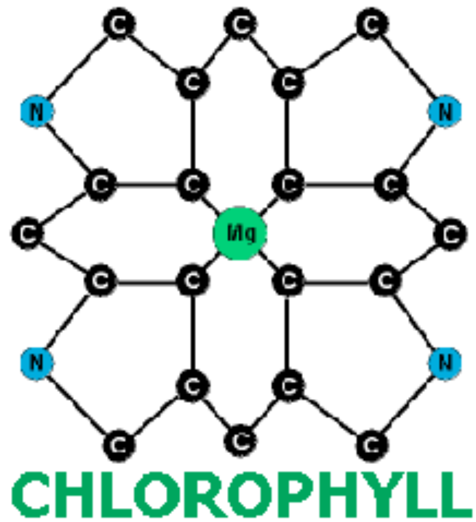


GEOLOGY INTO BIOLOGY

Carbon, Minerals & Microbes

tools to remineralize soil and restore the Earth

David Yarrow

February 2013

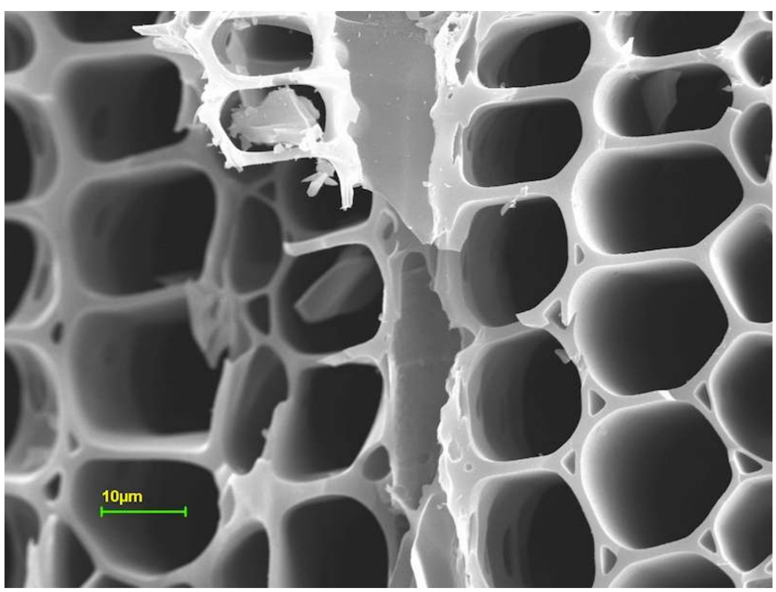
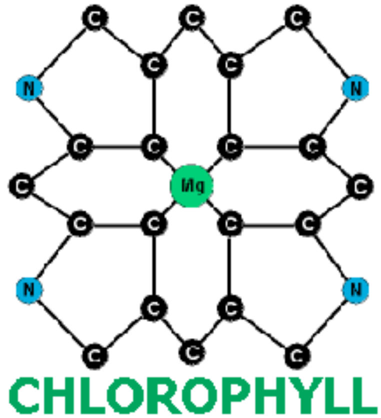


Fig. 1 **Scanning Electron Microphoto**

Cedar Chip Biochar

Juniperus virginianna

Wayne Teel, James Madison University, Harrisonburg, VA



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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 a living cell is four of the lightest, simplest elements. In a living organism, 95% of the atoms are (in order of amount): **Hydrogen**, **Oxygen**, **Carbon**, **Nitrogen**. These four **Organic Elements** are most of life’s physical substance.

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 twin, 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.

----------------------------------BREAK IN PAGE FORMATTING----------------

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.

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.

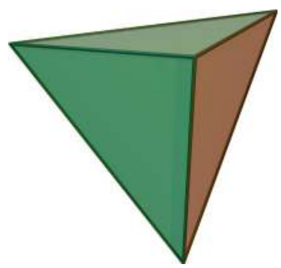


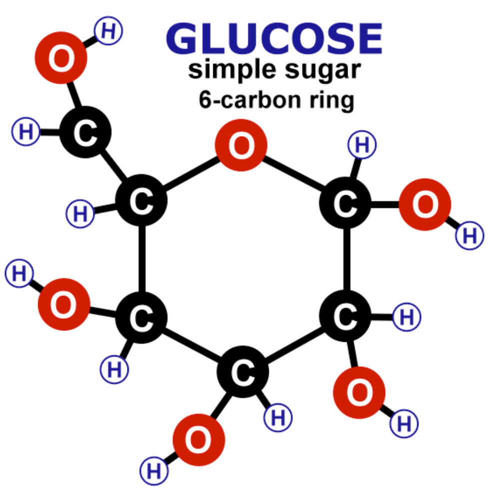
Fig. 2 **Tetrahedron**
4-arm symmetry

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!!

