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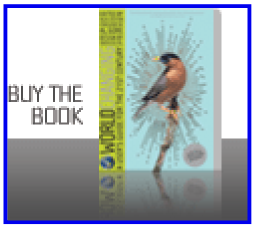

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A Carbon-Negative Fuel
Jeremy Faludi, 16 Oct 07

"Impossible!" you say. "Even wind and solar have carbon emissions from their manufacturing, and biofuels are carbon neutral at best. How can a fuel be carbon negative?" But listen to people working on gasification and terra preta, and you'll have something new to think about.

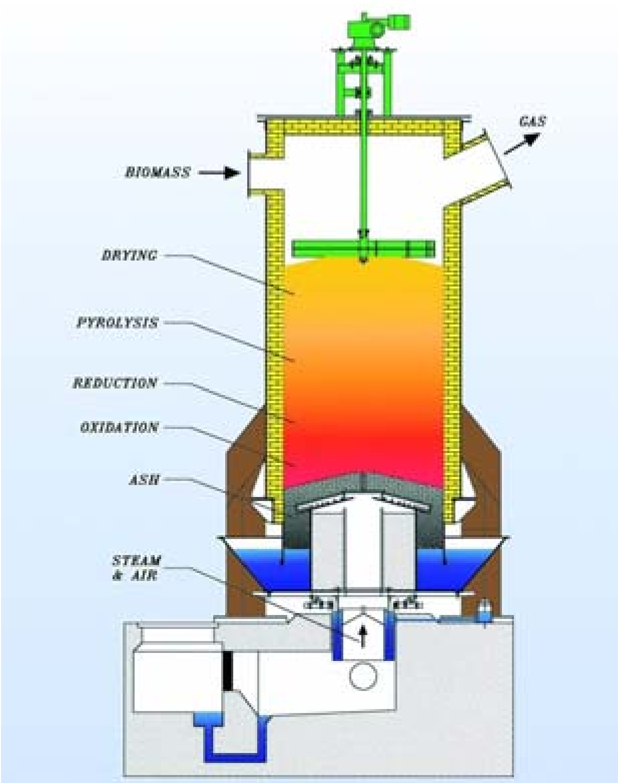
We've mentioned terra preta before: it's a human-made soil or fertilizer. "Three times richer in nitrogen and phosphorous, and twenty times the carbon of normal soils, terra preta is the legacy of ancient Amazonians who predate Western civilization." Although we don't know how it was made back then, we do know how to make it now: burn biomass (preferably agricultural waste) in a special way that pyrolisizes it, breaking down long hydrocarbon chains like cellulose into shorter, simpler molecules. These simpler molecules are more easily broken down by microbes and plants as food, and bond more easily with key nutrients like nitrogen and phosphorus. This is what makes terra preta such good fertilizer. Because terra preta locks so much carbon in the soil, it's also a form of carbon sequestration that doesn't involve bizarre heroics like pumping CO2 down old mine shafts. What's more, it may reduce other greenhouse gases as well as water pollution: according to Biopact, a network that promotes biofuels and biomass energy,

> *Char-amended soils have shown 50 - 80 percent reductions in nitrous oxide emissions and reduced runoff of phosphorus into surface waters and leaching of nitrogen into groundwater. As a soil amendment, biochar significantly increases the efficiency of and reduces the need for traditional chemical fertilizers, while greatly enhancing crop yields. Experiments have shown yields for some crops can be doubled and even tripled.*

As it happens, the process of burning/pyrolisizing agricultural char is also a way to produce energy. MIT Professor Amy Smith, a recipient of the prestigious MacArthur "genius award," gave a TED Conference talk in 2006 on using agricultural char as fuel in developing countries. It works because the chemical reactions that break down the long hydrocarbon chains also give off hydrogen gas, methane, and various other burnable fuel gases. (As well as tars and non-useful gases like CO2.) This is gasification. The fuel gas can be burned for heat, or if it's pretty clean (that is, if the tar levels are low), it can be used to power an engine.

