all life forms are among the Earth's most ancient communities. Yet, we ignore what we can't see—microbes—and focus on obvious, visible bulk ingredients—organic matter, compost and mineral fertilizers.

Bacteria are Earth's oldest life forms. While a singe bacteria is simple, as a collective community or culture, they are complex, and more intelligent than plants. One expression of this is that it is primarily bacteria that consume trace elements, and build them into complex biomolecules that perform key, often fundamental, metabolic and regulatory functions.

If minerals are the foundation of biology, microbes are the sill plate—where foundation meets superstructure. Microbes transform minerals into protoplasm in living cells. Bacteria are the primary consumers of mineral nutrients. They also synthesize critical biomolecules that more complex organisms require. For example, all B vitamins are synthesized by microbes, who then supply them to plants and animals.

For example, vitamin B12—so-called "vegetarian vitamin"—is not made by animals, but only by a bacteria. B12's mineral co-factor Cobalt has six valence electrons in outer orbitals, and thus makes six bonds to other atoms. B12 bacteria build a complex structure of Carbon rings to enclose an atom of Cobalt. Unlike Chlorophyll and Heme, whose Carbon rings are in a two-dimensional, flat disk, B12's more complex Carbon rings form a three dimensional structure. Thus Cobalt's magnetic energy is focused and harnessed to perform certain critical, universal energy exchange functions needed for DNA replication, hormone synthesis and red blood cell formation.

Thus, these simplest and least of all life forms digest trace elements to transform them into key biomolecules that are metabolic catalysts and regulators in larger organisms. Similarly, bacteria assemble minerals and biomolecules into primary units of protoplasm, which are fed to cells of larger, more complex life forms, including plants and animals.

Grandfather's Charcoal Garden

submitted by Ken Bourne 10-03-2012

using biochar in my organic nursery over 50 years.

My grandfather was a charcoal burner in Sussex England. He brought home smaller pieces, which he fed to his dogs (and me). He kept his charcoal in a hessian sack next to his compost. One day rain ran off compost to soak the charcoal. Grandfather was so mad he threw the charcoal on his garden, and got the best yields ever. This was his "secret" for years, passed on to my father, then to me.

A few years ago, I learned he wasn't the first to discover charcoal's benefits. Amazonians did a few thousand years ago. He didn't know charcoal is changed to biochar by inoculation with beneficial bacteria and microbes. I realized growing organic with biochar gives better yields and nutrient-rich crops.

Adding inoculated charcoal to poor soil, and using chemical fertilizer has no benefit, as chemicals kill bacteria that extract nutrients from soil. The greatest benefit is adding biochar to soil amended by organic matter with healthy bacteria. Biochar absorbs water, filters run-off, sequesters carbon.

A farmer must see immediate results, and learn why these results duplicate themselves. He must also learn to add rockdust, bonemeal and other organic matter. It's cheaper and better for his crops, family and profits.

Studies show char is an ideal substrate to culture many beneficial microbes. Features that make char ideal for water filtration media also make it optimum habitat for the smallest microbes. Larger particles soak up nutrients and water. With essential nutrients abundant and bioavailable, microbes take up residence inside char. Each bit of biochar becomes a host for colonies of bacteria and fungi, the primary cycle of the soil food web, and their presence anchors the rest of the soil biology. Larger char particles provide enough space for large-scale, fully diversified microbial communities to become established, and nurse the growth of their food-seeking networks.

For example, mycorrhizal fungi take up residence in char, proliferate by abundant sporulation, send whisker-thin hyphae out into soil to search for water and nutrients, and pump them to fungi living in char. Thus, char becomes an active storehouse to stockpile essential nutrients. Fungi interact with other organisms in symbiotic networks to create complex feeding webs. This interactive community helps soil breathe, absorb water, mobilize nutrients, support larger life forms. Together, this living community forms intelligent, adaptable and resilient systems.

Thus, char preparation's final step is inoculation with a wide diversity of microbes to jumpstart their presence and function.

Biodiversity of Digestion

As the emerging 21st Century biology paradigm spreads, it is spawning businesses and services that offer a variety of new inoculants to enliven soils. Many new probiotic products are becoming available on the market.

Most often, simply and easily, char is inoculated by blending it with compost. Properly mixed, in just a few days, char becomes colonized by beneficial microbes. These microbial colonies form a "culture" of interactive organisms that dramatically improve char's value as a soil enhancement. Compost not only provides microbes biochar to inhabit, but also supplies partially digested OM to feed microbes as they get settled into their new homes.