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 can interlink as cellulose fiber, cell membrane, or nuclear DNA. Ribose, a 5-carbon sugar at opposite ends of DNA's spiral stairway, is linked by amino acids “treads” of each rising step in the stairway. These complex bio-carbon structures are made by organisms as diverse as whisker-thin, white fungal threads deep in soil, to photosynthetic green needles in a redwood 300 feet overhead—as varied as mosquito or whale.

Nitrate, Ammonia, Amino Acid

Nitrogen, 4th Organic Element, is an odd member of this four. Nitrogen can make three bonds to other atoms, also in tetrahedral, 4-arm symmetry.

Nitrogen is ubiquitous. Stable Nitrogen gas (N_2) is 78 percent of Earth’s atmosphere—an inert form plants can't use. Until combined with Oxygen to form Nitrate (NO_3) by nitrogen-fixing bacteria, or by fertilizer industry, crops can’t grow as productively without Nitrogen.

Nitrogen is a reversible ion. As cation, it binds with Oxygen to form **Nitrate** (NO_3^-). As anion, it bonds with Hydrogen to make **Ammonia** (NH_4^+).

These two Organic Elements must be in certain ratios. Carbon/Nitrogen Ratio is a fundamental balance. Compost. Soil. Carbohydrate/Protein.

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.

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

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**.

More about these Organic Elements later.

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 elemental 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 have to 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 crystalline bedrock density, Nature dissolves, selects and re-organizes elemental minerals 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.

Trace Elements

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

KNOWN (proven essential)	
Iron	**Iodine**
Silicon	**Selenium**
Copper	**Fluorine**
Zinc	**Boron**
Manganese	
Chromium	
Cobalt	
Vanadium	
Germanium	
Molybdenum	
Nickel	
Tin	
UNCERTAIN (new data)	
Yttrium	**Bismuth**
Silver	
Gold	
Lanthanum	
Neodymium	
Platinum	

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.

Metamorphic.

Geological renewal. Annual flooding of rivers renews primary mineral supplies. Vertical import by deep-rooted plants and mineral springs. Horizontal import by water, wind, glaciers, and vulcanism.

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 restoration and Nature regeneration.

Bread from Stones

In Christian ***New Testament***, Satan tempts Jesus—who was fasting at the time—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. 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.

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 are anions, with 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

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)

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, with weak attraction for oxygen. Without B12, nerves have weaker 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.

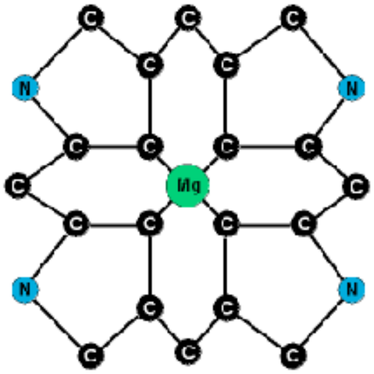
But lab data hints that a few elements are needed at parts "beyond billionths"—parts per trillion—millionth of a millionth. These "pico-elements" are present in cells at the current threshold of detection by laboratory equipment and methods. Even if biochemical assays detect these rare elements at these 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.

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.



CHLOROPHYLL

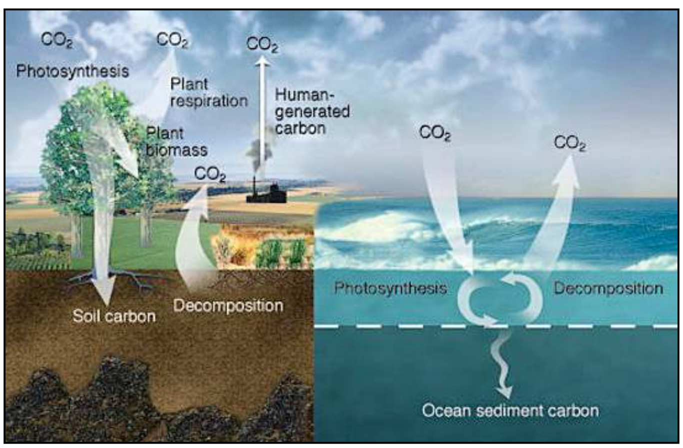
Thus, intravenous solutions for medical injection should contain—not just Sodium Chloride, or even only Major Minerals—but nearly every water-soluble element. And these elements must be in specific ratios or ranges suited to human physiology.

get the most from the least.

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.



I studied Basic Electricity in high school. Carbon was the "resistor" in our circuits. Carbon is neither a good conductor, nor a good insulator. It's a "semi-conductor," like the 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 and molecules to pad and insulate the charge. A cell can organize an energy field around an ion, and create a structure to package and harness the strong electric charge. In biochemistry, ions are commonly enclosed ions by rings of Carbon atoms and clouds of larger biomolecules.

Thus, in cell protoplasm and body fluids, a mineral ion is held in a matrix of Carbon atoms. Thus, a cell can hold a strong electric charge in a stable, sustaining shape. And at molecular, cellular and organism scales, shape creates identity. This ability to hold charge in a stable shape is what creates cellular memory.