I was first introduced to gasification by Jim Mason at Foo Camp, and helped a bit with his Burning Man project The Mechabolic. It's an art project designed to use gasification for motive power, electrical power, and gas-powered lights and heat, all at the same time. The Mechabolic is intended to run off of coffee grounds, or whatever ground-up dried-out biomass can be fed to it, with its own "mouth" parts to chop up and pulverize incoming material well enough to be fed into its gasifier tank. Jim points out that gasification is not new -- in fact, according to Professor Tom Jeffries at the University of Wisconsin, "Over a million wood gasifiers were used to power cars and trucks during World War II," when Europeans often lacked access to oil.

There are many kinds of gasifiers, each with advantages and disadvantages for different conditions and input materials. Babcock & Wilson Vølund have a helpful diagram (see below) with explanatory text that shows one kind in detail. The locations and sizes of the different zones will be different for other designs, but the sorts of chemistry described occur in all gasifiers.



Not all gasification is green. The coal industry routinely uses gasification all around the world to create syngas (synthetic gas) as a petroleum substitute of chemical feedstock. However, gasification plus terra preta has potential to be revolutionary.

I can't promise that using gasification for energy and using the resulting char as terra preta fertilizer will be a carbon negative fuel, because I haven't seen a credible lifecycle analysis of it. (If anyone has, please post it to the comments.) But it's quite plausible. Consider that it takes a certain amount of CO2 to grow a crop, such as corn. You harvest the crop and sell the food part, which leaves you with all the agricultural waste. Instead of burning it in the open air, or landfilling it (which is what's done today -- basically topsoil mining), you gasify it. You then burn the fuel gas you get from gasification, putting some fraction of that CO2 into the air; the agri-char (terra preta) that you're left with contains the rest of the embodied CO2 which the crops sucked up while growing. There's more carbon here than there was in the fuel gas. You spread the terra preta on the fields as fertilizer to grow more crops, and repeat the cycle -- and with each repeat, you pull more carbon back into the soil than you burn, resulting in a carbon negative fuel as well as crops fertilized with fewer petrochemicals. It's a double win.

Energy Policy and Farm Policy

Gasification and terra preta as a means of sequestering carbon is far cheaper than injecting CO2 into mine shafts, but it's still not cheap. Biopact calculated that "under a basic scenario sequestering biochar from biofuels produced by pyrolysis would be competitive when carbon prices reach US$37 (carbon currently fetches €21.55 on the European market, that is $30.5, and prices are expected to increase strongly in the near future)."

However, "[T]he great advantage of biochar is the fact that the technique can be applied world-wide on agricultual soils, and even by rural communities in the developing world because it is relatively low tech." In fact, the guts of Jim Mason's Mechabolic was mostly built with scrap steel tanks and whatever miscellaneous piping was handy, with nothing but a couple welders and some power tools -- nothing a well-equipped farm mechanic wouldn't have.

One of the 2007 Ashden Awards went to a company in India making gasification / char systems in Kerala:

> *BIOTECH has succeeded in tackling the problem of the dumping of food waste in the streets of Kerala through the installation of biogas plants that use the food waste to produce gas for cooking and, in some cases, electricity for lighting; the residue serves as a fertiliser. To date BIOTECH has built and installed an impressive 12,000 domestic plants (160 of which also use human waste from latrines to avoid contamination of ground water), 220 institutional plants and 17 municipal plants that use waste from markets to power generators. The disposal of food waste and the production of clean energy are not the only benefits of BIOTECH's scheme. The plants also replace the equivalent of about 3.7 tonnes/day of LPG and diesel which in turn results in the saving of about 3,700 tonnes/year of CO2, with further savings from the reduction in methane production as a result of the uncontrolled decomposition of waste, and from the transport of LPG.*

While still under the radar of most policymakers, gasification and terra preta are starting to appear on the scene. In the US this year, Senator Ken Salazar (D-CO) is promoting legislation that would give subsidies of up to $10,000 for farmers who set up gasifiers and use the terra preta on their fields, and $100 million in related research grants. Biopact has the full text of the bill online, and Biochar International has a summary of the bill.

