Biomass Waste Upcycling

Soil & Water Remediation Opportunities Using Biochar

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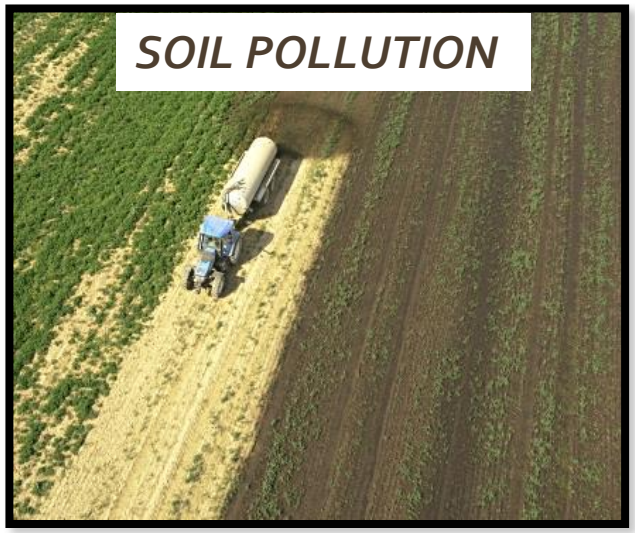
"In the 19th Century we devoted our best minds to exploring nature.
In the 20th Century we devoted ourselves to controlling and harnessing it.
In the 21st Century the best minds are working on how to restore nature."

Stephen E. Ambrose, American historian

Seminar Topics

- Introduction
- Global Soil & Water Crisis
- What is biochar?
- Biochar Research & Heavy Metals
- Biochar Installation & Delivery Systems
- Sample Projects
- Question & Answers

Global Crisis On The Horizon



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Biochar Basics

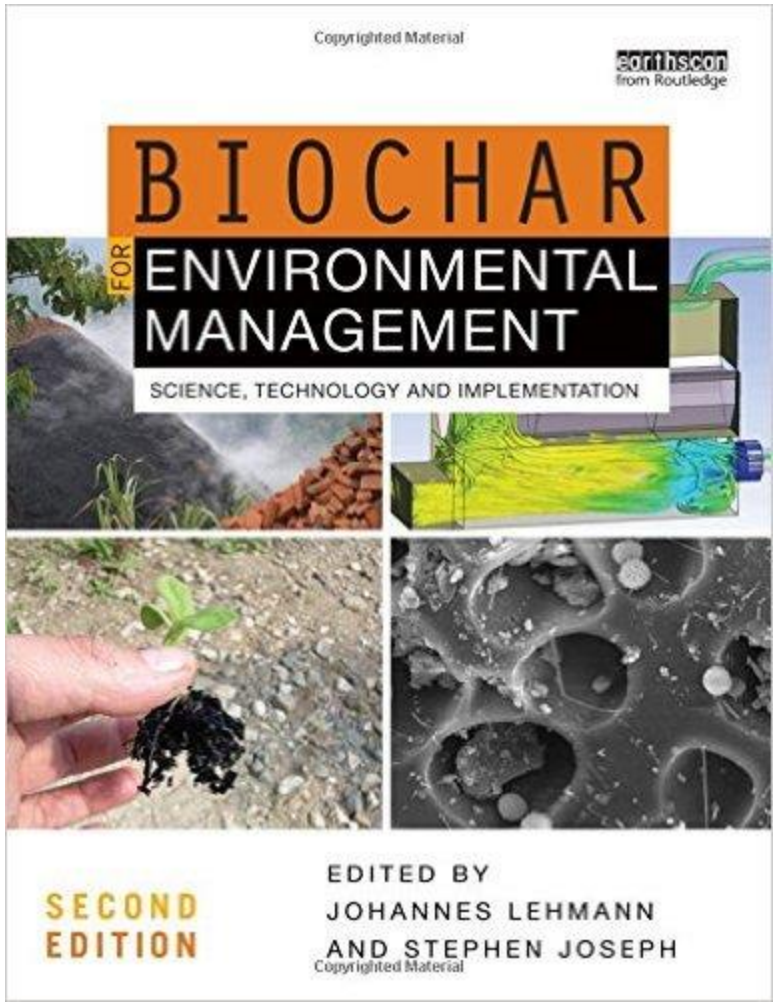
Ancient Technology & Process Rediscovered

What is Biochar?

- Ancient Technology – Terra Preta or "Dark Earth"
  - Some as old as 450 B.C.
  - 1st Documented by James Orton (1870)
  - International Awareness 2001-2002
- Biomass derived materials within the black carbon continuum (e.g., Charcoal)
- Thermo-chemically process using little or no oxygen
- Product varies based on biomass source materials & process temperature
- Only Carbon-Negative Process CO_2:C ratio = 3:1

Latosol vs. Terra Preta (Dark Earth)

Biochar Research & Development



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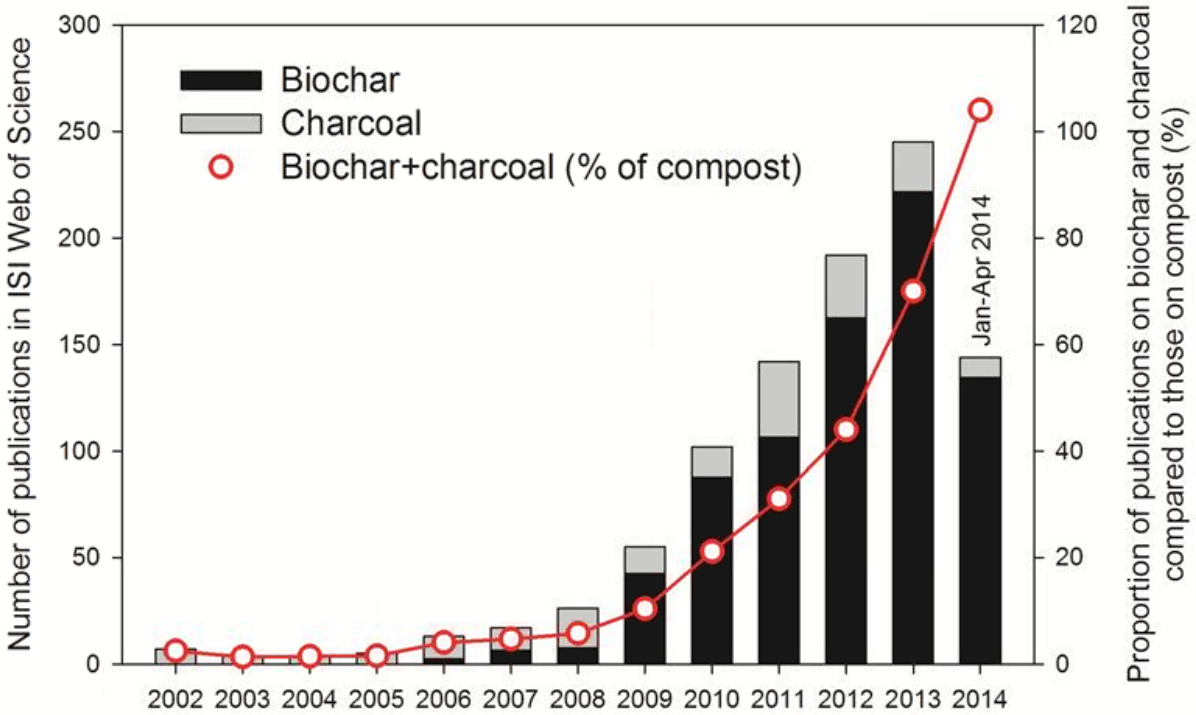
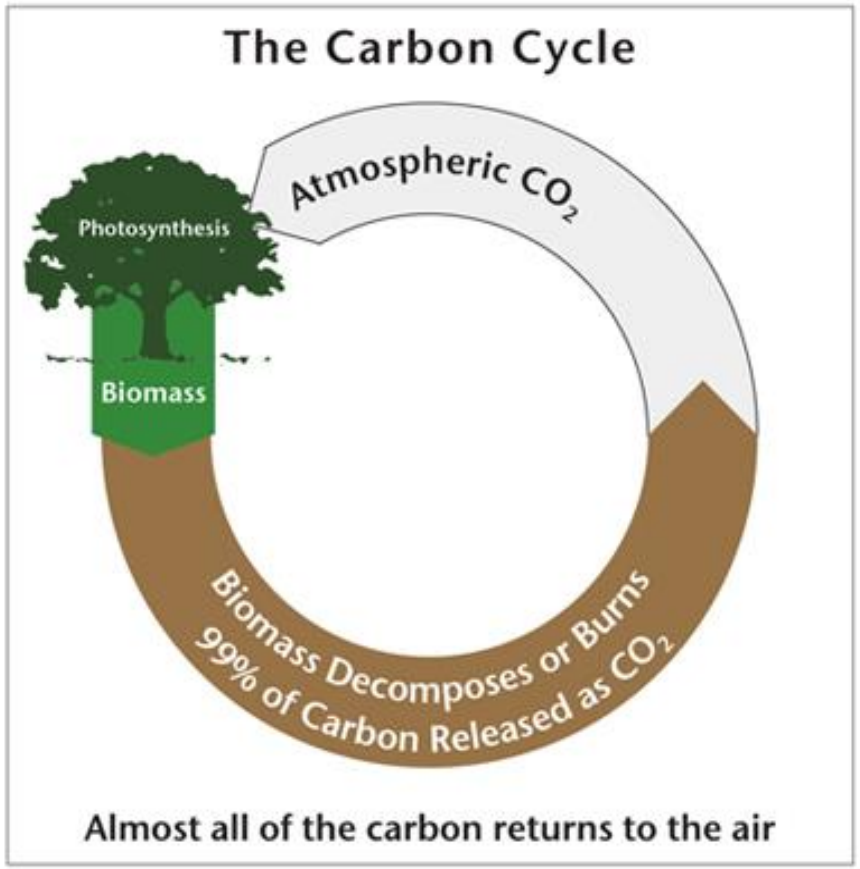