In biochemistry, this embedding of ions is called "chelation." In modern nutrition, mineral supplements are "chelated" with biomolecules to improve their efficient absorption in the intestine. Calcium, for example, as a raw mineral element, is only 15 percent absorbed. But *chelation* with Carbon biomolecules can boost calcium assimilation to over 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.

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.

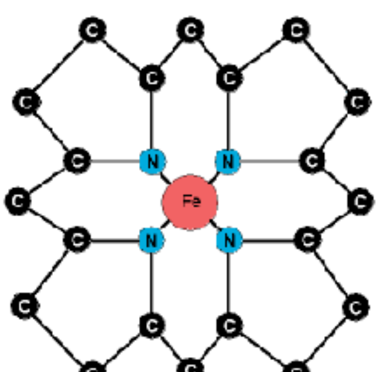
So, photosynthesis begins when a Magnesium antenna intercepts a photon of sunlight. High frequency light transmits an impulse to the Magnesium atom. This pulse triggers ringing in the Carbons around it—a molecular vibration that is transferred to other molecules in the plant's photoreaction center.

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.

This remarkable Ion—Carbon geometry, symmetry and synergy of Chlorophyll 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



HEME

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 the most mobile and facile atoms. It constantly moves around the planet, forms molecules in new organisms, assumes seeming endless forms and complex structures, from microscopic fungal mycelia to giant redwoods and whales.

Carbon is in constant change, and moving around the environment.

Global warming has made 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 living cells 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 to burn for energy.

Carbon assumes its most amazing disguises as Amino Acid and Carbohydrate. As sugar and protein, Carbon forms the biological bodies of plants and animals. As living organisms, Carbon achieves its greatest complexity and diversity.

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

Carbon is accumulating in Earth's atmosphere, fed by fossil fuels, deforestation, soil destruction, and industrialization. This movement of carbon from biosphere to atmosphere is causing a thermal imbalance known as "greenhouse effect." Our own 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 balance is now falling out of balance, threatening rapid-onset, runaway climate change.

Food production is generates at least 30% of greenhouse gas emissions. Deforestation to remove trees for farmland is 20% of carbon emissions. Carbon and nitrogen outgas from farm fields subject to routine tillage, monoculture and synthetic nitrogen fertilizers. Half of US-produced hydrogen is used for nitrogen fertilizer, and most is 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. Similarly, biological activity in soil dropped, as soils became increasingly sterile and lifeless—inert dirt.

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.

But humus is never static. It's dynamic, always changing, in constant digestion. So, it's hard to refer to it as "end product." The 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. Almost 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. 2*).

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 method to extract humus from soil has yet to be devised. This itself limits the study of humus. Further, humus in one soil is different 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.

Stable humus adds few available nutrients to soil, but provides essential physical structure.

Humus, while very stable, continues to decompose at a very slow rate, dependent largely on external climatic factors such as temperature and moisture. The lifetime of humus in soil is easily a few decades, and in some environments, humus may remain for centuries.

Humic acid. Fulvic acid.

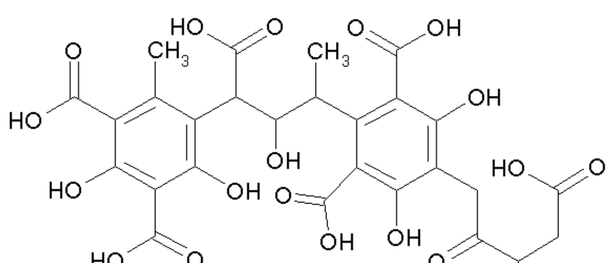


Fig. 3 **Humic Acid**
small, water soluble molecule
28 Carbons — 2 rings

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 table, 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 the foundation of organic farming is the 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 rest of the least of the elements. These embedded ions support SOM structures and clusters, and create electric charge sites on the surfaces of SOM's huge molecules.

SOM holds other mineral ions on its surfaces by ***adsorption***, a weak electric attraction between atoms with opposite charge. The adsorbed 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 OM, metal ions are far less likely to dissolve and move through soil with water from rain or irrigation. Thus, nutrients to stay in soil near the top, where they're available to microbes and rootlets.

SOM also improves soil structure and increases water absorption and retention. OM's large, complex Carbon molecules separate soil particles to 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 within and around clusters of OM molecules store water within soil, keeps 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 the cells and bodies of these living organisms. One cup of living soil is estimated to contain a few billion microbes, a few million fungi, a few thousand pinhead-size creatures, and two earthworm cocoons. The interactions 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 part of sustainable soil fertility, and for the conversion of currently infertile land into productive soils. The new, 21^{st} Century probiotic agriculture studies this soil biology, mimics microbial interactions and harnesses their symbiotic functions to grow stronger, healthier crops. We need learn much more about this living soil ecology, and employ them as allies in soil fertility.