Image: The Mechabolic at Burning Man. Credit: Michael P Byrne

COMMENTS

Jeremy, nice post. But Worldchanging readers, please help me on this. This is not to criticize terra preta, but . . .

Why is the "nontechnological" capture of atmospheric carbon through photosynthesis, and the biological process (which is fastest in temperate perennial grasslands) of formation of stable soil organic matter (humus, glomalin, etc. etc.) so invisible to us?

Various strands of modern alternative agriculture (e.g. holistic planned grazing, Keyline systems, pasture cropping, permaculture, also including organic farming and no-till farming) have been shown to be able to build soil organic matter rapidly while maintaining production--not from external inputs, just from enhancing the biological processes on and in the soil. Soil organic matter is 58% carbon. All it would take to run atmospheric CO2 down below 300 ppm is a net average increase of 1.6% in the organic matter of the world's crop and pastureland soils. Many alternative ag people do this in a year or two in favorable environments with favorable soils.

Non-use is not what is required to do this, but intensive management, working WITH rather than against the basic eco processes of water cycling, mineral cycling, solar energy flow, and community dynamics. Most of our industrial or "robbery" agriculture works AGAINST these processes, making soil our #1 export, far surpassing even empty shipping containers. And releasing huge quantities of CO2 to the atmosphere as the soil organic matter is oxidized through tillage, ammonia fertilizer, and exposure of soil.

Soil carbon is the perfect opportunity to fix climate change. The carbon we capture from the air doesn't need to be tilled in or spread--the plants do it for us. And it's not a hazardous waste disposal problem, like it is for the carbon capture schemes.

Taking carbon from the atmosphere takes ENERGY. It's combustion in reverse. Technology can't do that. Why do we forget that photosynthesis is the reverse of combustion/respiration?

Some hypotheses for why we ignore the photosynthetic/soil carbon opportunity:

1. There are no pipes, valves, stainless steel tanks, or gauges involved. (We love technology.)

2. We feel good when we add things (e.g. biochar) to the soil, when we do work to achieve a result, even if it may not be necessary.

3. Biological processes such as the decay of shed grass roots into humus aren't sufficiently technological or visible to interest us.

4. When we think of photosynthesis, our attention is captured by the large, obvious plants such as trees (which are hokum as a carbon sink, because they rot or burn too quickly).

Terra preta is worth pursuing, perhaps particularly for tropical soils which metabolize organic matter quickly. But why can't we see the direct photosynthetic soil carbon opportunity?

more info: http:/managingwholes.net

Posted by: Peter Donovan on 16 Oct 07

What's great about this is that putting biochar in the ground is permanent - that Terra Preta carbon was put there centuries ago. On the other hand, if you just use organic material, you are just churning atmospheric carbon, not permanently sequestering it. When organic matter decomposes, it produces gaseous carbon - methane and CO2, which is held in the soil by inertia mostly. When somebody tills the soil it just 'burps' back out. But if it's in the form of activated charcoal, it stays put. That is a net reduction in atmospheric carbon.

Posted by: Clark on 16 Oct 07

Here's a video of Chicken John Rinaldi's gasifier-powered pickup truck at Burning Man:
http://www.chickenjohn.com/mayor/innovation.html
Chicken John is a friend of Jim Mason's and a co-conspirator in the "power generation as art" movement. He's running for Mayor of San Francisco this November, and part of his platform is to build a large gasifier to generate electricity for the MUNI light rail system.

Posted by: Jeremy on 16 Oct 07

"Terra preta is worth pursuing, perhaps particularly for tropical soils which metabolize organic matter quickly. But why can't we see the direct photosynthetic soil carbon opportunity?"

Peter, can I add that it could be of use as a by product of weed control. We have major problems with ground fuel loads in summer, specifically from Broom (Cytisus scoparius) and Gorse (Ulex europeaus). Currently these are sprayed, but only where they are near towns.

