THE INGENUITY OF BIOCHAR & RELATED TECHNOLOGIES FOR EMERGING TOXICS, SOIL & WATER HEALTH, CLIMATE RESILIENCY & CIRCULAR ECONOMIES

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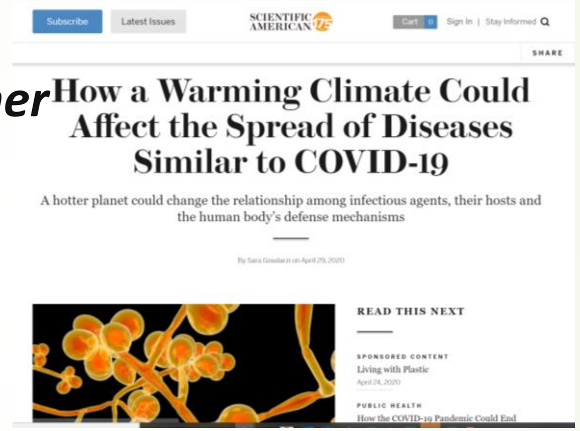
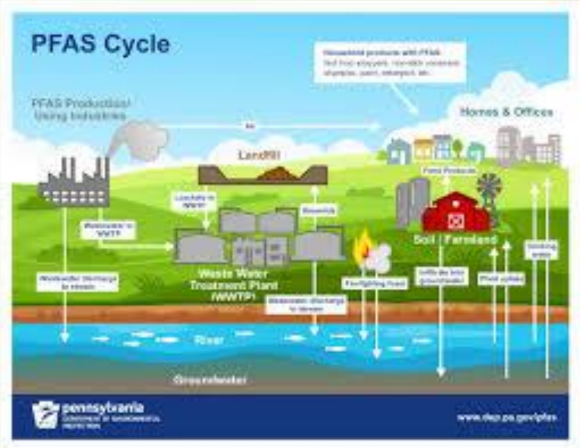
WHY IS THE TOPIC OF BIOCHAR FOR SOIL, WATER & CLIMATE HEALTH EVER MORE IMPORTANT TODAY?

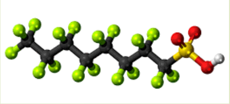
Coronavirus Pandemic – Climate Emergency- PFAS and Emerging Contaminants, Underlying Global Health & Socio-Economic Crises

New Research Links Air Pollution to Higher Coronavirus Death Rates





"The growing crisis of 'forever chemicals'"



HEALTHY FOOD & WATER ARE MATTERS OF GLOBAL NATIONAL URGENCY, SECURITY & RESILIENCE

Waste Management – An Area of Increasing Concern

Biosolids & Land Application Under Increased Scrutiny Due to Emerging Toxics

Solid waste is expected to grow to 3.40 billion tons by 2050 under a business-as-usual scenario.


U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF INSPECTOR GENERAL

Cleaning up and revitalizing land

EPA Unable to Assess the Impact of Hundreds of Unregulated Pollutants in Land-Applied Biosolids on Human Health and the Environment