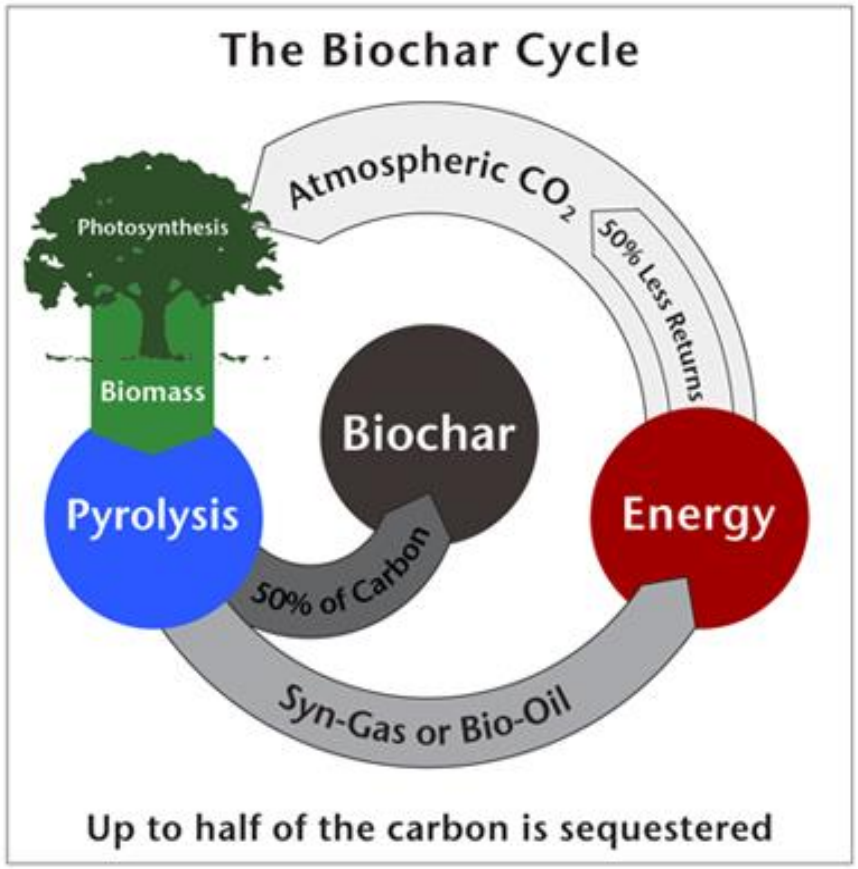
Lehmann and Joseph, 2015 Earthscan

International Biochar Initiative

http://www.biochar-international.org/

Carbon Cycle and Biochar





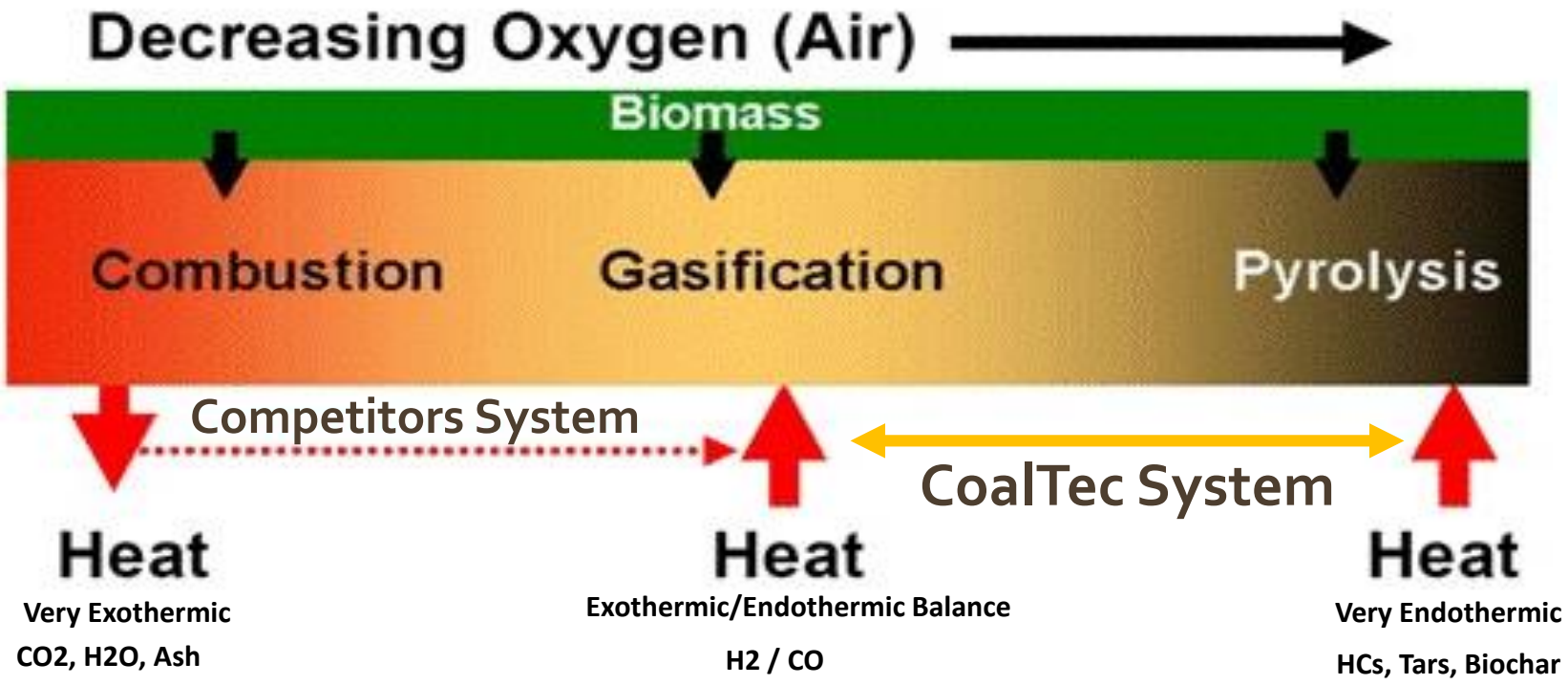
- The only carbon negative process where 1 ton of biochar:

= approximately 3 tons of CO_2 Sequestered

= emission sequestered for 1.7 cars per year (assuming EPA 5.1 metric ton/year)

No "Burn" or "Incinerate" In Our Process

Gasification is the partial oxidation of the organic content of a feedstock to produce a H2/CO containing syngas



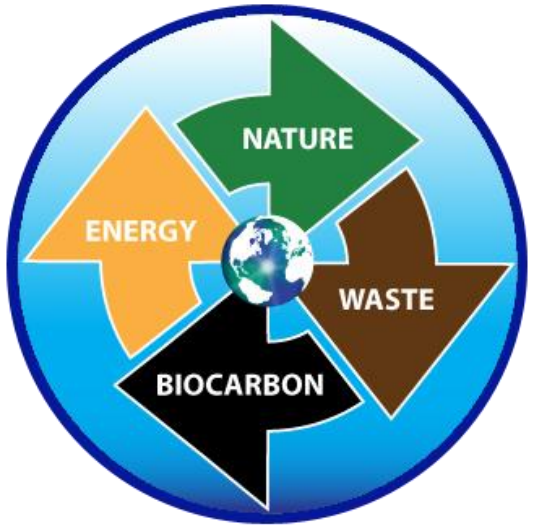
The CoalTec System is a blending of the processes handling a wide array of feedstocks. Results are CO2, H2O, Biochar and Mineral Ash

Waste Stream Materials Tested

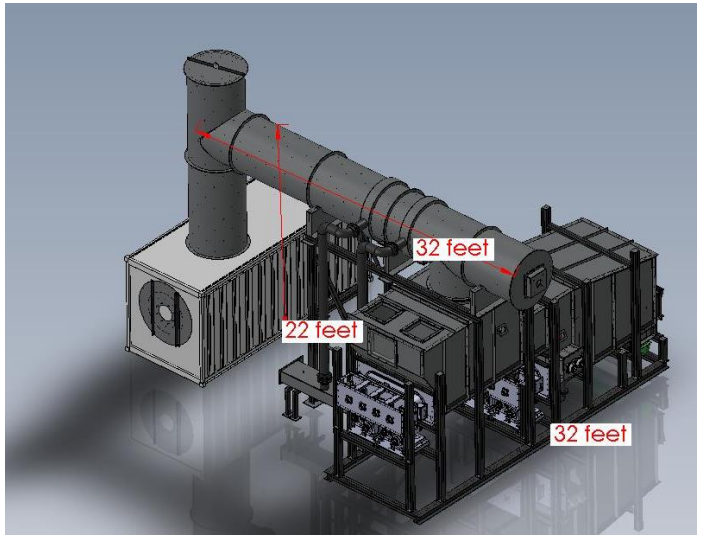
FEEDSTOCK ENERGY METRICS TESTED IN GASIFIER					
FEEDSTOCK TYPE	MOISTURE	BTU (DRY)	BTU (WET)	ASH	SULFUR
Raw Coal 1/4" Screened	17.0%	11,910	9,864	12.0%	3.90%
Paper Fluff (Recycled Oil Filter Elements)	6.1%	10,825	10,167	15.4%	0.17%
Plastics	55.2%	10,507	4,707	6.5%	0.07%
Ethanol Mash	54.0%	9,507	4,397	1.8%	0.50%
Brewery Spent Grain	72.0%	9,346	2,601	0.5%	0.11%
Packaging waste	50.4%	9,121	4,522	1.9%	0.07%
Sheanut Cake Waste (Ghana)	9.9%	8,934	8,046	5.9%	18.00%
Wood	**14.1%**	**8,386**	**7,207**	**1.5%**	**0.12%**
Building Demolition Debris (Screened)	26.7%	8,102	5,942	3.4%	0.09%
Horse Muck	34.2%	7,732	5,086	16.4%	0.14%
Corn Stover	8.5%	7,682	7,031	3.0%	0.04%
Hog manure - dried to 20% for testing	81.9%	7,462	1,353	23.3%	0.54%
Manure - Dairy	30.0%	6,773	4,770	18.0%	0.40%
Fine Coal Refuge	23.0%	6,475	5,012	45.0%	1.20%
Biosolids	5.8%	6,459	6,087	33.6%	0.74%
Refuge Derived Fuel (RDF)	19.9%	6,432	6,432	21.2%	0.12%
Manure - Turkey	24.0%	6,282	4,795	14.0%	0.40%
Manure - Chicken Cake (Layers)	18.4%	5,689	4,643	36.4%	0.28%
Manure - Chicken Litter (Broilers)	30.0%	5,456	3,819	22.4%	1.57%
Paper Sludge - mixed BDD for test	57.0%	3,653	1,571	21.4%	0.03%
Building Demolition Debris (Unscreened)	11.0%	3,609	3,213	59.1%	0.15%