Compost and biochar aren't competitors contesting for available raw materials, but complementary. Wet biomass is best made into compost, while dry biomass is ideal to convert to char. After production, char and compost are perfect partners for soil. Fresh char is lifeless, and needs compost to populate its empty micropores. Char is an ideal media to transfer microbes into new biomass and kickstart compost's digestive processes. Compost benefits from char's super-stable habitat for microbes.

Unfortunately, quality compost teeming with a full diversity of microbes is hard to find. Compost is often treated as inert organic matter, and a way to dispose of "wastes." Much compost is made from high Carbon mono-materials, like wood chips or leaves, and lack fully diverse microbial cultures. Inadequate attention is given to assure strong, diverse, multi-function digestive organisms.

Thus, for biochar inoculation, it's crucial to select compost that delivers a full diversity of microbes. One solution is to use compost made with animal manures, especially from herbivores. Animals with ruminant digestive systems have far more diverse and active microbial cultures. It also helps to include diversity sources of raw biomass that break down into a variety of organic substances. The highest quality composts even include herbs, mineral supplements and even biochar.

In Europe, newly developed EU protocols recommend most biochar is fed to animals. This accomplishes microbial inoculation by passage through animal intestines. Indigestible char moves through an animal gut to be spread with the manure on soil, fully colonized by a full range of digestive organisms.

Currently, several microbial inoculants, inoculation strategies and microbial starter foods are available for purchase:

Rudolf Steiner, in early 20th Century Germany, was among the first to envision holistic soil microbiology. Steiner taught Biodynamic Agriculture, an advanced farming method that uses eight preparations (BD preps). Some Steiner preparations are microbial cultures and stimulants to inoculate soils with microbes, nurse these cultures into optimum activity. Most relevant to soil microbes is Steiner's cow horn prep.

Dr. Teruo Higa, in 30 years of research in Japan, developed Effective Micro-organisms (EM)—cultures of lactobacillus, photosynthetic bacteria and algae. EM isn't just a product, but a complete technology that includes techniques to incubate and propagate cultures, application methods for many situations and environments, and extensive scientific testing.

Dr. Michael Melendrez, founder of Soil Secrets in New Mexico, first coined the phrase "soil food web" in a 1976 research paper. He developed high quality humus-based inoculants and microbial foods to transform extreme soils of the Southwest. His passion is to create North America's largest collection of oaks, but he first had to transform New Mexico's alkaline, arid soils.

Dr. Elaine Ingham popularized "soil food web", and perfected compost tea as a way to propagate and distribute soil microbes. Compost tea involves adding a little compost, with all its digestive organisms, to a lot of water, plus essential nutrients—minerals, sugar, organic matter. Air bubbled through the water (or whirled in a vortex) for 24 hours adds abundant oxygen to nurse a microbial population explosion. This brewed tea is sprayed on plants, soil and biochar as inoculant. Thus, microbes in a small amount is compost proliferate to cover a large land area or biomass volume.

Dr. Michael Amaranthus at Oregon State University authored over 70 scientific papers on mycorrhizal fungi and their use in soil restoration and maintaining productivity of plants. He created a full array of mycorrhizal inoculants, and had two mycorrhizal genera and many species named in his honor. His company Mycorrhizal Applications produces the world's largest selection of mycorrhizal inoculum used by landscapers, farms, nurseries, soil restoration & erosion control companies, and distributors.

Many new probiotic microbial products are appearing each year. For example, SCD Probiotics. a new company in Kansas City, offers a wide range of microbial cultures packaged for varied applications, including agriculture, livestock, household, compost, and personal health. Their BioAg™ product, with lactic acid bacteria, yeast and phototrophic bacteria, is used as a liquid biochar inoculant by soaking char in a solution for 48 hours.

A special concern is Nitrogen-fixing bacteria, since Nitrogen, the 4th Organic Element of life, is a major growth-limiting nutrient. A National Science Foundation report cataloged over 250 species of Nitrogen-fixing bacteria. Each inhabits its own specialized environment, including strains that live in symbiosis on the roots of specific host plants, such as *Rhizobia* on legumes. Of particular interest for biochar are free-living N-fixing bacteria.