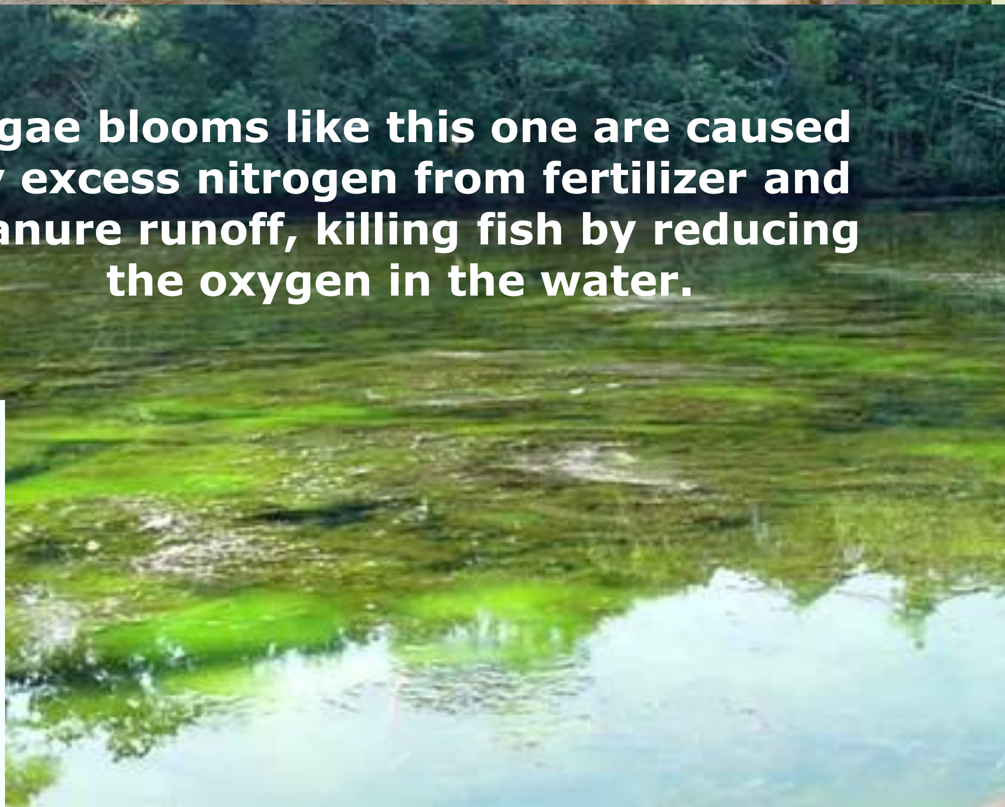
Report No. 19-P-0002 Novemb

Household Chemicals and Drugs Found in Biosolids from Wastewater Treatment Plants USGS (2006)

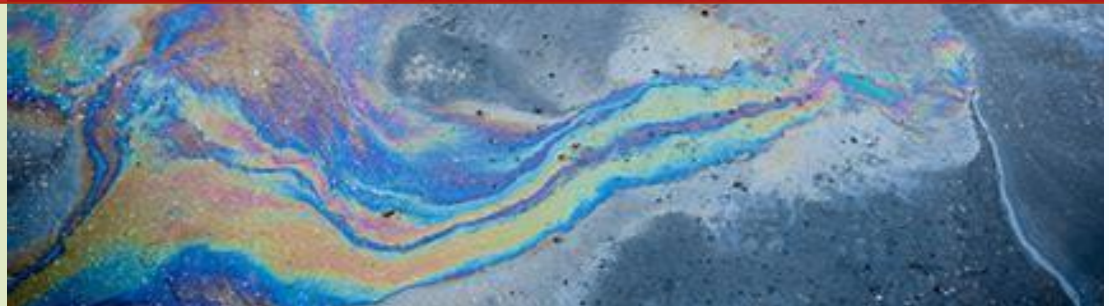
Dairy cows rest outside at Stoneridge Farm in Arundel, Maine, in August 2019. The farm was forced to shut down after sludge spread on the land was linked to high levels of PFAS in the milk. Photograph: Robert F Bukaty/AP

NPS Stormwater Pollutant Challenges to Soil & Water Quality –
Areas of Increasing Concern!

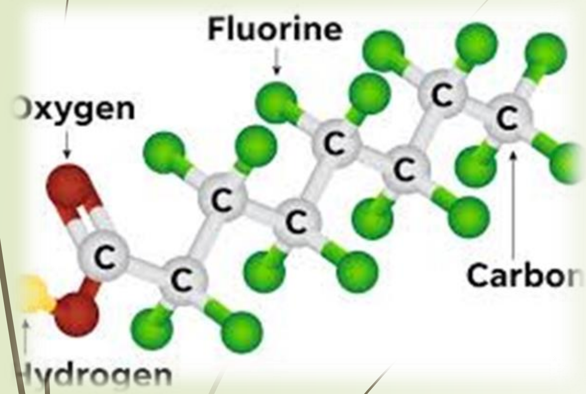
- Pathogens
- Algae/HABs
- Perfluoronated Compounds
- Nutrients
- Pesticides – Arsenic, e.g.
- Lead & Heavy Metals from Contaminated Sites
- Manure Land Applications
- Biosolids & Landfill Leachates
- Air Deposition
- Endocrine Disruptors
- Plastics



Algae blooms like this one are caused by excess nitrogen from fertilizer and manure runoff, killing fish by reducing the oxygen in the water.