Energy Gasifier 50 Tons/Day Unit

Maximizing the value of your waste stream while improving the environment

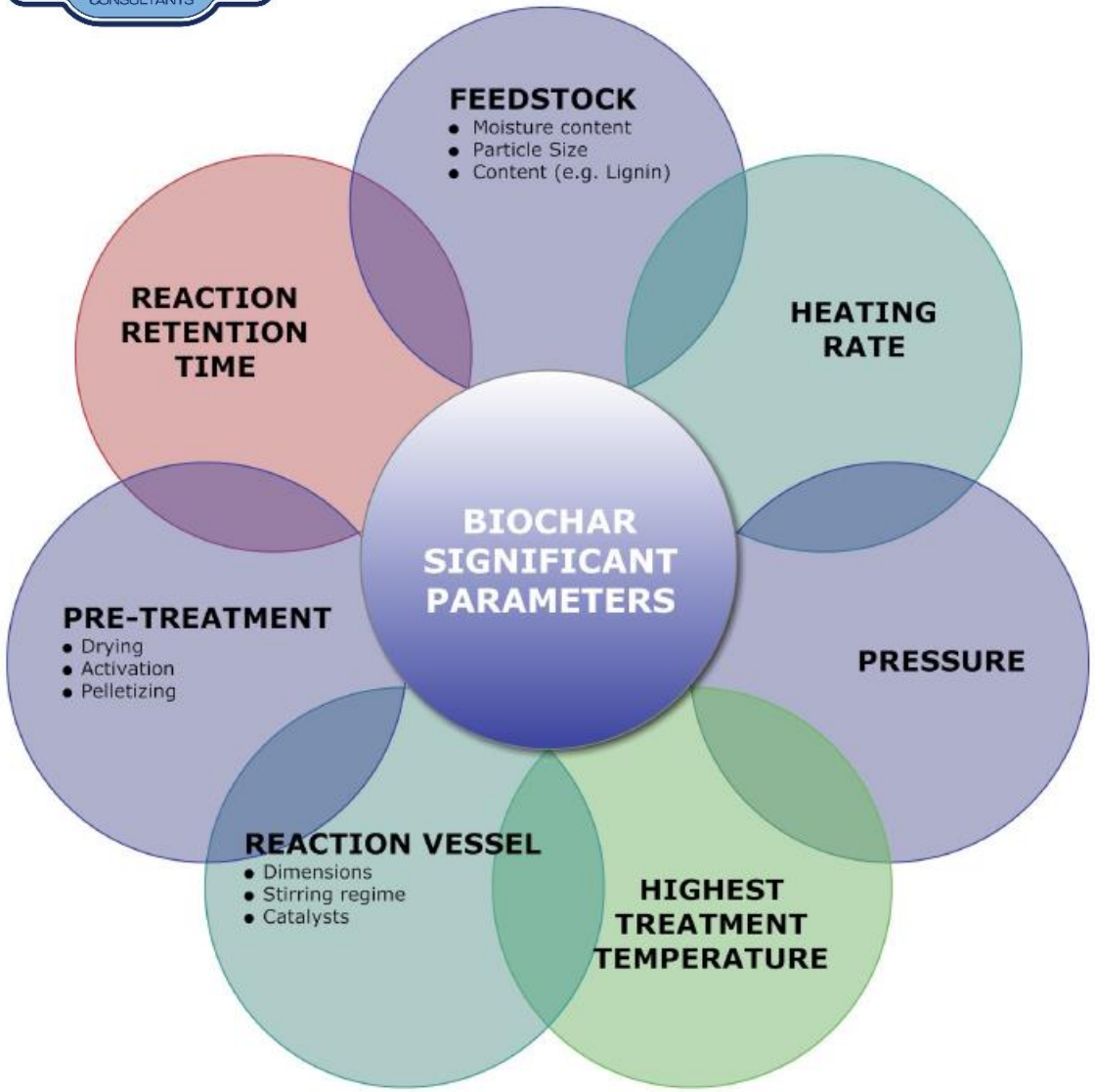


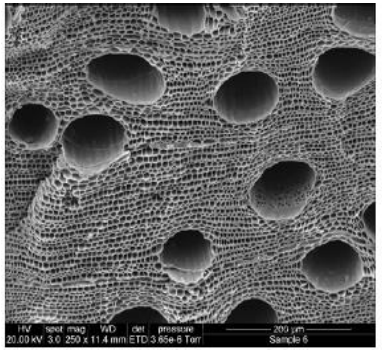
Eco Technologies, Inc. ©

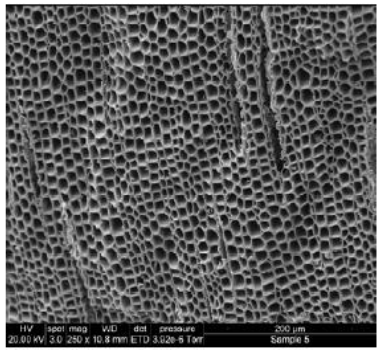


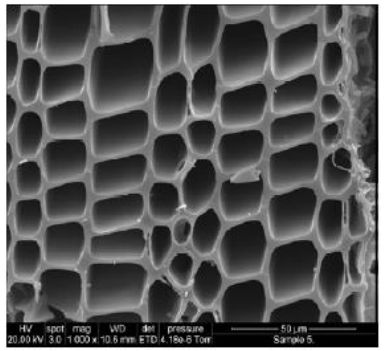
http://tinyurl.com/nokb7cx

Biochar ≠ Biochar but Biochar(S) - Biochar Properties



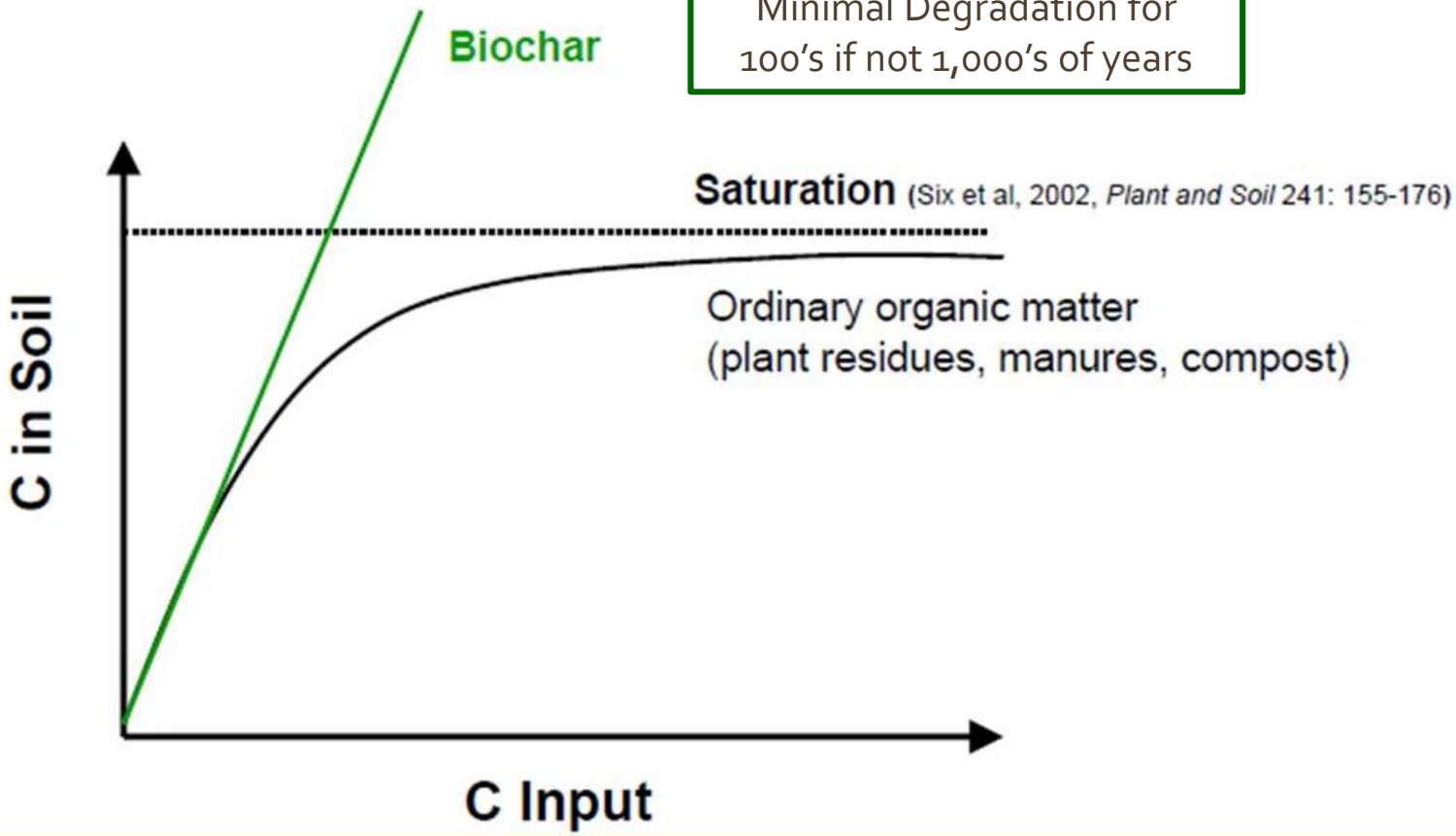






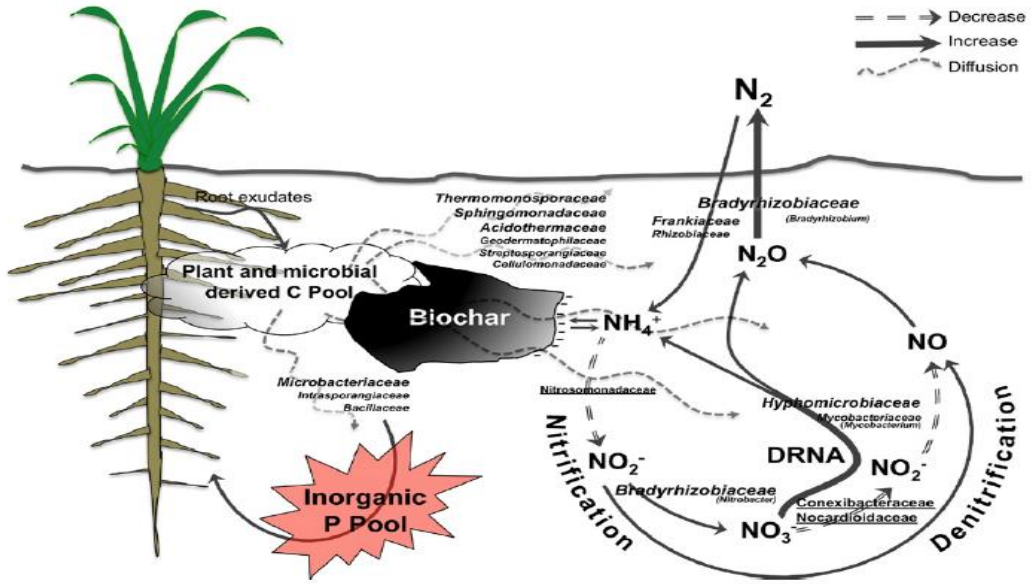
Biochar Stability & Stabilization

Minimal Degradation for
100's if not 1,000's of years



Terra Preta "Dark Earth" Soils in the Amazon after thousands of years

Biochar Research & Development



Chesapeake Bay Stewardship Fund

Dare to be first.

Reducing Stormwater Volume and Nutrients with Biochar

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES

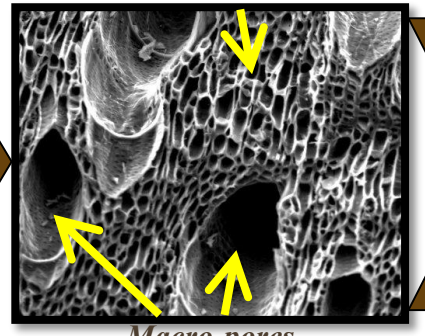
Dare to be first.

Reducing Stormwater Runoff and Pollutant Loading with Biochar addition to Highway Greenways

MATS UTC

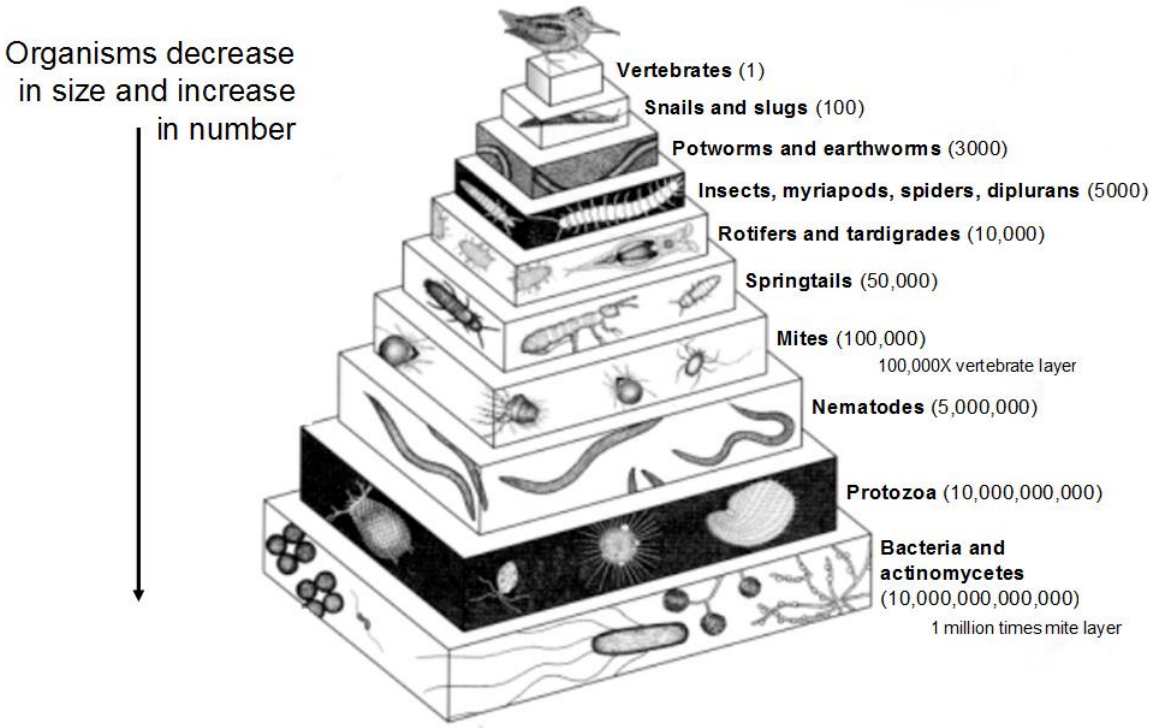
Dare to be first.

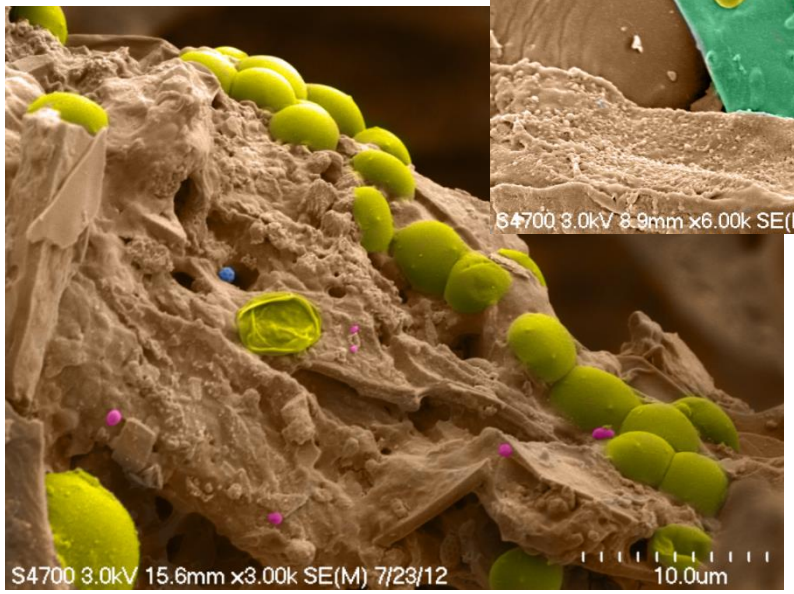
Simultaneous Removal of Nitrogen and Phosphorus from Stormwater by Zero-Valent Iron (ZVI) & Biochar in Bioretention Cells

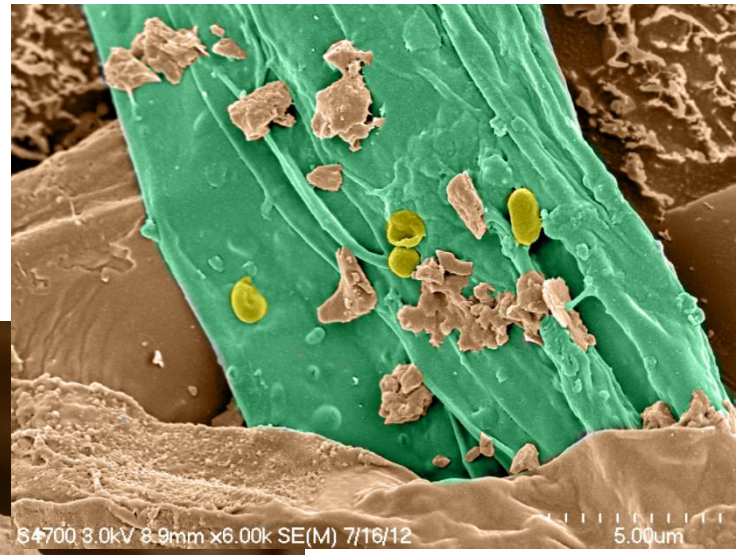


Soil Microbial Communities Fostered by Biochar

In one square meter of soil....