High nitrate levels found in Amazonian *terra preta* suggest that biochar hosts unique strains of free-living, Nitrogen-fixing bacteria. Thus, it seems properly inoculated char can provide additional ways to fix Nitrogen into nitrates. The more the needs and nutrients of these specialized bacteria are readily available, the faster they will proliferate and spread in soil. Biochar plus trace elements can meet these requirements.

So, a key issue is to find these strains of free-living bacteria, and be sure they are inoculated into new biochar.

Carbon-Smart Farming

In 2006, Virginia Tech University began field trials adding biochar to soil growing tomatoes, potatoes and sweet corn. Virginia Tech research demonstrated and highlights that biochar properly prepared by being charged with minerals and inoculated with microbes can achieve remarkable results with very low rates per acre, instead of several tons per acre. These results are immediate, not in the second or third year.

Biochar was supplied by CarbonChar, a new company producing inoculated biochar. Jon Nilsson, an east coast soil scientist and compost expert, guided CarbonChar to create a biochar-based inoculant with beneficial microbes, substrates and microbial food. In initial research with sweet corn, Nilsson found that biochar-based inoculant applied in the planting row at rates as low as 7.5 pounds per acre saw significant increases in yield and mycorrhizal colonization of roots.

When a biochar-based inoculant was used at 2.5 % by volume in a transplant growing mix, it had the following results:

- 30 lb/acre savings in nitrogen for Potatoes (2006)
- 10% increase in Sweet Corn yield (2006-07)
- 22% increase in Tomato yield (2007)
- 51% increase in Tomato yield at first pick (4-year average)
- Tomato yield was 1-2 weeks earlier than untreated plots

Tomato yields were achieved with two cups of char plus inoculant in five gallons of transplant potting mix. In 2010 trials, four cups per five gallons of mix was used, resulting in even higher yields.

Jon Nilsson reports, "Virginia Tech research was replicated results over four years. Trials weren't based on biochar alone, but also included changes in cultural practices:

- soil had decent fertility when we started
- low salt fertilizer used at transplant time (fish emulsion)
- cover crop turned in prior to planting
- low salt fertilizer at low amounts in growing season

"We saw changes in the field through soil penetrometer readings. If my stuff works, who cares what I call it, or what your beliefs are. Bottom line is beneficial microbes are salt intolerant, and much easier to kill than a germinating seed. Farmers using high-salt fertilizers won't benefit from this technology."

Jon Nilsson tells farmers, "Microbes are more efficient than any product you ever bought. They work 24/7, and are lots cheaper than fertilizer. Inoculated products lower costs, yet maintain or increase yield. That's money in a farmer's pocket."

Jon is emphatic: "Agriculture will turn on a dime when bio-inoculants show farmers permanent changes to soil fertility and cost reductions. My job is to cut costs and increase yields." (For further information: **Biochar-Based Amendment Enhances Tomato Transplant Growth and Early Fruiting**, Dr. Ronald Morse, Professor Emeritus, Dept. of Horticulture, VA Tech and Jon Nilsson, Soil Scientist, Biochar Applications, Mills River, NC)

This is our 21st Century challenge: to transform farming from antibiotic to probiotic. The future of farming isn't methods that just increase yield, but rather, to create a full menu of soil minerals, regenerate microbes and the entire soil food web, and grow nutrient-dense foods. And the future of humanity hinges on farming that restores Carbon to soil and reduces global warming due to the greenhouse effect.

Key to Agriculture Transformation

To change agriculture, a key principle is that farmers grow food for a market. Farming isn't a hobby. It's a business to produce profit. Before buying seed and fertilizer, farmers need markets to buy the food, feed and fiber they grow. If the buyer is ADM or Cargill, farmers will grow GMO grain. In recent decades, consumers demanded organic, so farmers adapted to grow foods for that special market.

If consumers demand carbon-sequestering food, then farmers will change how they farm to supply that demand. If shoppers buy carbon-smart food in preference to other food, farmers have a market-based reason to adopt carbon-conserving methods. And if consumers pay premium prices for carbon-smart food, this is a potent financial incentive for a carbon farming revolution.

Currently, no market exists for "climate-conscious" or "carbon-conservative" foods. Thus, farmers lack a monetary incentive to apply biochar to soils. Without markets for carbon-smart foods, only altruism will motivate change to farming practices. Without financial reward, agricultural change will be too slow to alter our oncoming climate calamity.