Currently, the only simple, economical way to evaluate the presence of soil organisms is a Solvita-style respiration test. A soil sample is sealed in a container, and the conversion of O2 to CO2 is measured. We need better, simpler tools to evaluate these biological components of soil fertility.

Dozens of types of denizens, each with families and species, all working together to sustain the fertility and stability of soil. A tiny, invisible world easily as complex as our large scale biology and ecology. Among Earth's oldest communities of life. Soil a living tissue—as Gaia's skin.

Soil Food Web

In recent years, science has begun study the complex biochemistry and ecology of soil biology, and thus SOC. My own experiences talking to USDA and NRCS directors and board members convinces me that this new biological paradigm is firmly in the minds of most agricultural leaders.

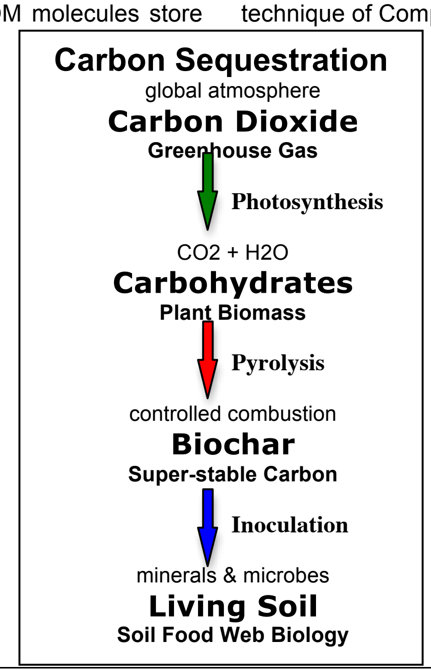
Dr. Elaine Ingham, a leader in this research, developed the concept of the **Soil Food Web** to identify and describe this complexity of cooperating organisms. Dr. Ingham developed methods to assay and quantitatively evaluate the many different categories of soil organisms. Dr. Ingham has trained hundreds in Soil Food Web technology who now serve as soil consultants all over the world. Dr. Ingham also developed methods to propagate and promote this living soil biology, most notably, through the technique of Compost Tea.

So, peering into Carbon's roles in soil opens windows into complex biochemistry, and complexities of cells and microbiology. , tremendous, yet tiny, scales of microscopic and molecular life. We are 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 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 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. Biochar's public promise 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 soils. But what is new to western science and farming has a 6000-year history of success in South America.

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

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 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 called "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 and sold 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, growing 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 his book ***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 charcoal. At first, his idea was rated preposterous, but Wim made a solid scientific case.

Since then, further studies have documented that *terra preta* is man-made. Archeologists from several countries made dozens of digs to document *terra preta*, prove their human origin, and assay their characteristics. Aerial surveys with canopy-penetrating radar detected thousands more hectares of these Carbon-rich soils. We now know enough *terra preta* was created by indigenous tribes to feed a population of at least five million, and perhaps up to 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. By converting plant biomass to char and adding it to soil, significant CO2 can be moved out of the atmosphere into a safe, stable, solid form. —enough to perhaps…...

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

Once biochar is properly put in soil, it stays for centuries. USDA soil scientist David Laird believes charred Carbon has a life cycle in soil of 1600 years. Thus, farmers who add biochar to soil invest in several lifetimes of soil fertility. To be sequestered, science calculates Carbon must be removed from air at least 100 years. Biochar sequesters Carbon 16 times longer.

By comparison, fresh, raw organic matter has a soil life cycle measured in years. Even large woody limbs rot away in a decade or two. Stable humus has a soil life cycle of a few centuries. So,

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 biochar is a super-stable form of Carbon.

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.

Ten years after Wim Sombroek published his 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 biochar burners have made test biochar for 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 carbon-smart agriculture, and restore a solvent foundation to community economies.

And we can grow high quality, nutrient-dense foods.

Is Biochar A Fertilizer?

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 charged by blending with compost. Another approach is feeding it to livestock. But once in soil, nutrients of soil organic matter goes 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, roots and microbes. Biochar decreases nutrient leaching from soils, as the biochar matrix becomes a nutrient reservoir and relay.

Blocking off pores with soil organic mater, living and dead cells, and minerals is definitely a process to be taken serious.

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. And a smaller fraction of Carbon escapes as volatile gas, such as ethylene, a plant growth stimulant.