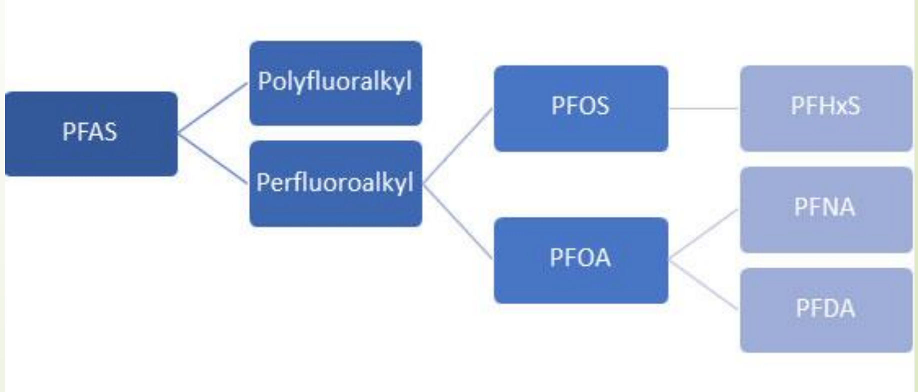


Per and Polyfluoroalkyl Substances (PFAS) – Exposure Pathways



- **Drinking contaminated municipal water or private well water (Groundwater; Surface Water)**
- **Eating fish caught from water contaminated by PFAS (PFOS, in particular) (**Surface Water; Sediments**)**
- **Accidentally swallowing contaminated soil or dust (**Soil**)**
- **Eating food that was packaged in material that contains PFAS**
- **Using some consumer products such as non-stick cookware, stain resistant carpeting, and water repellant clothing.**

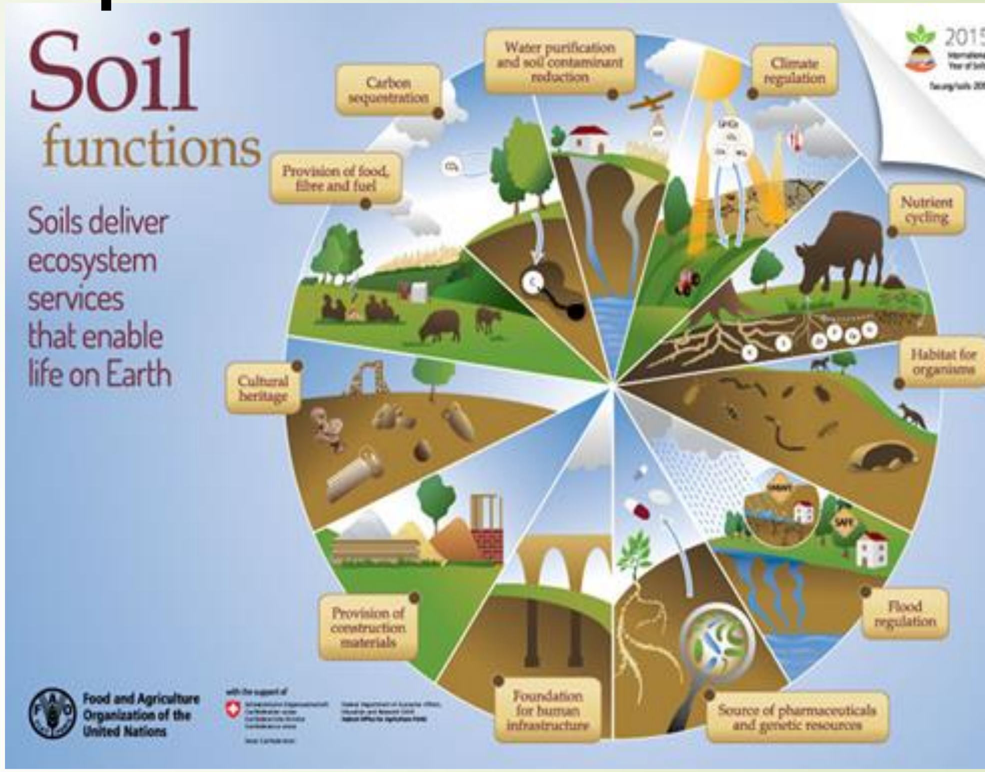
FOCUS AREAS OF OUR TREATMENT, TESTING & ANALYSES



Importance of Healthy Soils for Carbon Sequestration

Soils help to combat and adapt to climate change by playing a key role in the carbon cycle.

Currently, soils remove about **25 percent** of the world's fossil fuel emissions each year.



The Earth's soils contain about **2,500 gigatons* of carbon—**that's more than three times the amount of carbon in the atmosphere and four times the amount stored in all living plants and animals. *Note – a gigaton=1billion tons.

HEALTHY SOIL = HEALTHY WATER

Biochar & Carbon Sequestration

Cornell University estimates that producing biochar from biomass could sequester carbon equivalent to 12% of global CO2 emissions - on par with emissions from the global transport sector.