For consumers to buy carbon-smart foods, they need a way to identify food grown by methods that remove carbon from Earth's atmosphere. Shoppers have no clue what foods decrease our planet's CO2 burden. Consumers have no way to recognize such foods, and select them. Nobody educates them about carbon-smart shopping, or assures that products are authentic and effective to reduce our carbon footprint.

The first key issue is consumer choice. To encourage shift to a green economy, consumer products are tagged to indicate their energy-saving value. Appliances have Energy Star tags for efficiency. Cars are rated by miles per gallon. Even buildings are assessed by a LEEDS rating. And a battle is underway for consumers right to know if foods contain GMOs.

So too, consumers need a label to identify foods that reverse our carbon footprint and sequester carbon. A simple, uniform system must define and mark carbon-sequestering foods to track them from farm-to-market and assure point-of-sale authenticity. Marketplace visibility, product identity and quality distinction are primary purposes for trademarks and brand names.

This is why 25 years ago, "**Certified Organic**" was created as a market label for foods grown without synthetic chemicals. A USDA insignia assures consumers of authentic no-chemical food. Without scientific support, with active resistance by corporate industry, and despite a higher price, "**Certified Organic**" is now the fastest growing sector of America's food system.

Now, we need a simpler, hopefully easier way to label carbon-smart foods that reverse our farm and food carbon footprint. Consumers need clear choices about the carbon consequence of foods they buy. It's imperative to create a marketplace identity for carbon-smart foods grown by carbon sequestering methods, produced by earth-sensible, soil regenerating, climate mitigating farming, by farmers pledged to learn and use sustainable, global cooling farming and marketing.

Cool-Food

A plan has been proposed for a "**Cool-Food**" label—a new trademark to identify foods grown and marketed with materials and methods that remove Carbon from Earth's atmosphere and restore it to soil. First qualification to use the **Cool-Food** insignia is to add a minimum of biochar per acre to soil. Also, growers must adopt probiotic methods to increase SOM, SOC and soil biology. Currently, there will be seven criteria, principally:

1) add a minimum annual amount of biochar to soil
2) sign a **Carbon-Smart Farmer's Pledge**
3) soil test of minerals
4) soil test of organic Carbon
5) soil biology assessment
6) soil Carbon management plan
7) eco-local, Carbon-smart marketing

To issue licenses to use **Cool-Food** labels and marketing materials, **Carbon-Smart Standards** must be drafted and published. This must be led by a panel of growers and marketers with experience and insight. The **Cool-Food** Board must also prepare a simple, practical **Growers Manual of Carbon-Smart Farming** to detail **Best Practices** to prepare, apply and evaluate biochar use in soils, information sources and research.

The immediate task is to create a simple model to show how to link a market label with carbon-sequestering farming. We need to implement a Cool-Food label and marketing service to illustrate how to direct food dollars into agricultural transformation and ecological regeneration. More than just a label, this must link eco-conscious consumers with eco-responsible farmers.

Carbon-conservative agriculture doesn't exist yet as full function farming systems. Carbon-smart farming isn't distinct, well-articulated, field-tested guidelines. While many basics are known, much must be done to define an agriculture that captures

Carbon in soil, and minimizes emissions. We must create carbon-smart farming systems in the next few years, and teach the methods to a new generation of growers.

We need this **Cool-Food** label fast, because a melting arctic ice cap and massive methane hydrate release warn we're at a tipping point of global climate calamity. We don't have another decade to fiddle with short-sighted solutions. Failure of America's 2012 corn crop from historic extreme drought in the Midwest previews what lies ahead if we don't curb our greenhouse gas emissions, start sucking CO2 out of the air, regenerate soils, and repair our planet's damaged climate engine.

Carbon and Community

Carbon is the element of life—the backbone of biomolecules. So, Carbon is special among all the elements, and is a signature element needed in abundant amounts, with qualities that support and sustain the vast diversity of forms and functions of biology.

At atom scale, Carbon has a high bonding energy to link to other atoms. So, Carbon is slow to react, but when it does, it forms bonds that are strong, stable and durable. Carbon's stable bonds give persistent, fixed form to molecules to build structure for living organisms. This also means Carbon burns at high temperature. So, in arc welding, Carbon's high combustion heat melts most metals, and is preferred fuel for forges and smelters. In an electric arc, Carbon emits brilliant white light—preferred light for early Hollywood movies.