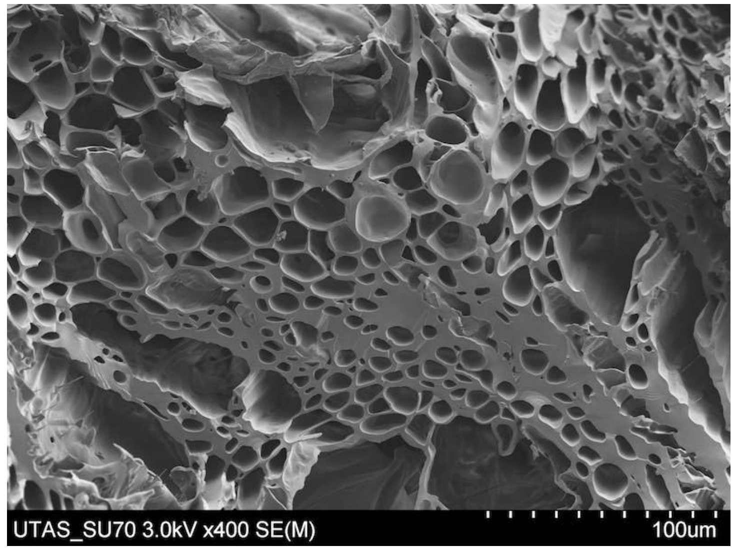
But over 95% of well-made char is super-stable, stays in soil for centuries. It's truly an inert ingredient. Yet, biochar continues to sustain soil fertility, apparently, in the Amazon, for centuries.

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. Char is lightweight because it's



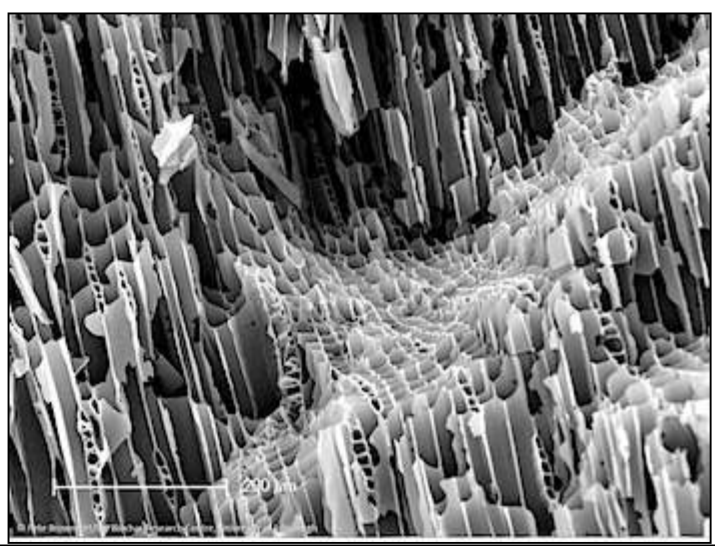
empty. It floats because air is trapped in those tiny tubes and pipes. Those bundles are like a sponge, and give char a huge internal capacity to soak up and hold water and other substances. And even as char is empty, open and porous inside, it causes soil to become lighter, looser, more open to air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

Nature makes multiple uses of this emptiness. Char's profusion of microscopic pores is Nature's nano-technology. Water, oil, glycoproteins, and other substances are drawn 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.

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 those inner chambers are many times greater than outer surface. The added internal capacity of char is estimated between a few thousand, to maybe a million, times more than external surface.

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.

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.

Micropore structures engineer the architectures of soil and larger organisms like plants.

Adsorption: Why Carbon is Black

Char isn't just Carbon. Held in the Carbons are minerals. If you burn charcoal, the final product is white ash—mostly metal oxide minerals. These embedded minerals create sites in the char with electric charge. Also, char has numerous Oxygen atoms (OH, OOH, etc.) that create other electric charges.

These embedded electric charges attract atoms and ions in molecules of opposite polarity. Their charge isn't strong enough to form bonds in which atoms exchange or share electrons, but it is enough to hold atoms near the char. This loose association is based on a subtle mutual attraction. 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 char's limited external surface is augmented by complex internal surfaces of biochar's micropores. These hollow, empty internal spaces give char vast internal surfaces. The inner walls of char's empty chambers provide a far greater ion adsorption capacity than almost all other natural materials. Calculations vary, as do characteristics of various feedstocks, but biochar easily has a few thousand to over a million times more internal than external surface area.

Char actually draws ions to itself, separates them from solution, and holds them tightly at char surfaces by weak electric attraction, not a 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 rootlet, or to microbial membrane. This easy access ion exchange makes adsorped nutrients very 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, which 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, in prairie fires, significant charred Carbon was created by slow-moving, low temperature grass fires with green, moist biomass. Over centuries of recurring fires, the charred Carbon accumulated in soils, and the char changed those soils to improve their fertility.

In July 2012, six scientists published a paper in the Environmental Science and Technology of theAmerican Chemical Society showing that in the Midwest, highly productive, grassland-derived soils (Mollisols) contain char generated by pre-settlement fires that is structurally comparable to *terra preta*. These soils are much more abundant than previously thought (40—50% of organic C). Oxidized char residues are a particularly stable, abundant, fertility-enhancing form 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

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

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

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.

Sulfur.

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 uses for biochar as a phosphorus trap on dairy farms. 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 documented over 50 percent reduction in phosphorus leaving the farm and entering the lake.

curtails outgassing of NOx. Methane emissions are also reduced. This is the adsorption power and capacity of biochar.