Biochar sequesters carbon by converting it into a stable element of the soil that can stay in the ground for millennia.

Biochar needs 90% less energy to be produced than Activated Carbon! It's also much less expensive!

	Biochar	Activated Carbon
Energy Demand	6.1 MJ/kg	97 MJ/kg
GHG emissions	- 0.9 Kg Co2e/kg	- 6.6 Kg Co2e/kg
Price	< $1.00/kg - $ 5.00/kg	$5.50/kg

ACTIVATED CARBON ~ $3500/TON

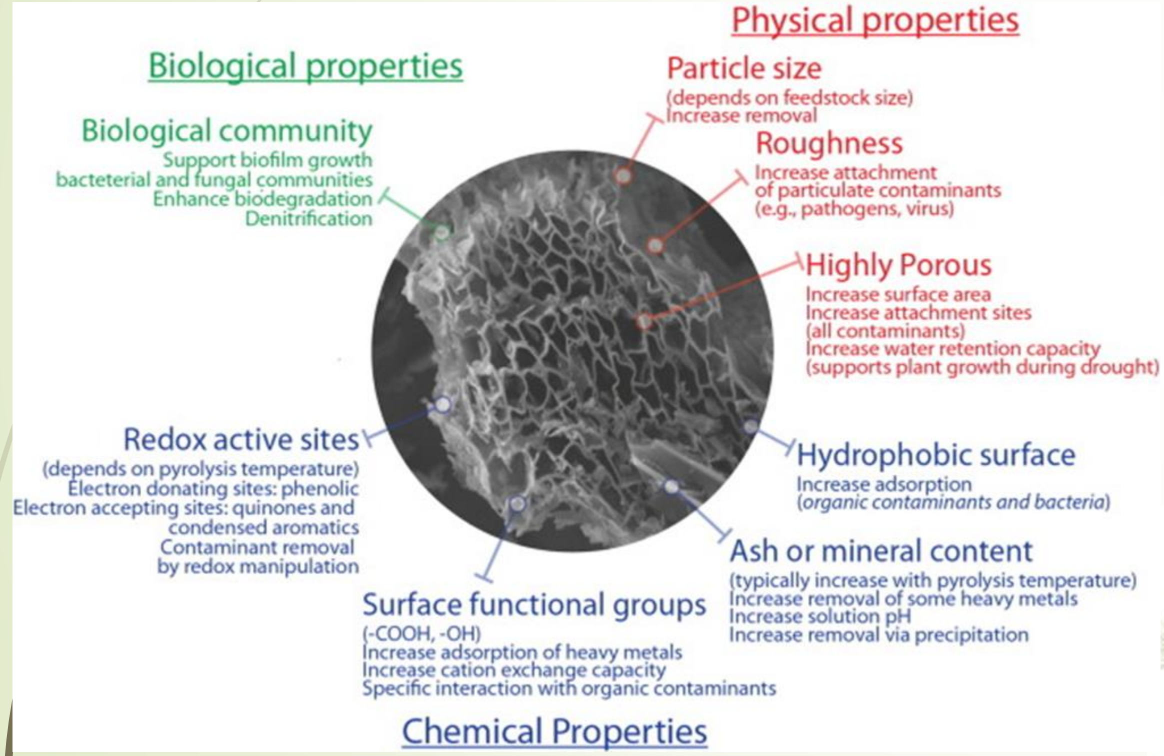
- ECOCHAR ~ $ 600 - $800/TON

BIOCHAR IS A GREAT SOIL AMENDMENT!