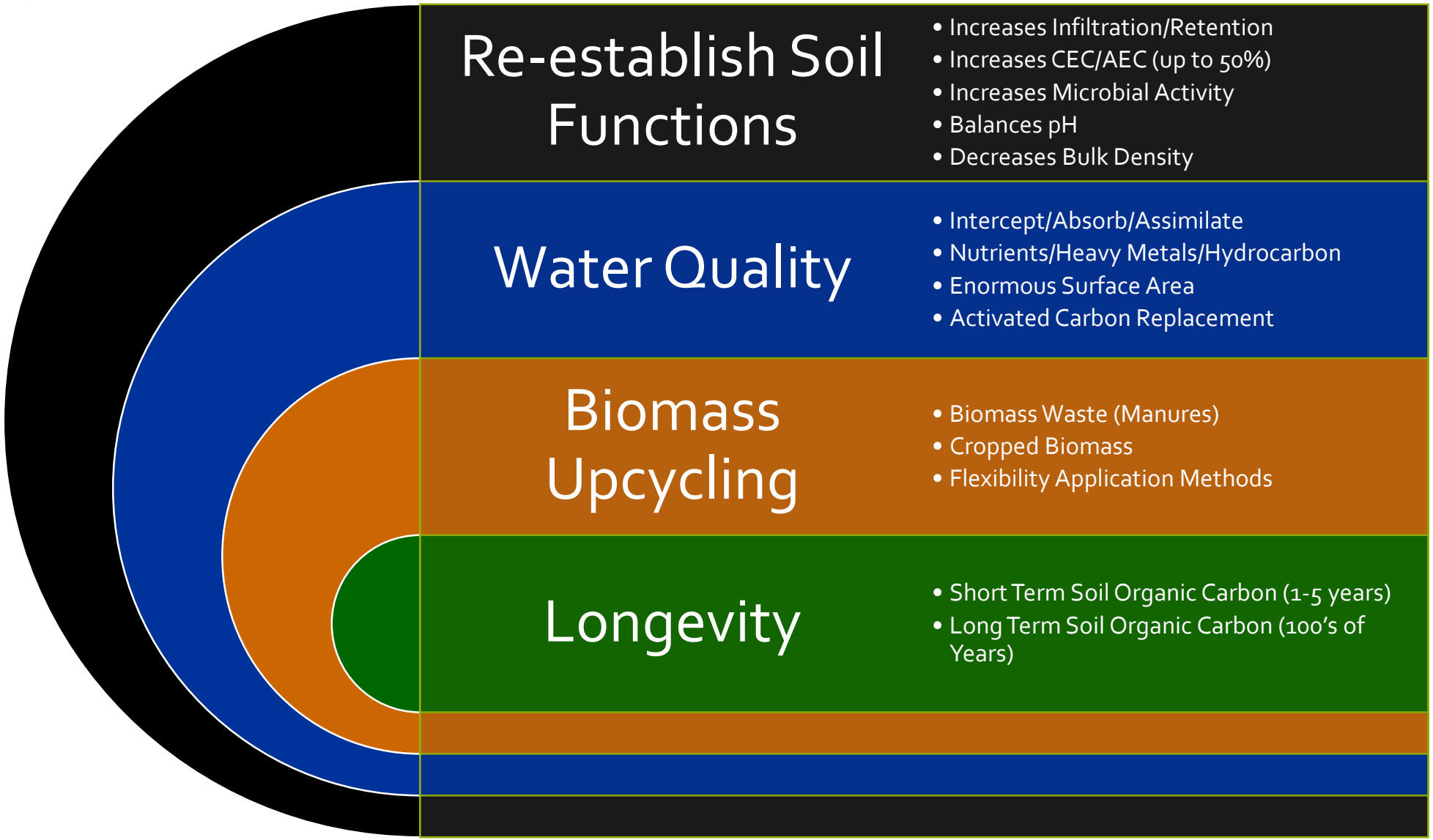




Soil Facts - 1 Teaspoon of Healthy Soils has:

1 Billion Bacteria | 900 Feet of Fungi | 50,000 Protozoans | Dozens of Nematode's

Summary of Biochar Benefits



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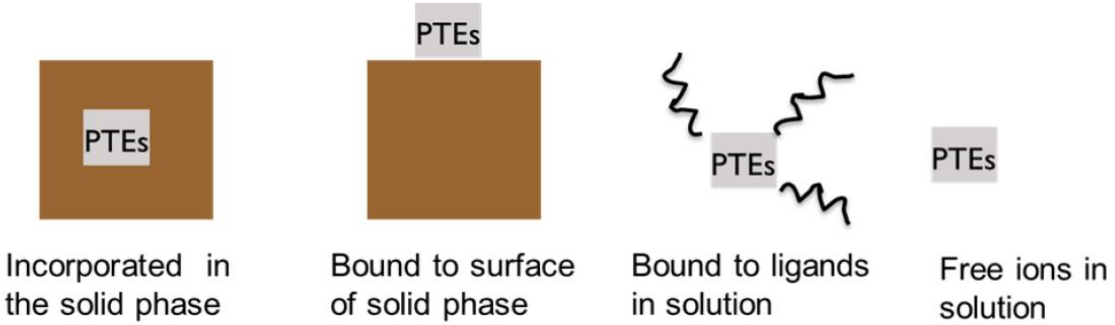
Biochar Research

Remediation & Restoration

Heavy Metals

AN ANCIENT TECHNOLOGY & PROCESS REDISCOVERED

The Source-Pathway-Receptor Model & Remediation Options



Source of pollution: PTEs → Pathway that leads to the contaminant being taken up by the organism → Receptor: biological organism

Remediation

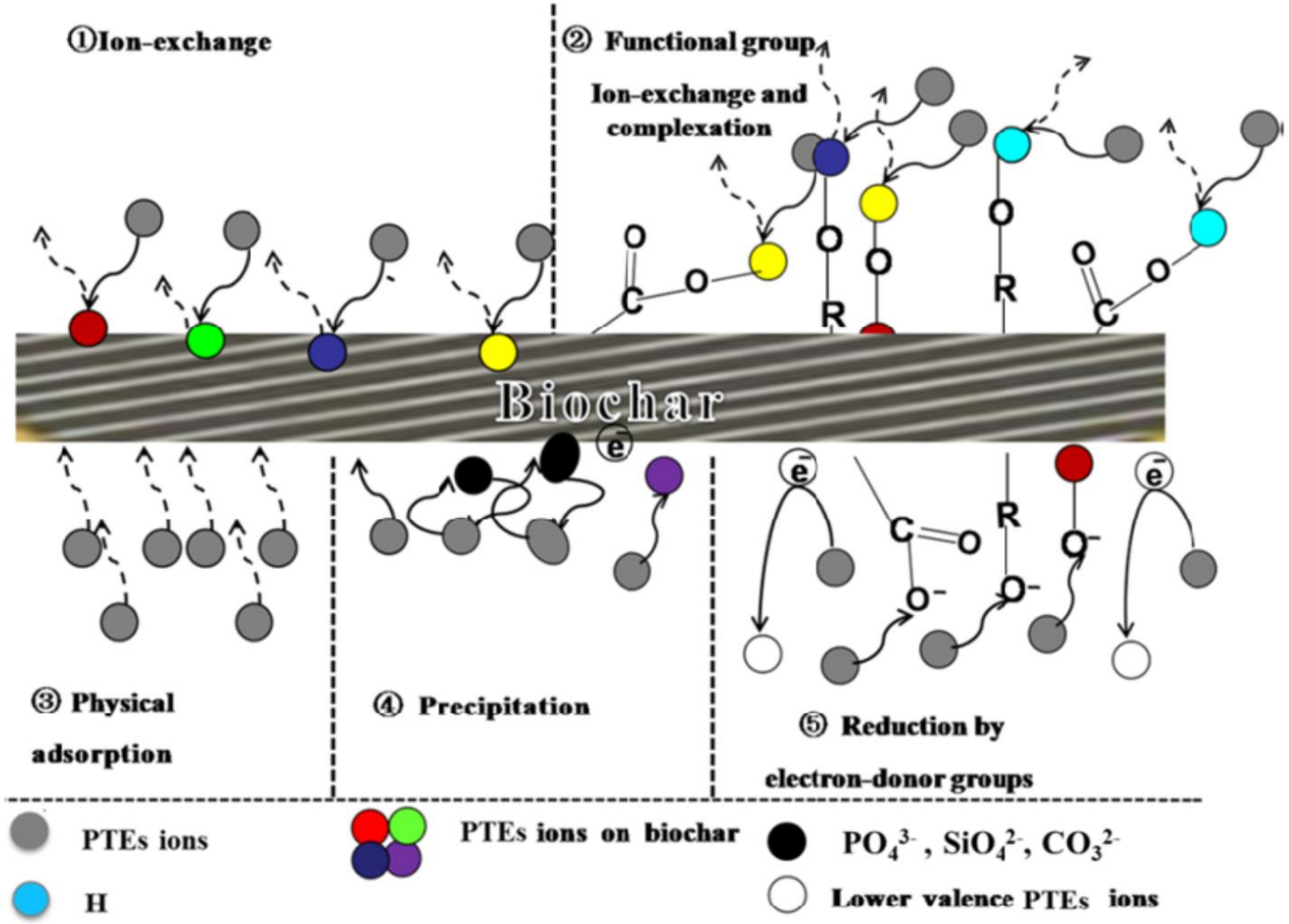
1) Removal of the source

2) Elimination of the pathway

3) Modification of the exposure

"Biochar for the Remediation of Soils Contaminated with Potentially Toxic Elements" Hailong Wang et al. International Biochar Initiative, July 2015.

Representation of the Possible Adsorption Mechanisms of Potentially Toxic Elements (PTEs) on Biochar



"Biochar for the Remediation of Soils Contaminated with Potentially Toxic Elements" Hailong Wang et al. International Biochar Initiative, July 2015. Graphic by Zhang & Wang, Unpublished

Biochar Research in Heavy Metal Adsorption

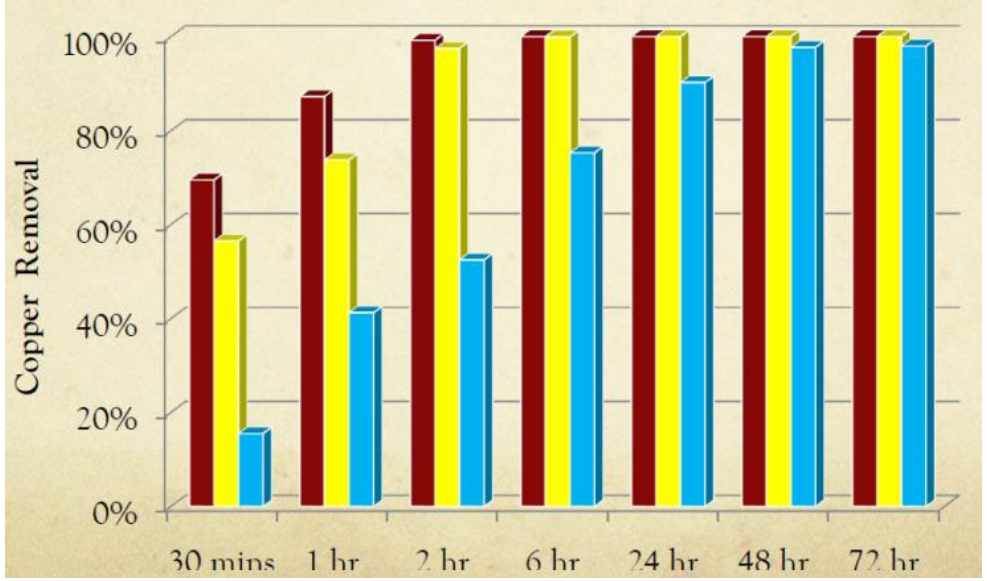
Environmental Problem	Biochar Captures & Resiliently Holds:			Biochar Supports Biological Degradation of:			Biochar Reduces:	University Studies
	Soil Contaminants	Water Pollutants	Air Emissions (Offensive Odors)	Soil Contaminants	Water Pollutants	Air Emissions (Offensive Odors)	Availability of Toxins to Plants, Animals, & Humans	
METALS								
Arsenic (As)	X	X		X	X		X	Beesley et al. 2011, Namgay et al. 2010, Namgay et al. 2010a, Wingate et al. 2009
Cadmium (Cd)	X	X		X	X		X	Beesley et al. 2010, Beesley et al. 2011, Cui et al. 2011, Namgay et al. 2010, Namgay et al. 2010a, Park et al. 2011, Regemi et al. 2009, Uchimaya et al. 2010, Uchimaya et al. 2011, Wingate et al. 2009
Chromium (Cr)	X			X	X		X	Wingate et al. 2009
Copper (Cu)	X	X		X	X		X	Namgay et al. 2010a, Park et al. 2011, Regemi et al. 2009, Uchimaya et al. 2010, Uchimaya et al. 2011, Wingate et al. 2009
Lead (Pb)	X	X		X	X		X	Namgay et al. 2010a, Park et al. 2011, Regemi et al. 2009, Uchimaya et al. 2011, Wingate et al. 2009
Mercury (Hg)	X		X	X	X		X	Wingate et al. 2009
Nickel (Ni)	X			X	X			Uchimaya et al. 2010, Uchimaya et al. 2011, Wingate et al. 2009
Zinc (Zn)	X	X		X	X		X	Beesley et al. 2011, Namgay et al. 2010a, Wingate et al. 2009
ORGANICS								
Petroleum Hydrocarbons	X	X		X	X			Cao et al. 2012, De Leij et al. 2006, Kookana 2011
Polycyclic Aromatic Hydrocarbons-PAH	X	X		X	X			Beesley et al. 2010, Cao et al. 2012, De Leij et al. 2006, Hale et al. 2011, Kookana 2011