At molecule scale, Carbon forms four bonds with other atoms in perfect tetrahedral, 4-direction, triangular symmetry. Thus, Carbon is "The Great Connector" that links atoms into complex structures. As a semi-conductor, Carbon has low charge polarity, and prefers to share valence electrons with other atoms and form covalent bonds. Thus, Carbon brings other elements together in structures that carry complex pattern, and hold memory, information, and intelligence. An ultimate expression of this potential is DNA, the spiral helix of genetic code.

At cell scale, Carbon creates shape. Carbon forms a vast assortment of molecules to build structures and functional units as containers and the machinery for life. A cell is a bubble of water enclosed in thin film of hydrocarbon chains (lipids) that form a cell membrane, reinforced with carbohydrates and proteins. Inside that bubble of fluid, Carbon's complex molecules impart rigid structure to organize the space in a cell, and direct flows of fluids, electrons and charge.

At organism scale, Carbon is form and food. Carbon—mostly complex carbohydrates and proteins—forms a mesh and matrix to surround cells with shells, shields and supra-structure. Thus, Carbon supplies safe, stable habitat within which cells can aggregate into multi-cell colonies. Colonies expand, evolve and collaborate together, sharing space and energy, forming tissue and organ in larger and larger organisms. Complex Carbon molecules also are food to supply substance to build more supra-structure, and charge to carry energy into and within organisms.

At ecosystem scale, organisms modify the environment and create habitat to support greater diversity and stability for life. Early in evolution, primitive bacteria in the sea learned to eat Iron and extract energy for metabolism. The Iron became insoluble, and precipitated to the sea floor. Over eons these sediments became iron ore, which today is mined to make steel. Then a new bacterium evolved to capture sunshine to combine Carbon with water to make Oxygen and Carbon rings of sugar. They became bluegreen algae, the first plants. This created conditions able to support the emergence of the first single-celled animals. This began the Carbon Cycle, which transformed life on Earth.

And at planet scale, Carbon creates community. Organisms interact to form colonies of independent, yet inter-dependent individuals. Bluegreen algae grew together in thick colonies, and enclosed themselves in a membrane to become stromatolytes, the first multi-cell organisms. Stromatolytes transformed Earth's anaerobic atmosphere with free Oxygen to cause the first mass extinction. Plants eventually evolved into trees that grew together in forests that supplied shade and shelter for hosts of other organisms. It was in the forests that humans evolved to join this growing Earth community. All this is formed from Carbon in ever-evolving complexity and diversity. This web of relationships created "culture."

Planetary Healing, Not Geoengineering

Today is the Carbon is the cause of a global ecological crisis called climate change, and this may precipitate another mass extinction on Earth. Conventional science says accumulating CO2, CH4 (methane) and NOx (nitrous oxide) in Earth's air is driving global warming, overheating atmosphere and oceans, unbalancing the planet's thermal engine, fueling extreme weather and warming climate. But Carbon is merely a scapegoat.

The honest truth is we, the human species, are the cause of this problem. We deforested much of the temperate zone, and now clear cut tropical and boreal forests, too. We plow and poison soil, and plant monocultures so soil has less than 1% Carbon, and is largely devoid of microbes or other life. We burn fossil Carbon fuels, and dump our combustion wastes Earth's atmosphere. We add acids to atmosphere and ocean, stressing the remaining trees, bleaching coral reefs. We dump and pump our wastes in waters, creating red tides and dead zones.

But Carbon isn't the problem. We're the problem. It is humans that must change.

If we restore to soil the elemental foundation of life—Carbon and all the minerals and trace elements needed by biology—then Earth and its ecosystems can heal themselves and restore the balance and biodiversity of life. Restoring Carbon to soils in its full diversity and complexity will re-establish the matrix for life's full, complete, complex diversity at every scale, every landscape. Putting Carbon back in soils will restore the soil food web, and all the web of life—living organisms and systems that collaborated for millions of millennia to assure a stable, habitable biosphere.

And it may be that returning Carbon to soils will initiate changes that support functional, successful, peaceful, healthy human communities. Carbon creates a matrix of structure to support essentially endless complexity and capacity. If the next generations of humans dedicate themselves to the humble, difficult work that regenerates soils from whence almost all life on Earth grows, we may also transform ourselves and our society.

APPENDIX 1

Testing Biochar

Given how new and immature our understanding of biochar and soil microbiology is, how complex the types of feedstock, and how diverse the production processes, before spreading any particular biochar in farm soils, growers are prudent to do simple tests to check for toxicity to microbes, plants or animals. While toxic biochar is rare, it does occur for varied reasons. So, it's wise to assess how much benefit a char supplies to soils and plants, and compare results of different chars at different rates.