The ability of biochar to curtail leaching, outgassing and pollution, and improve fertilizer effectiveness occurs at two levels. The first level 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 eat and process nutrients into biomolecules and protoplasm.

Soil Reef: 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 bursting with microflora the soils are. 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 diameters are 0.2 to 70 microns—average, three microns. Bacteria have no trouble populating biochar. In fact, 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.

Rice-grain-size char has enough micropore capacity to house thousands of bacteria. 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.

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.

Inoculation with *mycorrhizae* has quickly become standard practice in production agriculture.

Soil Reef: Substrate for Microbes

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

These symbiotic fungi inhabit char micropores to grow dense networks 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, and pipes them to fungi living in the char. Thus, the 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.

I've seen plants quickly become intimate friends with char.

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**

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 a quest to find the "missing Carbon" in soils, in 1996, USDA research scientist Sara F. Wright discovered Glomalin, named for the Glomales order of fungi.

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, to function as pipes to funnel water and nutrients—particularly phosphorus—to plants.

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 acid, once believed the main source of stable soil carbon. Glomalin also keeps other soil Carbon from escaping, 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 acid 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 live in communities with many other species of microbes and larger organisms. Microbial associations are inter-dependent, inter-active, share and recycle nutrients, and provide 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.

So, many organisms provide special services that benefit the wider community. Being super-stable, biochar offers microbes long-tern residence to develop a full diversity and supporting services. Create a fully functional culture of microbes with enough diversity to adapt and respond to changing food sources, climate and symbionts.

Consider the lowly earthworm—the plowman of native soils. Recent research discovered that earthworms are farmers. They consume raw plant wastes, and then regurgitate the partially digested pulp to line their tunnels. Fungal spores sprout and encase the plant biomass, further digesting starch, cellulose and protein. The earthworm returns 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 one or two years for raw, fresh char to effect a fertility shift in soil is because first, char must be colonized by microbes. Microbial population growth consumes most of the immediately available nutrients. But once the microbial communities and networks become established, they gather and make available a surplus of nutrients that are directed into roots and plant growth.

But for production agriculture, this 2-year dip in yield isn't acceptable. Farmers aren't likely to wait two years to harvest a profitable crop. Professional growers need to see fast response to an application, and a strong stimulus to growth. Economics and the logistics of handling require convenience, and a good response to a limited amount of applied materials.

Of special interest to soil science are Nitrogen-fixing bacteria that use some form of nitrogenase enzyme to create nitrate in soil. *Rhizobia* bacteria that live on root nodules of legumes are well-known and widely used in agriculture as inoculants. But there are over 200 other bacteria that convert Nitrogen gas into plant food. Each species adapted to specialized environments, often using unique enzymes and metabolic strategies. Most are symbiotic with particular species of plants, and all depend on the presence of certain "helper" bacteria.

Ongoing research is peering into biochar to learn which microbes prefer char as a host environment. The high nitrate levels in Amazonian *terra preta* suggests that certain nitrogenous microbes easily take up residence inside char.

Not just Nitrogen-fixing bacteria, but all various organisms that the drive The Nitrogen Cycle seem to happily reside in char, working together to support full function soil fertility and a stable, balanced environment. Microbes that convert nitrate to ammonia, and other organisms that flip ammonia back to nitrate seem to co-exist in char, and keep these forms of Nitrogen in balance in soil. Substantial research is needed to identify microbial strains, understand their interactions, and culture their colonies for specific soils, crops and climates.

Feedstocks: Weedy or Woody?

The photo above shows microscopic slices of eight hardwoods. It makes obvious that the microscopic structure of every living thing is unique and complex. So specialized and unique is each type of biomass, species of wood are identified by different cell structures in a microscope. Similarly, each type of biomass has different chemical composition. This variability of feedstocks adds yet another confounding layer of complexity to this carbon sequestration strategy.

Thus, the characteristics of biochar vary greatly with each type of biomass used as carbonization feedstock. Even given the same species, its conditions of growth, soil minerals, harvest method, post-harvest processing, carbonization technology—all these factors alter the quality of biochar. Production systems vary the temperature, time of heating, pressures, oxygen content, and other parameters, and each affects the final char. To understand and assess this overwhelming complexity is an immediate technical challenge. IBI has already 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 wood from trees, maybe brush.

But for use in soil, it is likely that agricultural biomass rather than forestry wastes are more desirable. Annual plant biomass such as straw, hay, cornstalks, seed husks, weeds, and other forms of grassy, weedy feedstocks may prove more suitable in soil than dense, tough, chunky wood.

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 hard oak char to soil particle size. And even as dust, oak char is dense and heavy, with smaller micropores and tighter internal spaces.

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

Most biochar pores are at least 20 microns in diameter, and almost all are at least 5 microns.

Unusual feedstocks: manures, humanure, high density (pits & shells), high resin & oil, bones. Torrefied wood.

Only in the last decade did scientists acquire tools to accurately map and measure these complex Carbon structures.