PTEs	Production temperature	Feedstock material	Effect	Reference
Cd	Not available	Bamboo	Removal of extractable Cd by 79.6% within 12 days.	6
Cd	450°C	Cotton stalks	Cadmium content of edible part and roots of *Brassica chinensis* were reduced by 49.43% to 68.29 %, and 64.14% to 77.66 %, respectively.	7
As	400°C	Hardwood	Significant reduction of As in the foliage of *Miscanthus*.	8
As, Cd, Cu, Zn	450°C	Hardwood	Reduction of Cd in soil pore water by 10 fold; Cd and Zn concentrations reduced by 300 and 45 fold respectively in column leaching tests.	9, 10
Cd, Cu, Pb	550°C	Chicken manure and green waste	Significant reduction of Cd uptake by Indian mustard.	11
Cd	500°C	Quail litter	Reduction of the concentration of Cd in physic nut (*Jatropha curcas* L.); reduction increased at increasing application rates.	12
Cu, Pb, Cd	Not available	Rice straw	Significant reduction in concentration of free Cu, Pb and Cd in contaminated soils.	13
Cr	550°C	Chicken manure	Enhanced reduction of Cr(VI) to Cr(III) in soil.	14
Cu, Pb, Cd	350°C	Peanut and canola straws	Increase in the adsorption of Cu, Pb and Cd by the soil amended with biochar.	15
Cd, Cu, Pb, Zn	750°C	Rice straw and bamboo	Decrease in concentration of extractable Cd, Cu, Pb and Zn.	16
Cd, Cu, Pb, Zn	500°C and 750°C	Rice straw and bamboo	Rice straw biochar was more effective than bamboo biochar in decreasing extractable PTEs in soil.	17

"Biochar for the Remediation of Soils Contaminated with Potentially Toxic Elements" Hailong Wang et al. International Biochar Initiative, July 2015.

Heavy Metal Adsorption (Copper) Research – WOOD BIOCHAR

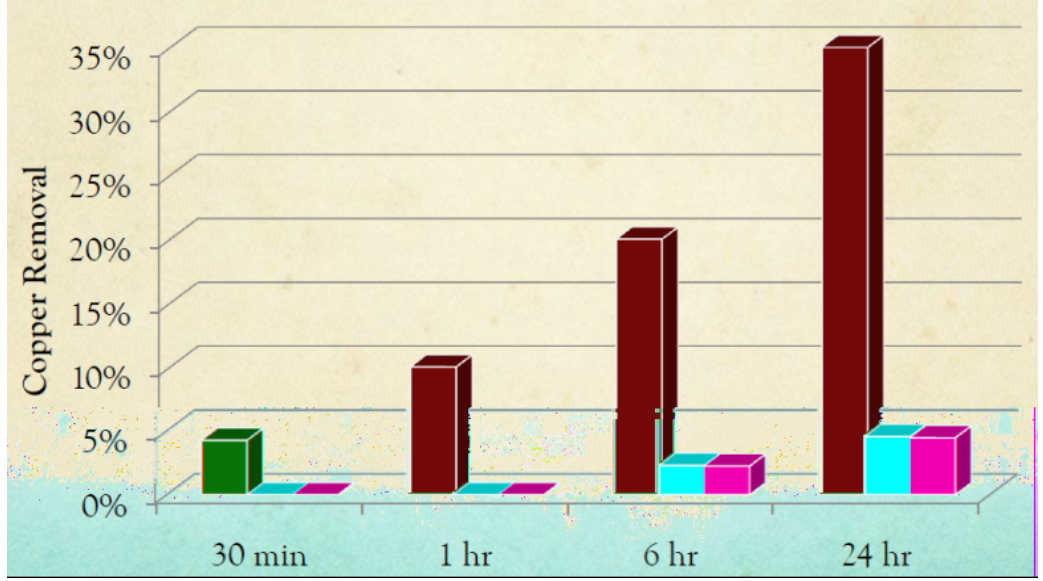
Biochar



Initial metal conc	pH
40 mg/L	7

■ 2 g/L ■ 1 g/L ■ 0.5 g/L

Powdered Activated Carbon



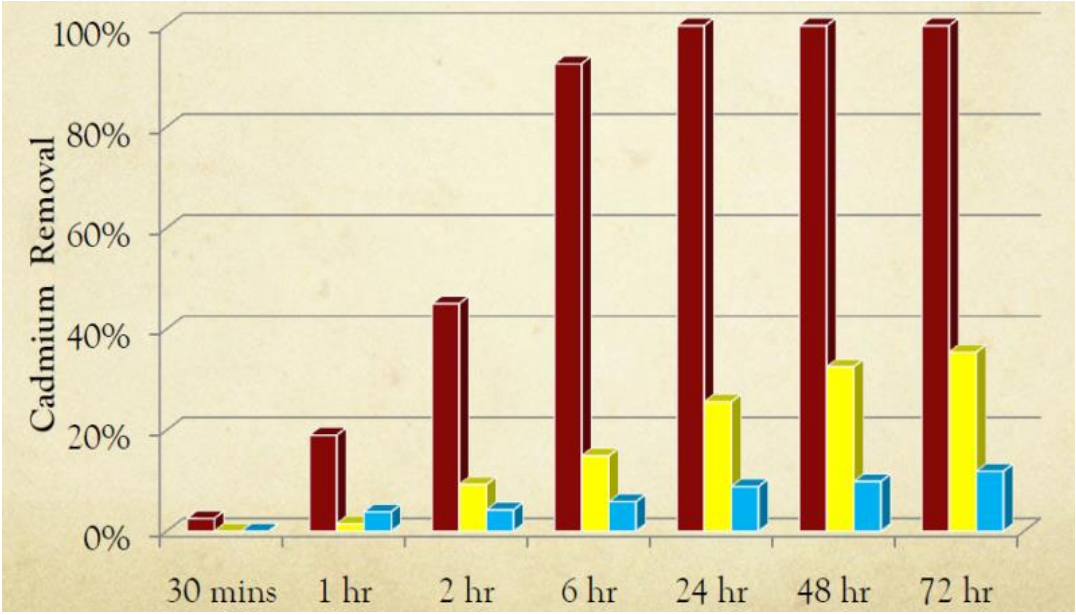
	Biochar	PAC (Calgon WPH)
BET surface area	70 m^2/g	726 m^2/g

Two metal solutions were treated with 2 g/L, 1 g/L and 0.5 g/L of biochar
Samples were collected at 30 mins, 1 hr, 2 hr, 6 hr, 24 hr, 48 hr and 72 hr.

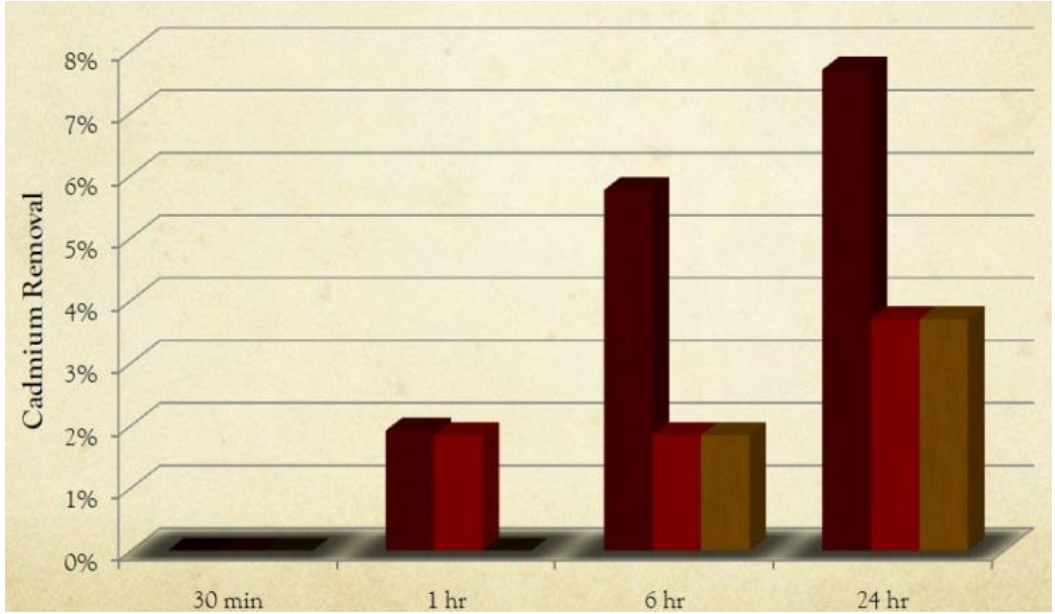
"Biochar: A Renewable Material for Removing Contaminants from Water." Kumar, Sandeep et al. NASA Langely Research Center, 2009.

Heavy Metal Adsorption (Cadmium) Research – WOOD BIOCHAR

Biochar



Powdered Activated Carbon



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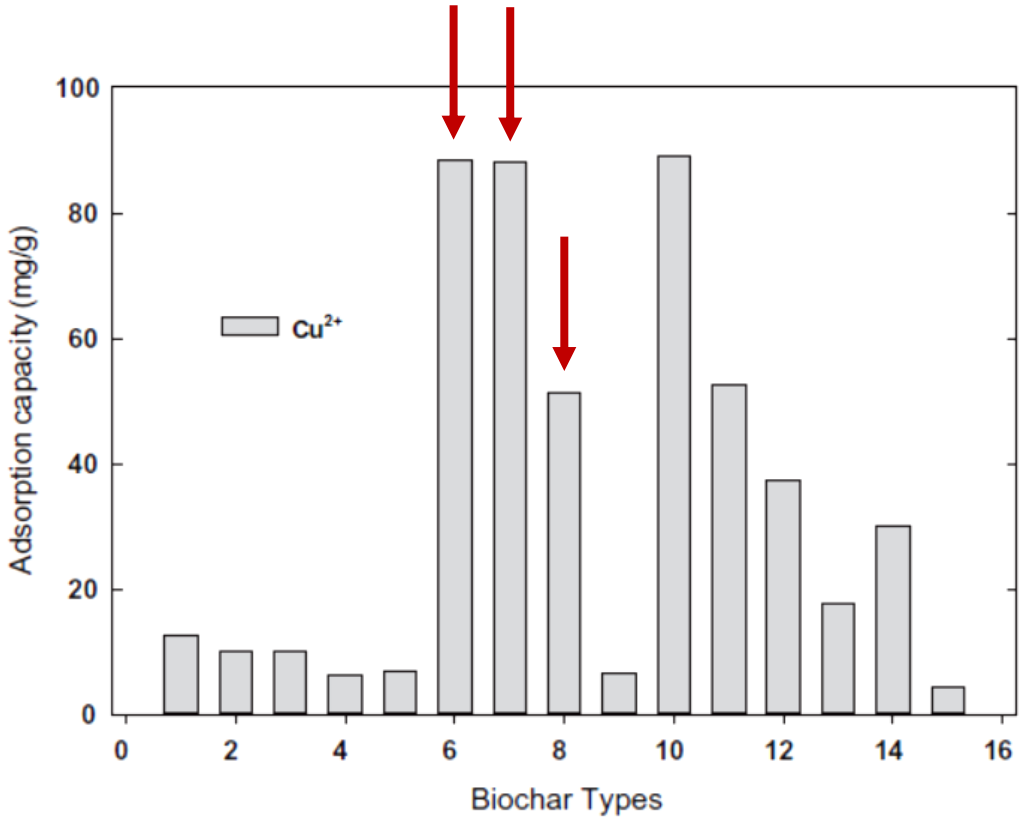
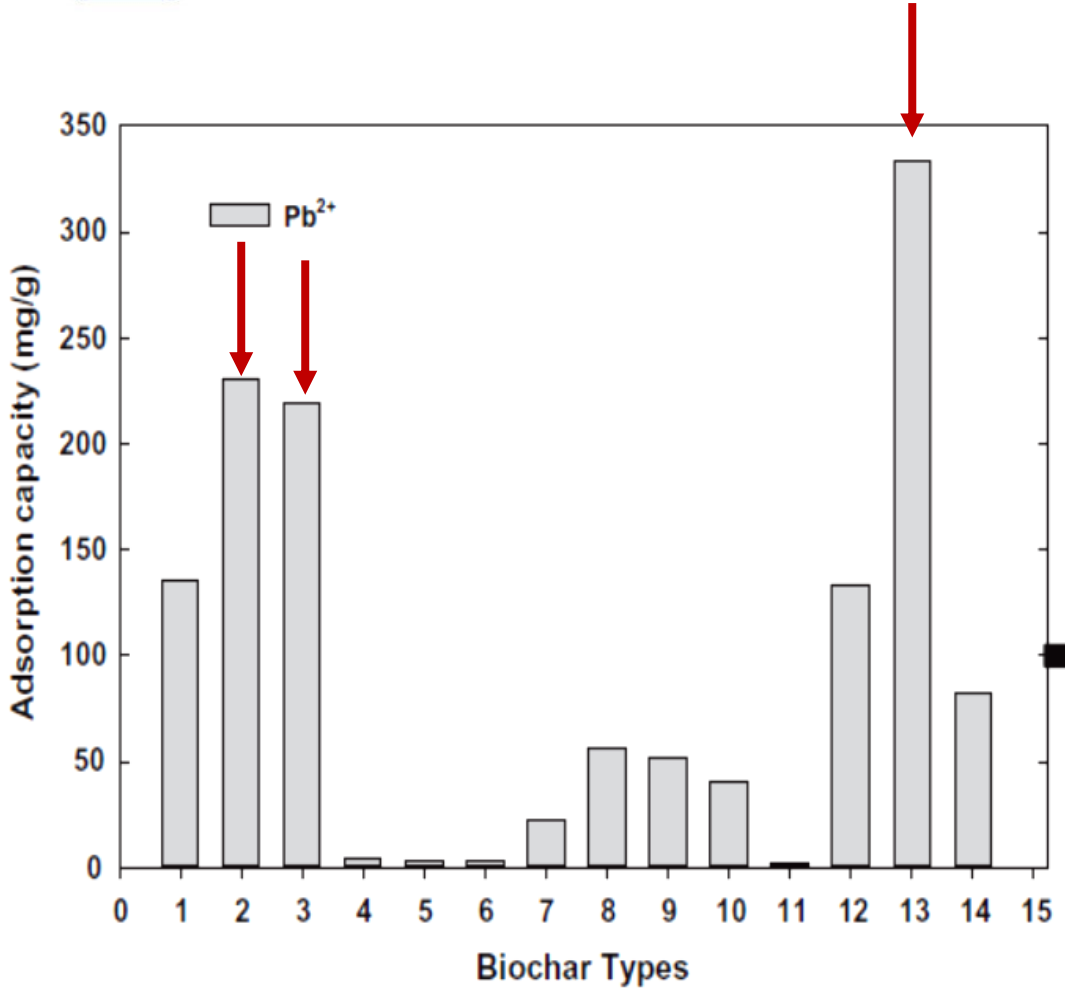
Biochar in Heavy Metal Adsorption - Copper