Being able to talk organic matter which is not currently being utilised, ie weeds, and turning it into a soil ameliorant (?sp?), which can then be used to build up our nutrient poor soils down here in Australia, "sounds" great.

However, I totally agree with your comments regarding soil conservation through responsible land management. No till farming, appropriate grazing rotation, and basic biological farming techniques are an effective way to build up soils, and increase soil carbon content in the process.

As well, my dream of taking woody weeds and turning them into agrichar might run into some costing problems at the moment.

Posted by: Luke Bunyip on 16 Oct 07

The Ashden award winners you mention utilize anaerobic digestion to convert waste food and feces into gas. The bacteria in the digesters consume what little energy is left in the feces, or the loads of energy in the waste food, and exhale (exhaust? whatever bacteria do...) methane. It is not a partial combustion process like the gasifiers discussed throughout the majority of this article.

While the results of the bill could be admirable, the Colorado Senator is also pandering to those constituents who work for and contract from the National Renewable Energy Laboratory, in Golden, Colorado.

Posted by: Paul on 16 Oct 07

By the way, this just in:

The Gasification Technologies Council is having their annual conference in San Francisco, today and tomorrow. If you're interested in this stuff and live around the bay area, pop on over to it!

See www.gasification.org.

Posted by: Jeremy Faludi on 16 Oct 07

Just a note: Peter Donovan's numbers are *way*, *way* off.

To remove 100 ppm CO2 from the atmosphere, it would require a build-up of ~200 Gt-C (billions of metric tons of carbon) in the soil. Right now, it is estimated that there are about 1200 billion tons in all of the soils in the terrestrial biosphere, not just the agricultural lands. So this a 16-17% increase in the soil carbon levels of all of the ecosystems, not just agricultural lands. If you had to do this on existing croplands (about 15 million square kilometers at last count), it require about a 100% increase in soil organic matter on all of the planet's farmlands.

While I like the spirit of his comments, the numbers are just wrong.

Posted by: anonymous on 16 Oct 07

Anonymous: Let me clarify. By a net increase of 1.6% I mean from say .5% to 2.1% organic matter in the top foot (more than a doubling in this case). Or to take another example, from 4% organic matter to 5.6% organic matter, or from zero to 1.6%. This would, averaged on the world's cropland and pastureland soils (figures from the World Resources Institute) take atmospheric ppm down by about 80 ppm. There can be no doubt that this would require a transformation of most existing agriculture.

Before 1830, it is estimated that many tallgrass prairie soils in the midwest contained 5-10% organic matter. Now, after years of corn and soybeans, quite a few are in the .5% range.

Many forms of soil organic matter are exceptionally stable. Rattan Lal of Ohio State estimates that the average residence time of carbon is 35 years in trees, 100+ years in soil organic matter. Barring sudden destruction by inversion tillage, which resembles fire plus earthquake for the underground bacterial and fungal communities.

When you consider the benefits of turning atmospheric carbon into soil organic matter--which alleviates drought and flooding, chelates heavy metals, salt, and other contaminants, improves water quality, food quality, all using abundant free solar energy--it's quite a deal.

For details on the numbers, see the papers of Dr. Rattan Lal, and Allan Yeomans's PRIORITY ONE (www.biospheremedia.org).

Posted by: Peter Donovan on 16 Oct 07

Sounds nice but theres a problem somewhere, I suspect its that the author hasn't included the carbon cost of running the gasifier.
Basically agrichar / terra preta is a very stable form of carbon created from a less stable form, vege waste. The reason some chemicals are more stable than others is that the bond energies/mol are greater in the more stable compounds, i.e. there is a net energy cost to producing argichar from organic waste. This energy will have to be supplied by conventional means.
Agrichar may well be a good way of locking up atmospheric carbon but it can't have a net liberation of energy associated with it as well.
For anyone whos interested in testing this argument try thinking about entropy.