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's 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 ARS 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 effective use of biochar:

1) bulk char, in one large load,

2) raw, uncharged char,

3) sterile, uninoculated char, with only a tad of microbial life on or in it,

4) intensive use of synthetic salt fertilizers, tillage and other antibiotic soil management practices.

Terra preta in the Amazon wasn't made by just adding char, nor created in a single fortnight. We know if we dump a few tons of raw char all at once into poor soil, plant growth is retarded one year, maybe two. But after that, plants erupt in impressive, vigorous growth. Clearly, char initiates a process that transforms the soil, and this process requires an extended period of months.

Also clear is other ingredients are needed for *terra preta*. Indigenous people added lots of "cultural debris" to their soils. Scientists study the village "middens" to understand how tribes made so much charcoal, so much pottery, so much fertile soil. Ultimately, what makes these soils so highly fertile and functional isn't Carbon, but the microbes.

While microbial populations initially grow and get established, fewer nutrients may be available to plant roots. But once the char is fully inhabited and the soil biology is fully alive, productivity rises each year thereafter, soon surpassing chemical fertilizers.

Fortunately, we are quickly learning how to prepare char for optimum effects on soil and crops. Biochar research in America is hardly half a dozen years old, but already solid research shows that properly prepared, carefully applied biochar has dramatic effects on plant growth at rates as little as 500 pounds per acre.

In 2006, Virginia Tech University began field trials adding biochar to soil growing tomatoes, potatoes and sweet corn. Biochar was supplied by CarbonChar, a new company manufacturing biochar. Guided Jon Nilsson, an east coast compost expert, CarbonChar created **CharGrow** biochar-based soil inoculant with beneficial microbes, substrates and microbial food. The formula to load char with microbes is a trade secret.

CharGrow had the following measured effects on yields of Irish Potato, Sweet Corn and Tomato:

- 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 yields were achieved by two cups of **CharGrow** in five gallons of transplant potting mix. In 2010 trials, four cups per five gallons of mix was used, resulting in even higher yields.

John Nilsson tells farmers, "Microbes are more efficient than any product you ever bought. They work 24/7, and they're cheap—lots cheaper than fertilizer. CharGrow will show change by soil penetrometer and higher Cation Exchange Capacity. CharGrow lowers costs, and maintains or increases yield. Either way, it's money in a farmer's pocket."

John is emphatic: "Agriculture will turn on a dime when bio-inoculants show farmers permanent changes to soil fertility and reduction in cost. My job is to cut costs and increase yields. If my stuff works, who cares what I call it, or what your beliefs are."

So, to prepare biochar for optimum effective use in soil, there are four fundamental steps, which I call "**The 4 M's**":

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

Moisten

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

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

Fresh char isn't just dry, it's hydrophobic. It repels water—actually resists water penetration. Residues of tar and resin left in the char are oily, and hydrophobic. Until these thin films and beads of hydrocarbon are etched out of the char, it will not accept water.

Without water, char is dusty. Charred carbon 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.

In normal char production, water is used to quench the char—to cool it down and prevent a charcoal fire. People beginning to make char are surprised how much water is required to extinguish a charcoal fire. By how much heat is held in charcoal, and how much water it soaks up. However, too much water yields char that is soggy, sticky and heavy. This makes handling messy, and screening for particle size more difficult.

But, with the proper amount of moisture and blending, char is still lightweight, yet cohesive in clumps that are easier and safer to handle, and don't disappear in a wind.

Micronize: intimate relations

Second step is to reduce particle size. Smaller particles disappear into soil faster, mix more thoroughly and intimately with soil particles and organisms.

The first benefit is to increase char surface area. In order for water. ions and microbes to soak into char, they must enter at the exterior surface. Smaller bits have more total surface available for absorption and adsorption. A 1-inch chunk has a surface area of—at best—six square inches. The same chunk shattered into a thousand fragments has thousands times more surface area. Water, nutrients and microbes can more quickly get onto smaller particles, and gain access to their interior spaces.

Smaller particle size also is distributed in soil more widely, more intimately. Dust—the smallest particles—is smaller than most soil particles, and inserts between soil particles. These bits of carbon insulate soil granules, isolating their electric charges. Thus, clay is less sticky, to create physical structure, aggregation and tilth.

Larger particles, with their sponge-like internal micropore matrix, soak up nutrients and water to increase the growth energy potential of soil. Smaller particles allows better penetration into the char of the ions and water molecules. By contrast, a 1-inch or larger chunk of char has a harder time drawing ions into its deepest interior spaces.

With essential nutrients abundance and easily available, the microbes move in and take up residence inside the char. Each bit of biochar becomes host for colonies of bacteria, fungi and other microorganisms.

The largest char particles provide enough space for microbial communities to become established.

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 be colonized by thousands of microbes. A 1-inch chunk of char can house a microbial population equivalent to our modern cities—millions of denizens inhabit and share a charred Carbon matrix.

Prefer a variable particle size, from rice grain size down to fine dust.