No.	Biochar Types	Reference
1	Corn straw biochar	(Chen et al., 2011b)
2	Orange waste biochar	(Pellera et al., 2012)
3	Rice husk biochar	
4	Olive pomace biochar	
5	Compost biochar	
6	Cow manure biochar	(Kołodyńska et al., 2012)
7	Pig manure biochar	
8	Dairy manure biochar	(Xu et al., 2013)
9	Hardwood biochar	(Chen et al., 2011b)
10	Peanut straw biochar	(Tong et al., 2011)
11	Soybean straw biochar	
12	Canola straw biochar	
13	Switchgrass biochar	(Han et al., 2013b)
14	Softwood biochar	
15	Pinewood biochar	(Liu et al., 2010)

Dinesh, Mohan et al, Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent – a critical review, 2014.

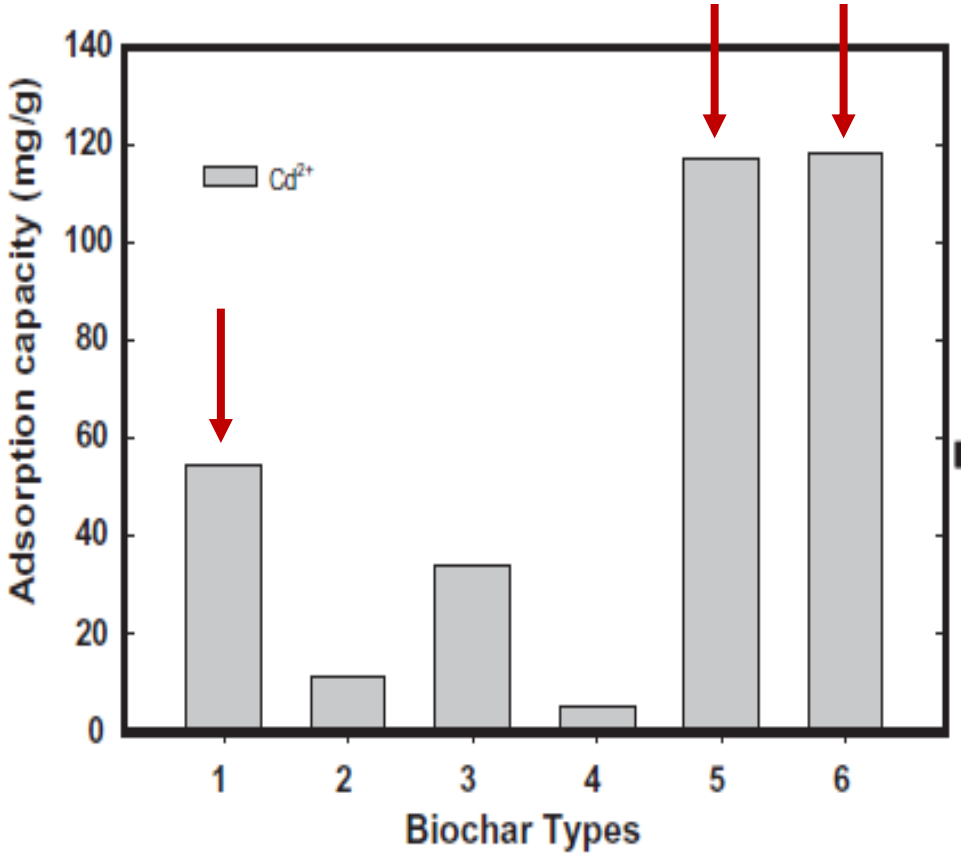
Biochar in Heavy Metal Adsorption - Lead



1	Sugarcane bagasse biochar	(Inyang et al., 2011)
2	Raw sugarcane bagasse biochar	
3	Pig manure biochar	(Kołodyńska et al., 2012)
4	Cow manure biochar	
5	Pinewood biochar	(Mohan et al., 2007b)
6	Pinebark biochar	
7	Oak wood biochar	
8	Oak bark biochar	
9	Magnetic oak bark biochar	(Mohan et al., 2013)
10	Digested dairy waste char	(Inyang et al., 2012)
11	Sugar beet biochar	
12	Rice husk biochar	(Liu & Zhang, 2009)
13	Dairy manure biochar	(Cao et al., 2009)
14	Buffalo weed biochar	(Yakkala et al., 2013)

Dinesh, Mohan et al, Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent – a critical review, 2014.

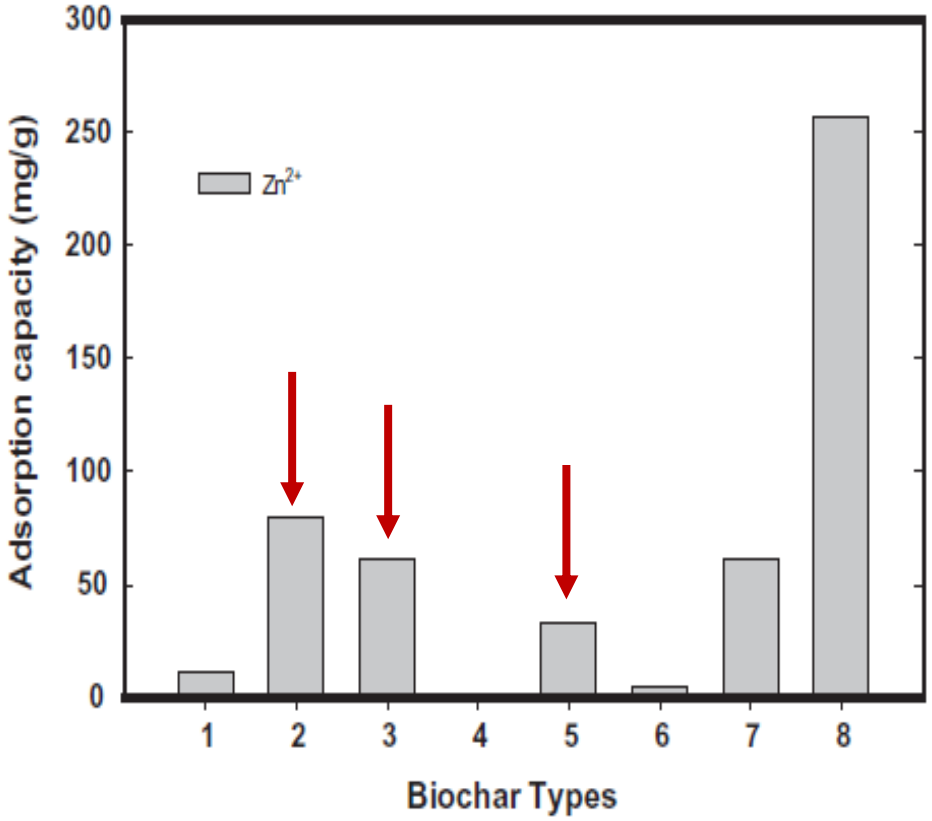
Biochar in Heavy Metal Adsorption – Cadmium



1	Dairy manure biochar	(Xu et al., 2013)
2	Buffalo weed biochar	(Yakkala et al., 2013)
3	Rice straw biochar	(Han et al., 2013a)
4	Oak bark biochar	(Mohan et al., 2007b)
5	Pig manure biochar	Kołodyńska et al., 2012)
6	Cow manure biochar	

Dinesh, Mohan et al, Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent – a critical review, 2014.

Biochar in Heavy Metal Adsorption - Zinc



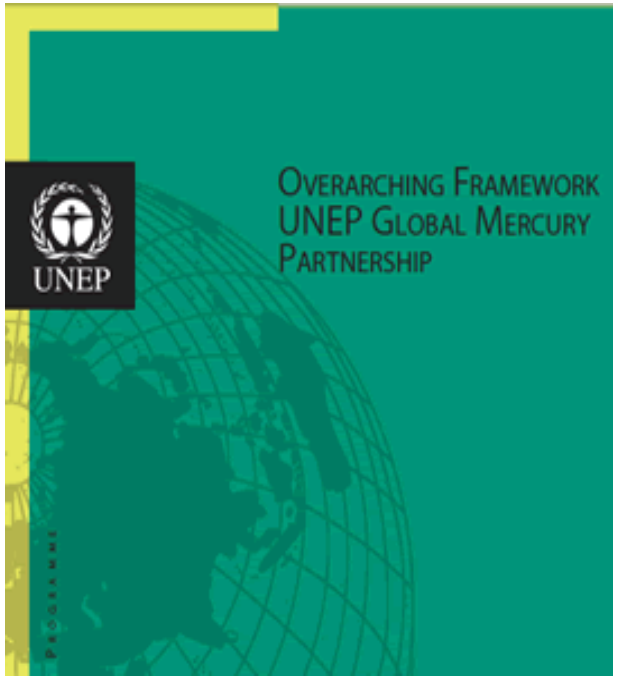
1	Corn straw biochar	(Chen et al., 2011b)
2	Pig manure biochar	(Kołodyńska et al., 2012)
3	Cow manure biochar	
4	Fruit branch magnetic char	(Mubarak et al., 2013)
5	Dairy manure biochar	(Xu et al., 2013)
6	switchgrass biochar	Han et al., 2013b)
7	hardwood biochar	
8	Softwood biochar	

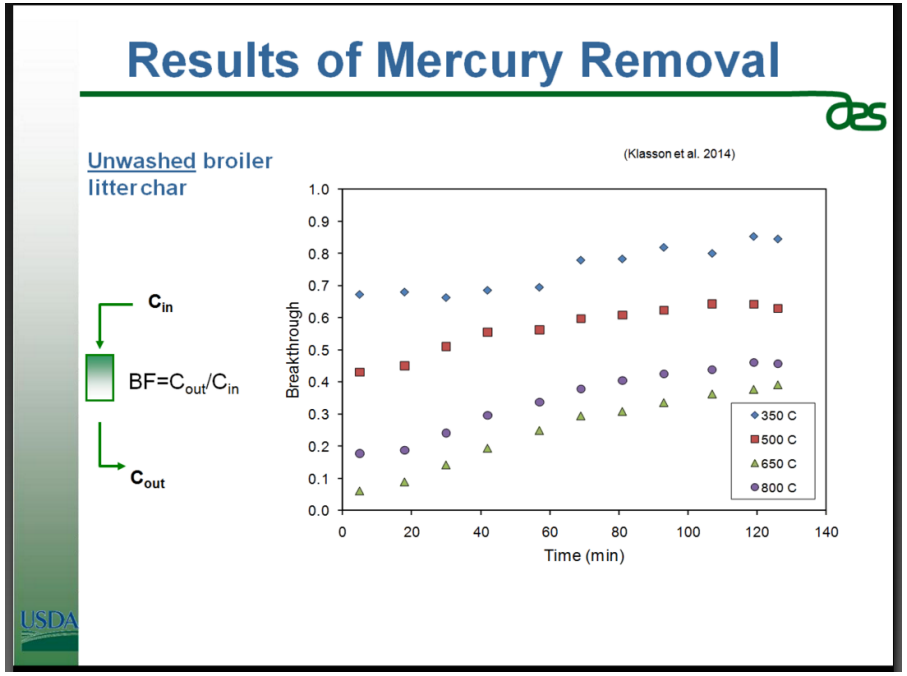
Dinesh, Mohan et al, Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent – a critical review, 2014.