Posted by: Steve on 17 Oct 07

Steve you have your thermodynamics backwards. If a compound is going from less stable to more stable you get energy. In this case from ligino-cellulose to char. Bond energy is the energy released when the bond is made not what is required to form the bond. Certainly outside energy is required to begin the charing process, but it should not overall (taking in to account energy gain from the methane/hydrogen released) be costing energy to produce the char.

Your comment on entropy is irrelevant. While the entropy of the universe is increasing. That of a system does not need to. This requires a flux of energy through the system. High quality energy in (light) low quality out (heat). It is perfectly reasonable to use some of the energy stored in plant waste to produce biochar and store some of the rest as fuel.

Wiser science gurus correct me if I am wrong.
Cheers

Posted by: Andrew on 17 Oct 07

"I can't promise that using gasification for energy and using the resulting char as terra preta fertilizer will be a carbon negative fuel, because I haven't seen a credible lifecycle analysis of it. (If anyone has, please post it to the comments.)"

Dr. Johannes Lehman at Cornell University can probably get you the information you're looking for. Terra Preta is a specialty of his.

Everything I've read cites 20-50% sequestration of carbon over and above the CO2 that is produced by pyrolysis and the energy it takes to pyrolize the biomass.

The actual amount depends upon the biomass used and the temperature at which it is pyrolyzed. It is also confirmed to stay in soils and not break down for hundreds to thousands of years (depending upon the climate)-- longer than compost, or naturally accrued soil biomass. Of course, you can't be transporting the stuff around over large distances without "offsetting" the amount of CO2 that is actually sequestered. It would have to be both produced and used locally for maximum effect.

Again, if you want specific life cycle info, Dr. Lehman can probably help. Here's his webpage at Cornell: http://www.css.cornell.edu/faculty/lehmann/biochar/Biochar_home.htm

I also wholeheartedly agree that we need to look at building soil carbon naturally and organically. I see both this and Terra Preta as tools in the toolbox that should both be used.

Posted by: Ed on 17 Oct 07

Peter,

Yes, but that's a HUGE relative increase in soil carbon. Prairie soils might be able to go that high, but not all of the world's agricultural land. There's absolutely no way.

I agree with your overall point, but as a scientist who works in this field, I get a little irked when people don't present their numbers carefully or clearly.

Posted by: anonymous on 17 Oct 07

This is pseudo-science of the worst order. Global warming is being accelerated by the amount of carbon dioxide gas in our atmosphere, and carbon sequestration is a popular short-hand phrase for carbon dioxide sequestration. Burying charcoal in surface soil does not remove CO2 from our environment, CO2 is released when charcoal is made.

Basic high school physics - the principal products of combustion are CO2 and water vapor. There is no free lunch in physics, you don't get to have your cake and eat it too.

Woodgas is very interesting technology, but it is definitely a niche item. Brazil is already way ahead of the rest of the world with ethanol usage, which does not release fossilized CO2 that has already been sequestrated.

Posted by: Sean McLaughlin on 18 Oct 07

Charcoal is carbon. It comes from a renewable resource (biomass), that pulled CO2 from the atmosphere.

The charcoal is stable in soil for thousands of years. The NET result of adding charcoal to soil is increasing soil carbon. The carbon that is being added to soil, came from the atmosphere. Seems simple.

Plus, added carbon in soil has been shown to increase actual biomass and production capability of the soil itself- thus increasing the rate of biomass production, creating a positive feedback loop.

I don't know if it is good way to get energy- but it is certainly the best way I have heard to improve agriculture, and reduce CO2 in the atmosphere. That's good enough for me.

Posted by: Tim on 18 Oct 07

Sustainable farms and gardens already exist that do not use terra preta. Since the Carthusian monastaries of the European Middle Ages, herb and subsistance growers have known how to acheive fertility using a mix of dynamic accumulators such as sorrel, dock, plantain, dandelion, stinging nettle, chicory, chamomile, astilbe, and comfrey, along with seasonally rotating cover crops such as clover, orchard grass (coltsfoot), rye and buckwheat, and biomass producers such as turnips and oilseed radish. Has anyone demonstrated on actual farms that adding terra preta carbon increases humus production or yield over what dynamic accumulators, cover crops, and biomass crops are already known to produce? Is not, why such wild enthusiasm for the untried and the unproven?