Testing can be done with minimal effort, very little time and almost no money. An earthworm test takes only two days. Seed germination is tested in a week. Seedling and root effects can be evaluated in three or four weeks. There are four specific tests:

1) earthworm avoidance
2) seed germination
3) seedling growth
4) root growth

Earthwork Avoidance Test

Earthworm avoidance is a standard test to check for potential toxicity or irritation to larger soil organisms. Earthworms are sensitive to their environment, and respond quickly if conditions disturb them. All that's needed is 10 to 20 earthworms, quart of soil, cup of biochar, and a six to twelve inch wide container.

Soil mix is divided in two portions. One has biochar blended in at a substantial rate—at least 10 percent. Biochar must be properly moistened, mineralized and inoculated. The container is divided with a partition into equal halves. One half is filled with soil mix; the other with soil mix plus biochar. The partition is removed, and at least 10 earthworms are added.

After at least 48 hours, the two soil portions are separated and removed, and the numbers of earthworms in each half are counted. Ideally, earthworms will be distributed equally between the two halves. Any unequal distribution suggests either a preference or aversion for the biochar. If any difference is observed, several replications of this avoidance test should be done to prove this is a consistent response.

One result that was proven in these earthworm trials is that worms avoid dry char. Fresh char that isn't moistened sufficient to overcome char's water repellent tars will repel earthworms. But biochar that is prepared properly to eliminate hydrophobic hydrocarbons and accept moisture is acceptable to worms.

Lettuce Seedling Trials

The second standard test is for plants and biochar for toxicity and response. A simple, four-week protocol can test a particular biochar for effects on seed germination and seedling growth.

Potting soil mix is divided in four equal portions. A control is soil mix only. Equal portions of soil mix have biochar blended in at different rates—generally, 20% (4:1), 10% (9:1) and 5% (19:1). Experience indicates 20% is an extreme maximum rate, 5% is a minimum, while 10% is a reasonable medium. The different blends are distributed in trays of seedling cells or pots, and seeds added. Lettuce is a sensitive crop commonly used to evaluate toxicity, although radishes germinate and grow faster for a quicker test.

The first week gives insight of the effects on seed germination. Consistently, biochar provides a boost to germination that's obvious in side-by-side comparison.

Second week reveals any effects of biochar on seedling growth. This early phase of seed growth relies mostly on food supplied by the seed, since roots have not developed much to supply a steady volume of nutrients.

Third week reveals any effects on the mobilization of soil nutrients to feed the seedlings. By the third week, seed stores of nutrients are exhausted, and roots must have sufficiently developed to supply most of nutrients used by a growing seed.

Fourth week sees rapid emergence of leaves, creating greater leaf surface area, thus a sharp increase in photosynthetic energy and nutrients delivered to the young plant.

While it's easy to monitor and measure shoot growth above ground, biochar is in soil, in direct contact with roots, so most likely roots are where effects occur that inhibit or encourage growth. So, root growth is the ultimate, most critical part of this test. Evaluating root growth may require washing soil mix off the seedling roots for visual comparison, and possible weighing.

Thus, in four weeks, this easy comparison test will reveal to simple visual observation if a particular biochar has any toxic effects that inhibit seedling germination and growth, or if the char has any benefit and at what rate of use.

APPENDIX 2

How to Make Biochar

Humans made charcoal for centuries. This by-product of burnt wood was perhaps human's first art media, seen as cave sketches thousands of years old. Charcoal is still cooking fuel of choice for a third of humans, because it burns hotter with less smoke than wood. Charcoal was the Industrial Revolution's first fuel, and catalyst of choice to forge steel from Iron. In the East US, most forests weren't cut for timber, but piled in pits and mounds to burn into charcoal for factories, forges and smelters. Anyone with simple hand tools could cut down trees and smolder them into charcoal to sell for fuel.

Most traditional and conventional ways to charcoal aren't suitable to make soil amendment, or to address climate change. Most create too much smoke and pollution, adding to the planet's burden of greenhouse gases. Others are inefficient, and waste energy and biomass. Some heat the biomass too hot—often over 1000 degrees C—degrading the char's micropore structures.

Modern industrial.

New methods.

Basic principle: carbon burns hottest, and thus burns last. Carbon arc lamps and welding.