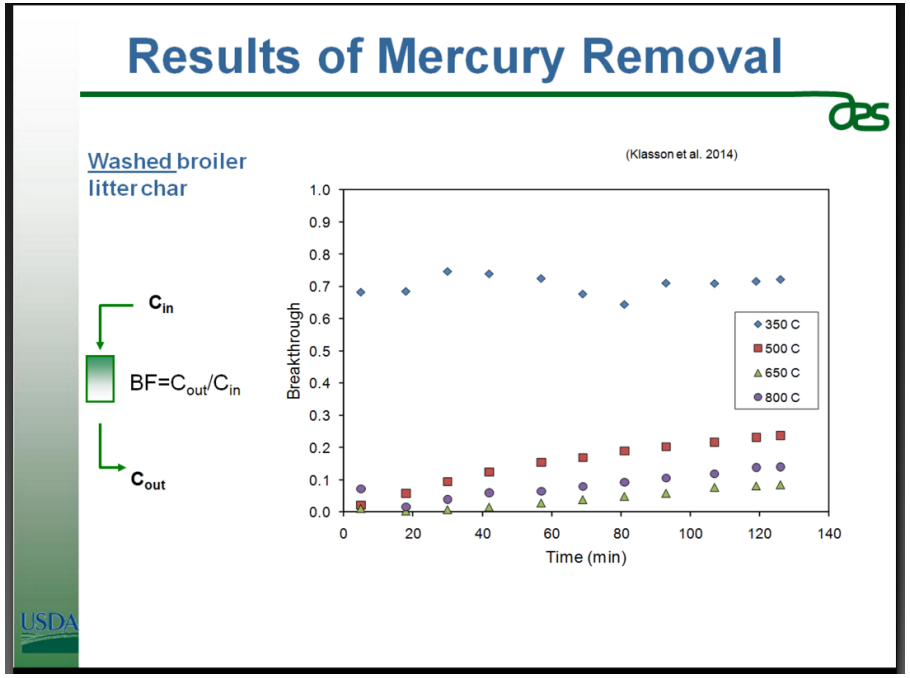
Biochar in Heavy Metal Adsorption

USDA ARS - Simulated Flue Gas with Elemental Mercury

- United Nations (UN) Mercury Treaty Launched
- Mercury Sources
  - Fossil Fuel Combustion
  - Incineration of waste materials
  - Mining







Biochar in Heavy Metal Adsorption

RESEARCH - Heavy Metal Absorption (Mercury) in River Water - DuPont / Oak Ridge

- Conducted on DuPont Site in Waynesboro, VA
- Batch Style Study and InSitu Onsite Ponds Field Trials
- Tested 40 Different Biochars

Media Tested	2 Days	14 Days
Mushroom Soils (MS)	96%	99%
Poultry Litter (PO)	96%	99%
Pine Wood Chips (WC)	80%	97%
Notes: Biochar (<2mm) added to Hg(II)-spiked (as $HgCl^2$) river water @ 1:75 Ratio. Initial Concentration @ 7780 ng/L. No information on MS as fresh, spent or mixed with PO. MS & PO indicated presence of carbonate groups (CO_3^{2-}).		

Biochar in Heavy Metal Adsorption

RESEARCH - Heavy Metal Absorption (Mercury) in River Water - DuPont / Oak Ridge

"Their [DuPont] initial results were a 95% reduction of mercury uptake into the food web…If DuPont goes full scale we could be eating fish from the Shenandoah river again within a decade. Also this high value work could provide the local poultry farmers hundreds of dollars more per ton for their High-P manure chars."
Erich Knight

Contaminated Sediments & Dredge Spoil

FINAL REPORT

Activated Biochars with Iron for In-Situ Sequestration of Organics, Metals, and Carbon

SERDP Project ER-2136

April 2012

Upal Ghosh
Jose Gomez-Eyles
Carmen Yupanqui
Huan Xia
Barbara Beckingham
University of Maryland Baltimore County

This document has been cleared for public release

SERDP
DOD • EPA • DOE

DOD/EPA/DOE RESEARCH STUDY

- In-Situ Sequestration of Organics, Metals and Carbon
- Primary objective was to test a range of biochars especially formulated for toxic chemicals
- Target Hydrophobic Organic Compounds (HOC)
  - PCBs, PAHs, DDTs
  - Many Pesticides
  - Dioxins
  - Mercury (Hg) and Methylmercury (MeHg)

LONG TERM EXPOSURE SOURCES

Aquatic Ecosystem → Biomagnification → Fish → Fish-Eating Wildlife → Humans

- ~ 10% of the sediments underlying the USA surface waters are sufficiently contaminated
- Unactivated vrs. Activated Biochar → PCBs porewater concentration → 18-80% reduction vrs >99% reduction
- Activated Biochar (Poultry Litter) → **>99% Hg removal @ higher concentration**
- Chemical activation impacted adsorption more than steam
- MeHg → Commercially activated carbon worked better than biochar. Different adsorption mechanism than Hg. More study necessary

Contaminated Sediments & Dredge Spoil

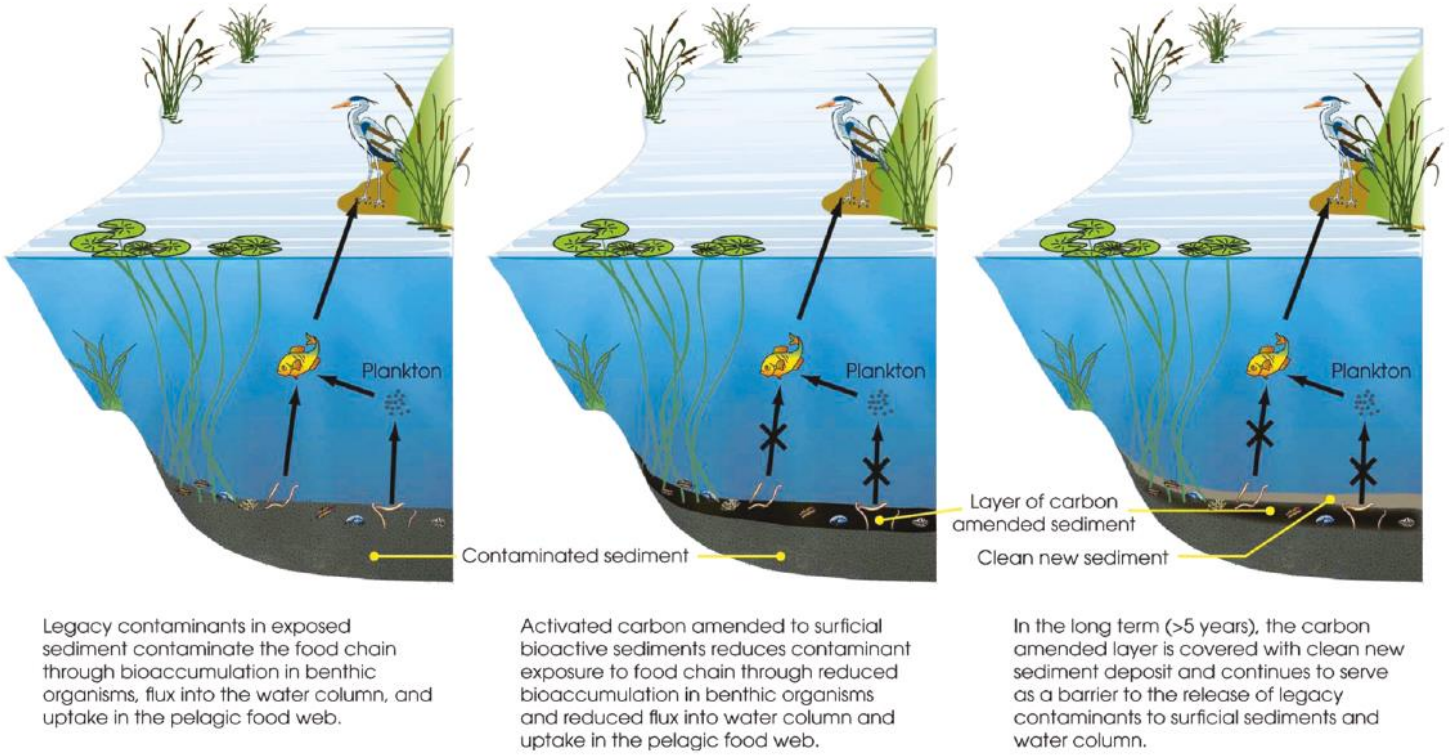
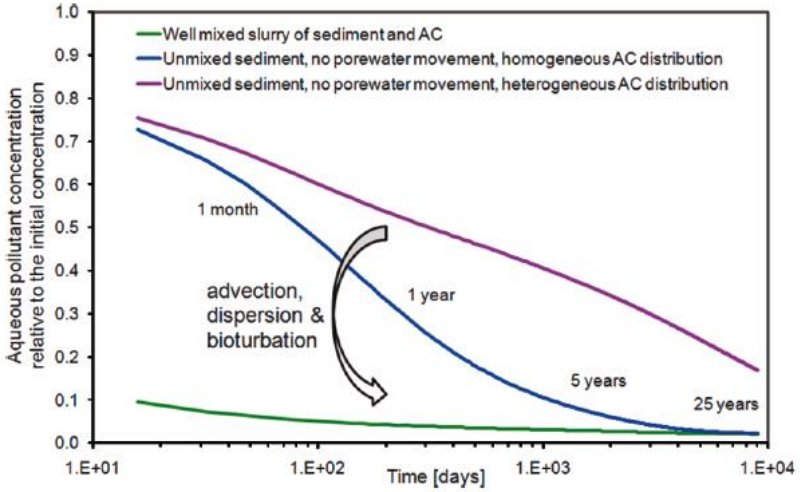


Figure 1. Conceptual model of how sorbent amendment of sediment reduces contaminant exposure pathways of benthic organism accumulation and flux from the sediment bed.



Soil Restoration

Methods & Opportunities

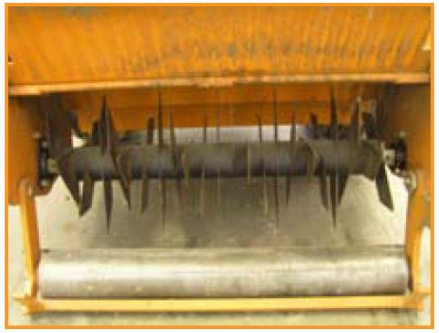
“The nation that destroys its soil destroys itself.”

Franklin D. Roosevelt

Residential/Commercial Application & Tools

Types of Soil Restoration Equipment

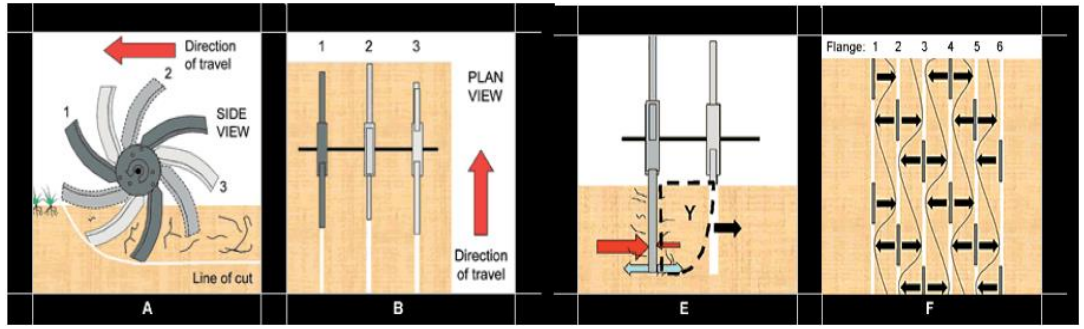
- Core Aerification (<6")
- Deep Tine Aerification (6"-16")
  - Hollow Tines/Solid Tines
  - Straight Up/Down (SUD)/Heaving Action
- Deep-Drill Aerification (up to 16")
- Water Injection Cultivation (< 8")
- Vertical Mowing
- Deep Vertical Mowing/Linear Aeration (10" – 16")
- Spiking (<12") & Slicing (<8")



Deep Vertical Mowing/Linear Aeration

Deep Drill Aerification

Deep Tine Aerification Heaving Action



Soil Injection (Air Fracturing Technology) – United Kingdom

- Wide variety of equipment designs for different conditions
- 1-3 feet deep aeration & de-compaction system using the TerraLift ® Technology
- Compressed air (100-350 psi) is injected into subsoil creating fractures & fissures
  - Breaks up compaction
  - Aerates soils
  - Improves infiltration
  - Allows for amendments to be injected such as biochar

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http://www.terrainaeration.com/flash/scamper-animation.swf

Video

Broad-Scale Soil Application

Hydro-seeding with Biochar Mix

PermaMatrix

U.S. Patent No. 8,430,599 Other U.S. Patents pending

BIOTIC SOIL AMENDMENT

Hydro-seeding with Biochar Mix

PermaMatrix

U.S. Patent No. 8,430,599 Other U.S. Patents pending

BIOTIC SOIL AMENDMENT

Soil & Water Remediation Projects

“The nation that destroys its soil destroys itself.”