Theoretical farming has a long way to go to equal the results of theoretical physics. I would like to see terra preta farms objectively evaluated in practice alongside sustainable farms based on other principles (e.g the natural farms of Masanobu Fukuoka and Kawaguchi in Japan or the Agroforestry Trust farm of Martin Crawford in Dover, England) rather than just assuming that terra preta farms will acheive excellence in sustainability because they sound "right." Many wonderful-sounding theories bite the dust when applied in the real world. Is the carbon product that comes from the pyrolizers really better than well-cured compost? Are there any commercial products for sale that farmers and gardeners can try for comparison to see if humus and soil fertility increase?

Bob Monie
New Orleans, La

Posted by: Robert Monie on 18 Oct 07

Sean McLaughlin -- the point of this is that the products of combustion are different than the products of pyrolysis. OK, so I just tried to write it all out in here and it was super ugly, so you might want to look here for the reactions involved in pyrolysis. The point, though, is that it releases gas much more useful than CO2 and also leaves the "char" or oxidized carbon as a solid to be used as a soil fertilizer.

Posted by: octopod on 18 Oct 07

I'm struggling here a bit. Say that I've got a few acres of land, and that the case you present convinces me enough to go for it. The acres are about half woods, so there's biomass by the cubic meter - downed trees, leftovers from the last corn harvest, grass clippings, leaves... There are also a few acres of production fields, and a decent sized garden, so lots of places to play... But what do I actually *do*? Do I build a gasifier? How? Or is a gasifier (a little?) different from a burner that makes charcoal?

What we need here is a "biochar for dummies" (or at least for people who've never built anything out of sheet metal). How do people like me, with plenty of good will and opportunity, but very little knowledge or experience, actually apply this?

Posted by: Scott Deerwester on 18 Oct 07

Scott: to make char, you need to burn/smolder the biomass in an oxygen poor environment. If you google "how to make charcoal" you should find some sites that will give you various ideas how to do it.

I think there may be some you tube videos on the subject too.

Sean: this isn't pseudo science. biomass pyrolysis sequesters more atmospheric carbon than the pyrolysis process produces-- including energy inputs. Plants grow, they remove CO2 from the atmosphere. Pyrolysis locks in a significant portion of that carbon in the form of char. The carbon stays in the soil hundreds to thousands of years longer than it does by composting, plus, it reduces needed fertilizer imputs in agricultural soils which reduces carbon emissions from fossil fuels used to make the fertilizer and apply it.

Posted by: Ed on 18 Oct 07

Here's a YouTube video by a guy who built a pyrolysing stove out of 5-gallon paint cans and tin food cans:

http://www.youtube.com/watch?v=BGXv7buNUMY

There are other videos that

Posted by: Ed on 18 Oct 07

While it is possible.

This is where you start kicking in "Oppourtunity Costs".

First off, for instance lets say that biomass gets an average of 3-6% solar efficiency.
http://greyfalcon.net/sugarsolar

But why not go with the theoretical limit (i.e. virtually impossible) of 11%.

Then you run that through a fischer tropsch gasification process, leaving you with only 32% of that energy left.

And then you distribute that fuel, leaving you with only 88% of that energy left.

And then you run that fuel inside a conventional gasoline engine at 20%, but for kicks, why not use a diesel engine at 40%.

So,

11% * .32 * .88 * .4 =
So we're looking at a maximum limit of somewhere around the range of 1.24% solar energy conversion into torque. With a more realistic range of 0.4-0.2%

Kinda crappy don't you think?

_

Especially when you compare it to say, a 50% efficient Luz2 style solar cocentrator.
http://www.luz2.com/apage/12219.php

With 85% energy kept after distribution.