TLUD: micro-gasification for compleat idiots

TLUD is for **T**op-**L**it **U**p-**D**raft, invented in the 80s by three scientists at the National Renewable Energy Laboratory (NREL). This very simple device is a container with restricted, controlled air flow that converts biomass to heat and charcoal. Wood is gasified in the container, then gas and smoke burns in a chimney for high temperature, high efficiency, complete combustion.

A TLUD is a cheap, simple, easy way to start making your own biochar. At the least, all you need is a barrel and two lengths of stovepipe. This controlled, containerized combustion is very safe, highly efficient and smokeless. I burn 55-gallon barrels of wood chips in 90 minutes with zero smoke. Except for the huge BTUs of heat radiated, no one notices the two raging fires inside.

Biomass is loaded in a barrel or bucket. The best biomass for these burners is small size, such as wood chips or pellets. But TLUDs adjust for a wide range of feedstocks, from straw to brush. Holes cut in the barrel bottom are "under-air" intakes. Biomass loaded in the barrel is lit at the top, then a lid is put on, with a few feet of chimney. This creates active up-draft to pull air from the bottom holes up through the biomass.

Like a cigar, fire slowly burns from top to bottom, drawn to fresh air entering below. As flames descend, intense heat "gasifies" the biomass, releasing volatile gases, vapors and smoke. All the oxygen in upward-moving air is consumed by this biomass gasification. Carbon burns hottest, thus, burns last. So, the flip side of biomass gasification is "carbonization"—wood is converted to black carbon char.

In a TLUD, oxygen is used up before Carbon ignites, so the descending, smoldering flames leave Carbon behind as "char."

Volatile gases are released as fire smolders down through the biomass. Super-heated gas and smoke rise up, and exit out the barrel top through a chimney hole. Without oxygen, this discharge is dense, smelly smoke. A TLUD without a secondary gas flare is a smoldering smoke pot.

Instead, as gas and smoke exit the barrel top, air is added to this upward stream through vents around the chimney base. Oxygen in this secondary "over-air" allows super-hot gas to ignite and flare up the chimney, burning the carbon, smoke and soot. Most energy released in a burn is in this gas flare.

The gas flare expands up the chimney, and further boosts up-draft as active suction pulls more air up through biomass in the barrel below. A tall chimney above the "over-air" intake assures strong up-draft to suck air up through densely packed biomass.

When the smoldering biomass fire reaches the barrel bottom, "under-air" is shut off, the top sealed to smother the fire, leaving behind charcoal. In efficient burners, up to half the biomass Carbon is retained in the barrel as biochar. My crude, leaky TLUDs do well to get 30% yield—often less.

TLUD stoves can be scaled to any size. They can be a tiny tin can burner, 1-gallon cookstove, or 5-gallon kitchen appliance. Several organizations distribute them worldwide to replace open fireplaces or cookstoves that emit smoky indoor air pollution that's a top world health issue. My TLUDs are 55-gallon barrels to make biochar for farm test plots. I plan to build a 30-gallon TLUD to heat a greenhouse. Largest I saw was 400-gallons, built by Alex English at Burt's Greenhouses in Odessa, Ontario.

Alex also retrofitted Burt's wood chip furnace that heats 15 commercial greenhouses. Alex can adjust under-air and over-air to the combustion chamber. In mild weather, Alex starves the fire of oxygen so it yields biochar instead of ash. Retrofitting fossil fuel furnaces to burn renewable biofuels and produce biochar is a key strategy in our oncoming confrontation with climate change.

Biofuels: Gasification By-product

Next step up in controlled combustion technology is a **Retort & Kiln**. To bake a cake, we put batter in an oven, and heat the oven from outside. This cooks out water. We don't set fire to the batter. We just heat it in a box beyond water's boiling point.

Similarly, to make char, we don't need to burn the biomass. Instead, put biomass in a container—a **Retort**—and heat it from outside to cook out the volatile substances. As temperature rises, larger, heavier molecules are baked out of the biomass. Eventually, all that remains is mostly Carbon and minerals.

To bake bread, 350 degrees F cooks out water. But to make charcoal, gasification needs at least 500 degrees C (??? degrees F). To get such high temperatures, a Retort is enclosed in a **Kiln**—an insulated chamber. The Retort is nested inside the Kiln, with a small gap between the two containers, to allow flames and heat to circulate around the Retort.