Franklin D. Roosevelt

Inland Bays, Delaware – Bioretention Facilities

- Native soils mainly sand
- Tilled to 12 inches and blended in
- Biochar installed June 2014
- Testing 2@5%, 2@9%, 1@12% and 1@15% all by weight

Washington DC – Regenerative SWM

- TMDL/NPDES Project – sediments/nutrients/heavy metals
- Mixed 8 cyd of Biochar with sand & wood chips
- Biochar installed May 2013
- Pre & Post Monitoring by UM

Mine Reclamation – Hope Mountain Mine, Aspen CO

313% Increase in plant cover over conventional alternatives
3.5 times more moisture in soil over conventional alternatives

Heavy Metal Sorption

Dec, 2011.	Method- Columb of packed biochar, saturated with IR treated water and sat for 24hrs, columb was drained. Loaded solution was filtered through char with a 4 to 8x repitition.							
Metal	Aluminum, Al	Arsenic, As	Barium, Ba	Beryllium, Be	Cadmium, Cd	Cobalt, Co	Chromium, Cr	Copper, Cu
	91%	54%	66%	99%	98%	92%	98%	99%
	Mulybdenum, Mo	Nickel, Ni	Lead, Pb	Selenium, Se	Tin, Sn	Vanadium, V	Zinc, Zn	Lithium, Li
	45%	91%	99%	54%	100%	75%	98%	39%

West Hylebos Log Yard Biofiltration, Washingon

Port of Tacoma
People. Partnership. Performance.

Kennedy/Jenks Consultants
Engineers & Scientists

West Hylebo Log Yard

- 25 acres of log handling, storage, debarking
- Stormwater issues with Zinc and Copper
- Project Goal to design a staged media filtration stormwater treatment system to meet permit benchmarks
- Six key parameters – pH, Zinc, Copper, Turbidity, TSS and COD

West Hylebos Log Yard Biofiltration, Washingon

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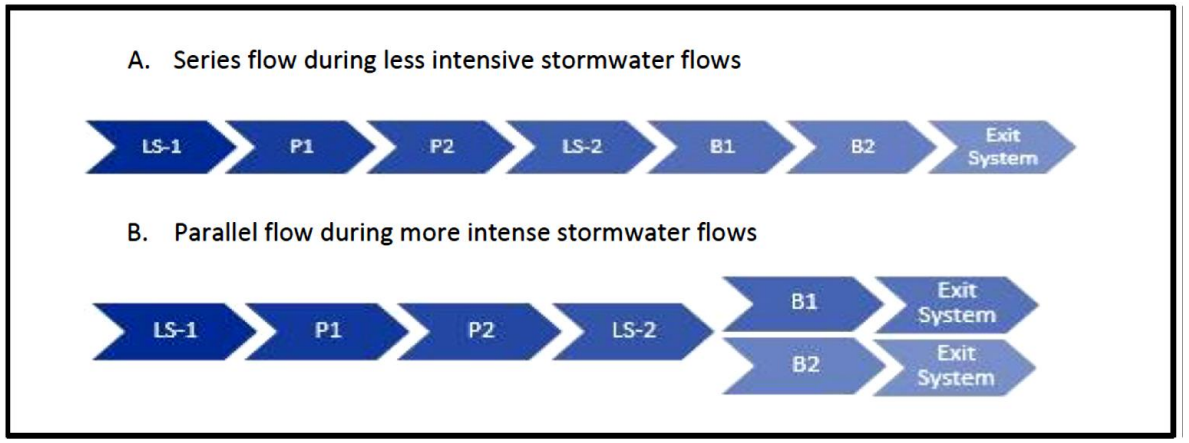

- Pretreatment 1 – Pea Gravel / Physical Filtration – Large Solids
- Pretreatment 2 – Sand Amended w/ biochar /Physical & Chemical Processes – Fines, metals & organic contaminants
- Biofiltration 1 & 2 – Sand Amended w/ Compost, planted with vegetation

West Hylebos Log Yard Biofiltration, Washingon

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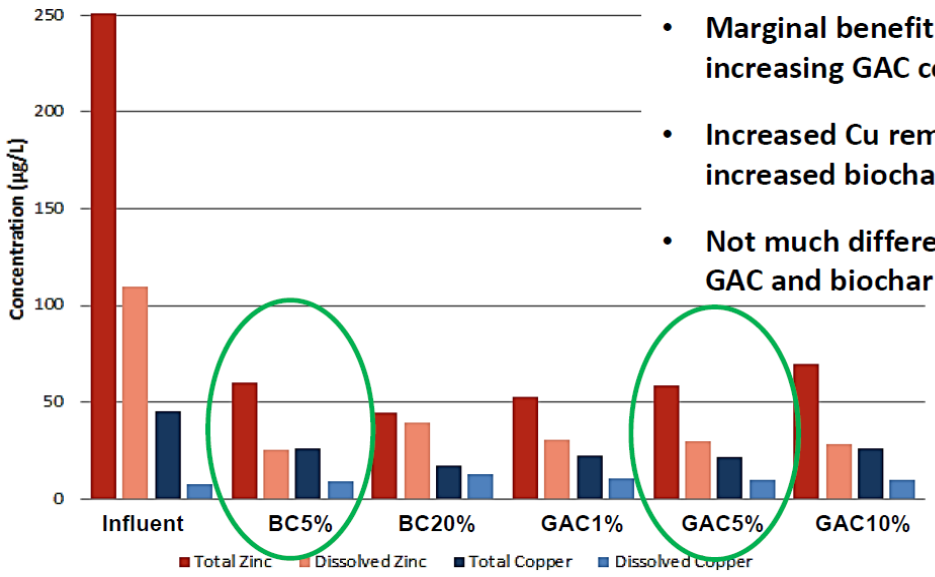
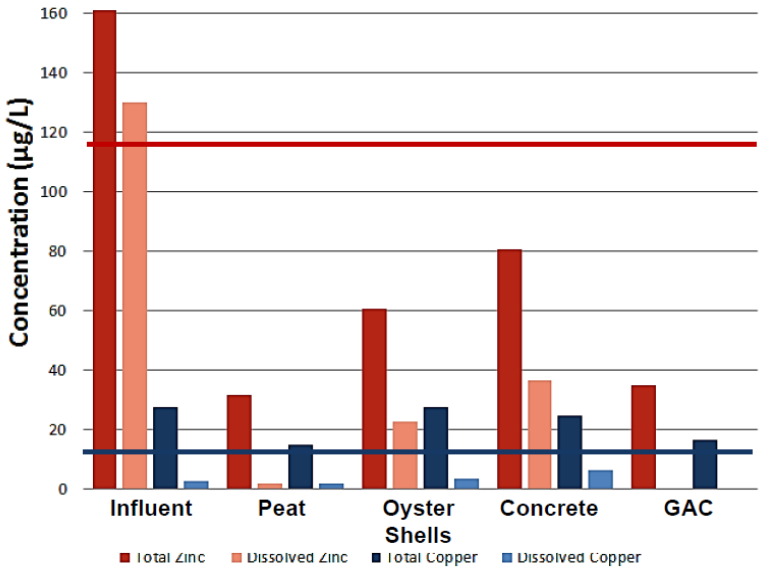
Sand + GAC vs. **Sand + Biochar**

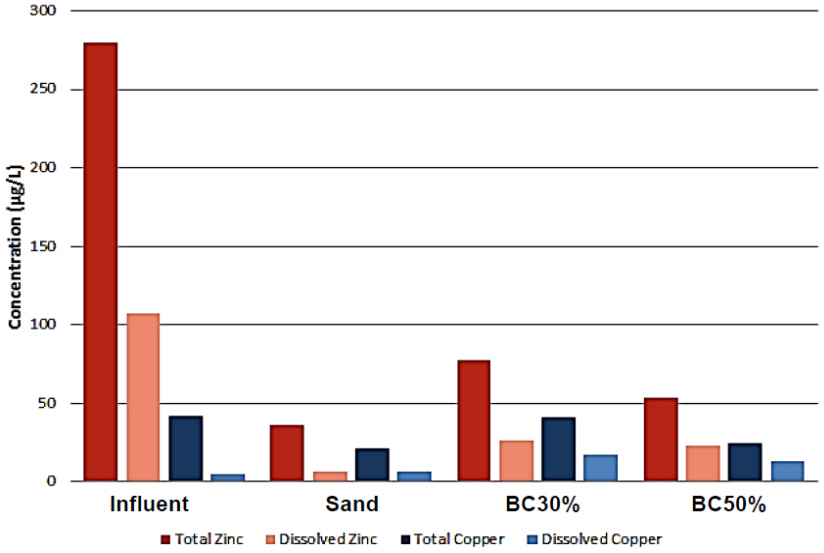
Note – Wood Based Biochar Used



- Marginal benefit from increasing GAC content
- Increased Cu removal with increased biochar content
- Not much difference between GAC and biochar



- Zn below benchmark (117 µg/L)
- Cu above benchmark (14 µg/L)
- GAC removed the most metals and COD



- Sand removed the most metals
- Increased metals removal with more biochar
- Increased COD removal with biochar

West Hylebos Log Yard Biofiltration, Washingon

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System Performance & Cost Analysis

- Immediately met 5 our of 6 permit benchmarks for pH, Zinc, Copper, Turbidity & TSS
- Met 6 out of 6 with adjustments for COD

	Alternative	Constructed Cost	Life Cycle Costs-30 year	Revenue loss due to encumbered land	*Totals
1	Discharge to Sanitary Sewer	$4,106,000	$4,905,000	$1,067,000	$10,078,000
2	Stormwater Wetland	$3,541,000	$498,000	$4,835,000	$8,874,000
3	**Bioretention/Biofiltration**	**$1,084,000**	**$955,000**	**$2,304,000**	**$4,343,000**
4	Advanced Treatment System	$6,824,000	$3,856,000	$711,000	$11,391,000
5	Transfer to Sanitary Sewer/Bioretention	$6,205,000	$1,913,000	$1,906,000	$10,024,000
6	Off-site Bioretention	$2,396,000	$1,199,000	$2,261,000	$5,856,000

*Conceptual Estimates from revised Conceptual Project Plan, Kennedy/Jenks, September 7, 2011

Influent Effluent

Up to 80% to 90% Reduction in Concentrations for All Permit Parameters

Thank You

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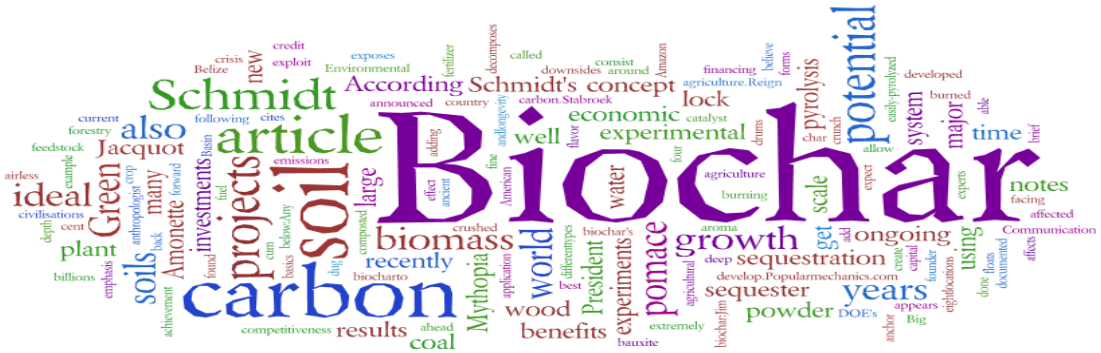
chegberg@skellyloy.com

DOCUMENTS LOCATED AT –
https://goo.gl/4901Vy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