And 90% of the energy turned to torque by an electric engine with regenerative braking.

50% * .85 * .9 = 38.25%

_

Now ask yourself, is photosynthesis really up to the task of providing the energy?

Then ask yourself again, could it be done better, cheaper, and faster without biomass.

Frankly, oil is a biofuel.
It just had millions of years to accumulate.
Almost all of which was from wild algae in the oceans.

Trying to make that all back in real time with terrestrial crops is just asking for failure.

Not to mention that by keeping biofuels alive, we have to deal with all the dramatic emissions increased causes by current biofuels.
http://greyfalcon.net/n2ostudy.png
http://greyfalcon.net/palmoil

The risks and costs heavily outweight the benefits of biofuels.

Certainly research could change that, but considering we got 20x more federal resources pegged in biofuels research than Solar, it's just disgusting.

Frankly, all non-R&D subsidies for biofuels should be scrapped and put towards more realistic solutions.

Posted by: David Ahlport on 18 Oct 07

For people interested in finding out more about biochar, who is working on it and where, I direct you to the website of the International Biochar Initiative This organization began in July 2006 and has been instrumental in serving as a platform for the international exchange of information and activities in support of biochar research, development, demonstration and commercialization.

Posted by: Ellen Baum on 19 Oct 07

David: you can't forget a couple of important points:

1. that biochar added to agricultural soils reduces the need for fertilizer inputs. Since it stays in the soil so long, this is a huge amount of money-- and energy savings-- over the long run.

You're looking at only one portion of the process instead of looking at the potential for optimizing for all the components: biofuel, improving agricultural productivity which will reduce fossil fuel use, restoration of depleted soils which will, when restored, begin removing carbon from the atmosphere; and the heat that is generated from the gasification process that would have industrial uses-- like combined heat and power. Then there is the value of soils restored with char of cleaning up surface water.

2. We need to remove carbon from the atmosphere as fast as possible to address climate change. It has been argued that it's not unrealistic to have enough pyrolysis plants worldwide to remove 9.5 billion tons of carbon from the atmosphere annually-- more than is now emitted. Combine this with efficiency plus other renewables (wind, solar, tidal, etc) and we could make significant dents in the carbon concentration of the atmosphere within the lifetimes of today's young children.

There has been a lot of work done already on the energy returns, etc. Since you're into the numbers end, it may be helpful for you to dig through the literature on the subject. I haven't gotten into the technical end myself, but the work is there.

Posted by: Ed on 19 Oct 07

More information than you want

Posted by: Duane on 21 Oct 07

Hi,
photosynthesis releases 2.66 grams of oxygen for every gram of carbon fixed from the atmosphere.

When you pyrolize or partially combust (gasify) with oxygen-starved air input, you get producer gas plus char.

So for every gram of carbon in the char you have 2.66 grams of oxygen in the atmosphere (for us to breathe).

And terra preta is perfectly suited to combination with all those other sound farming systems like keylines, alley cropping, intercropping, agroforestry, Zai holes and lots more. Use every trick in the book and be happy ever after.

My own small experiments have shown that it is highly advantageous to prepare sugar water (molasses will do) and soak the char prior to digging into the soil. Soil life just loves this.

Here is one way of making char from rice husk plus cooking gas.
diazotrophicus
http://www.bioenergylists.org/en/beloniocfrh

Posted by: diazotrophicus on 21 Oct 07

Please join in the discussion here
http://forums.hypography.com/terra-preta.html

Posted by: Michael Angel on 24 Oct 07

Hi,

The link below will show you simple carbon negative energy from corn.

Rob.

http://www.youtube.com/watch?v=UVhXrvCCILw

Posted by: Robert Flanagan on 24 Oct 07

Hi,

Sorry the wrong link pasted over, this is the link to the carbon negative stove
http://www.youtube.com/watch?v=PpozW9039_o

Rob.

Posted by: Robert Flanagan on 24 Oct 07

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