The advantage of weedy feedstocks. Easily crushed to dust. Larger pore sizes, for greater internal living spaces. Weed versus woody feedstocks. The common reflex of most people is that charcoal is made from wood. But after a few years of fieldwork, we may discover that weedy is better than woody for agricultural soils.

Water soluble Carbons. Up to 100 Carbons in size. Still able to be suspended in water. Very useful in foliar and other spray applications, assimilated through leaf pores and strengthens them structurally and energetically. Biochar equivalent to humic and fulvic acids which are currently extracted from humates, a geological fossil carbon.

Mineralize: charge the soil battery

Third step is to add minerals to the char.

Think of soil as a battery that absorbs and holds electrons and ions, and makes them available to living organisms. Carbon is especially effective to capture and hold free electrons.

In our emerging understanding of nano-carbon such as bucky balls and carbon fibers, modern science is developing graphene batteries. Graphene is a nano-technology to deposit a molecular-thin layer of carbon

Charging up this biological battery begins by adding ionized and ionizing minerals. Cations contribute electrons to the soil battery, while anions provide receptors to hold electrons, ransport them, and deliver them to metabolic reactors. Because of biochar's immense ion adsorption capacity, it's a highly efficient media to hold and deliver ionized minerals and their electrons to soil.

High efficiency delivery system. Optimum bioavailability, minimum leaching and outgassing.

Given the weak, depleted and deficit state of most soils, I recommend this start by adding sea minerals to char.

sea minerals
major minerals
nitrogen
phosphorus

Microbial Inoculation

The fourth step to prepare biochar for soil is to add life to it. With char stocked with water and nutrient ions, and vast empty micropore spaces, microbes move in. We don't eat our houses, and microbes don't eat char. They live in it.

In the paradigm shift from chemical to biological, the culture of symbiotic organisms is a crucial step. Microbes have been managing soil, to sustain and increase fertility for endless eons. Creating fertile soil is a microbial job description

Microbes ="no-see-ums" = the least & smallest of all

Most often, char is inoculated by blending with compost, or spraying with compost tea. Within a few hours, char's micropore structures are colonized by bacteria and fungi. These colonies of microbes are the "culture" of interactive organisms that make char a superior soil enhancement.

Studies with char demonstrate that it is an ideal substrate to culture microbes. The features that make char an ideal water filtration media also make it an optimum habitat for beneficial microbes.

If properly mixed, it takes only a few days for char to become fully charged with water and minerals, and colonized by beneficial microbes.

For example, mycorrhizal fungi take up residence in the char, and proliferate through abundant sporulation. These fungi send their "hyphae"—white whisker-thin threads of glycoprotein—outwards into the soil, searching for nutrients and water. Each hyphae is a tiny tube with a mouth at the far end. The tubes scour up water and nutrients, and pump them back to the fungal body living n the char. Thus, the char becomes an active storage warehouse stockpiling these essential nutrients.

ideal habitat for bacteria, fungi, other microscopic life.

One special interest of *terra preta* research is nitrogen-fixing bacteria. There are over 200 kinds of N-fixing bacteria, each inhabits its own specialized environment, including specific host plants. For example, Rhizobia is a well-known bacteria that inhabits the root nodules of legumes, and uses the trace element molybdenum in a nitrogenase enzyme to convert Nitrogen gas into water soluble, plant available nitrates.

It seems that biochar hosts certain unique strains of N-fixing bacteria. So, properly inoculated char will provide additional pathways to fix Nitrogen.

Nitrogen cycle.

Soil biology. Soil food web.

Paul Stamets and Fungi Perecti.

Other pioneers, such as Michael Amaranth with Mycorrrhizae.

helper bacteria

symbiotic networks. The soil feeding pipeline. Hundreds of miles of mycelial threads, each a tiny tube with a mouth moving water and nutrients around soil.

fermentation, digestion

oxygen, water, food.

Primary cycle: bacteria and fungi.

soil breathes.

Soil water digestion: water penetration, retention, return, capacity.

interactive communities

intelligent systems

earth most ancient communities

inoculants: EM, BD preps, manures, composts, compost teas.

Earthworm Avoidance Test

Biotoxicity to soil organisms….

Lettuce Seedling Trials

Given how new and immature our understanding of biochar and soil microbiology is, growers should adopt a standard procedure to test any new biochar before they add to soil. Once it's….

Carbon and Community

Carbon is special among the elements. At a molecular sale, its ability to form four bonds with other elements make it the great connector that links other atoms to form complex molecules. Its equalized bonding energy minimizes the polarization of charge. Carbon brings the other elements together for form larger structures that carry pattern, information and intelligence.

At a cellular scale, Carbon creates a safe, neutral habitat that allows microbes to aggregate and associate, and form larger communities.

Ultimately, it may be that restoring Carbon to soils will also initiate changes in human society that supports for functional, intimate and successful communities.

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: By-product of Gasification

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.