The Retort is sealed, so air can't enter. However, a pipe allows steam, gases and vapors to be vented and released as the biomass bakes and breaks down. Heat cooks the lighter, simpler, more mobile chemicals out of the biomass, which we can collect. This process is called "pyrolysis" ("pyro" = fire, "lysis" = to break). Gases, vapors and liquids vented from the retort are processed into varied gas and liquid biofuels, and useful organic chemicals.

As retort temperature rises, volatile molecules cook out of the biomass. First, at around 100 degrees C, water comes out—seen as fragrant white steam leaving the retort. After most water is distilled out, temperature rises to near 200 degrees C, and lighter gases begin to emerge—mostly Hydrogen, some Methane and Carbon Monoxide ("syngas")—all of them flammable fuels.

Next, as temperature rises further beyond 200 degrees C, lighter liquids distill out—mostly organic acids: Formic and Acetic ("wood vinegar"). These are useful plant growth stimulants, insect repellents and microbial food. As Retort temperature rises still higher, heavier, denser molecules will cook out of biomass.

When temperature reaches 500 degrees C, the densest, heaviest tars and resins are extracted. All that remains of the once-living cellulose skeletons is charred Carbon, embedded minerals, and the very thickest resins. Generally, beyond 700 degrees C, not much more is gained by this fractional distillation.

This method has several advantages. One is much larger chunks of biomass can be charred in a Retort. TLUDs are limited to feedstocks less than 2 inches thick. But a Retort can char much big chunks of wood, even "logs and hogs."

The best advantage of Retort is to extract and capture gas and liquid chemicals to re-process into biofuels. Instead of burning off volatiles in a gas flare, a Retort taps gas and liquid emissions to be trapped for use later. Or pyrolysis gas can be burned straight away to generate electricity, power a vehicle, or heat water.

It's uncertain suitable profit can be made selling char to farmers. But biofuel is where the gold is. Producing renewable fuels from biomass is a key technology for any hope of a sustainable future. Biofuel is a secondary product of pyrolysis with an alternate market that can assure profitable production and distribution of biochar for agriculture. And biofuel is fully consumable every day, but biochar stays in soil for centuries.

One straightforward way to implement this biofuel strategy is gasifier-powered transportation. Woodgas powered vehicles n the past, such as WW2. Early days of mechanized farming woodgas-powered tractors were

A leader to develop this biofuel technology isn't a corporation or well-studied scientist, but Alabama farmer Wayne Keith, the "woodgas wizard." In 2004, gasoline went over $4/gallon, and Wayne refused to pay, and converted his farm pickup to run on woodgas from his homemade gasifier. Since then, Wayne outfitted eight more pickups to run on woodgas generated by an onboard gasifier. Anywhere Wayne goes, he makes biochar as he drives, powered by waste wood from his sawmill. Wayne's pickup was clocked on video doing 80 mph, and his pickups regularly tow several tons trailers of hay bales.

At another scale, Coolplanet Biofuels leads to develop biofuel substitutes for gasoline. Using patented, proprietary catalysts, CoolPlanet produces liquid biofuels that are ready to blend with or replace gasoline. For two years, CoolPlanet has operated a biorefinery and test farm in southern California. In the next few years, CoolPlanet plans to build prototype plants to demonstrate their technology and introduce biofuels to the market. Two sizes are envisioned: a large scale urban facility yielding thousands of gallons per day, and a smaller village scale unit.

Many more methods make charcoal. Inventors, engineers and designers worldwide are building new equipment to make and market biochar. Startup companies appear almost monthly now. Scientists in several nations are funded to study this biochar strategy for climate, soil and energy. In the US, the National Science Foundation, US Dept. Of Agriculture, US Forest Service, Dept. of Energy are all investing in primary research, advanced applications and practical methods.

We are witnessing the birth of new industry: biochar. New product, new uses, new technology, new markets.

In a rush to "get the gold" selling biofuels and sequester carbon, we mustn't lose sight of the original purpose of this method: to create fertile soil to grow healthy food.

Operating a Biochar Facility

Most of effort and expense is acquisition and preparation of feedstock. Gathering. Transport. Handling. Drying. Sizing.

Continuous feed versus batch.

Efficiencies of assembly line production.

Co-generation CHP+B. Making use of process heat. Draying feedstock. Space heating. Hot warter. Electric power.

My ideal is a greenhouse heating system powered by a biochar combustion system. Make heat and biochar in the cold season, extending food production. Have lots of biochar to work into soil each spring. Especially valuable as potting mixes.