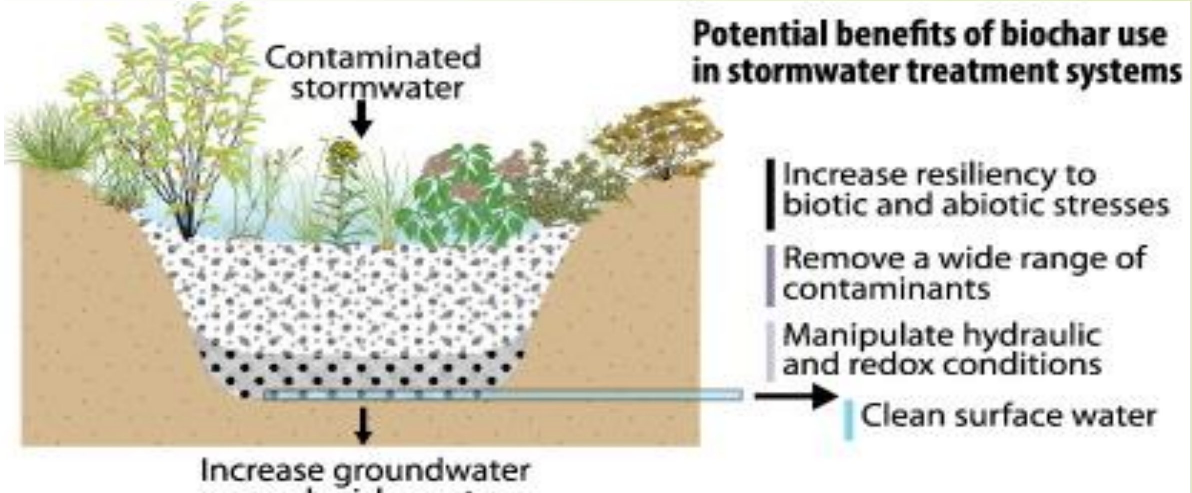
The carbon in biochar is viewed as 'carbon-negative' –it will remain in the soil (and out of the atmosphere) for centuries or longer.

Beneficial Uses of Biochar to Enhance Green Infrastructure/Stormwater/Water Quality Treatment

Biochar-amended soils exhibited significantly higher total porosities (50%) than the unamended controls (41%) after 105 d



Physical, chemical, and biological properties of biochar for removal of contaminants from stormwater.



Science of The Total Environment
Volume 625, 1 June 2018, Pages 1644-1658

Treatment of "Historic Fill" with Manure-Based Biochar (Ecochar)

LAB ANALYSIS RESULTS

"I've looked at the data. Quite interesting and a bit of what I expected as far as **superior performance of the manure-based biochar (Ecochar)** as compared to that of the **plant-based biochar**, albeit a bit surprised that the plant-based biochar did not seem to tackle lead but did reduce copper concentration slightly."

"Also importantly is the fact that neither biochar seems to contain in its composition significant amounts of the compounds measured. **My extensive research also pointed to manure based biochars as the best candidates for heavy metal remediation, hands down! Also to be noted how well the manure based biochar (ecochar) removed the significantly high lead levels, more than 99% removal at either 10 or 20% dosages.** "

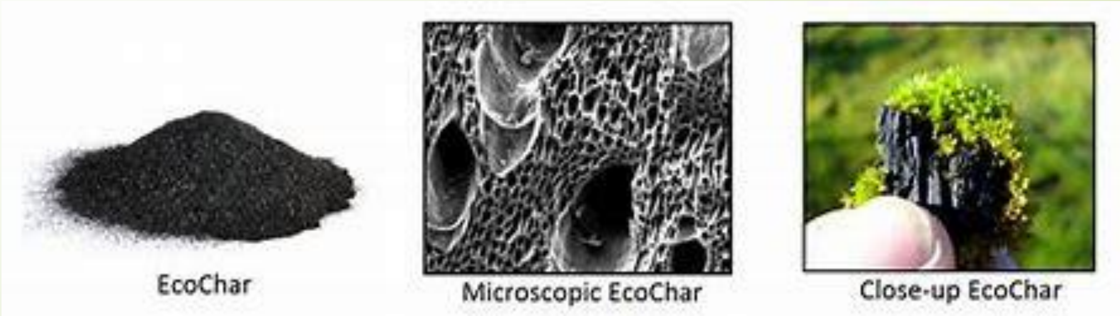
Isabel Lima, Ph.D.
Research Chemist
Commodity Utilization Research Group
USDA, ARS, SRRC

What is Biochar?

- Carbon-rich solid produced by heating biomass in the absence of oxygen (pyrolysis or gasification)

- Residual product of bio-energy production, porous solid with a number of beneficial properties, that depend upon feedstock, pyrolysis conditions, and pre- and post-treatments

- Biomass-derived char (biochar) is a versatile source of renewable energy with the potential to generate heat, electricity and liquid biofuels.



What is Biochar?

- Gasification allows for the reuse of agricultural solid wastes and wood, as well as refinery wastes. The thermochemical processes by which bio-mass can be converted are: slow pyrolysis, fast pyrolysis, flash carbonization, hydrothermal carbonization (HTC), gasification and torrefaction.

- Biochar's immense surface area and complex pore structure creates tremendous surface area. A single gram can have a surface area of over 1000 square yards.

Carbon Sequestration as an Integral Part of Watershed Management

BIOCHAR – The "Environmental Superstar!"

Dr. Dorothy Hamill, NASA

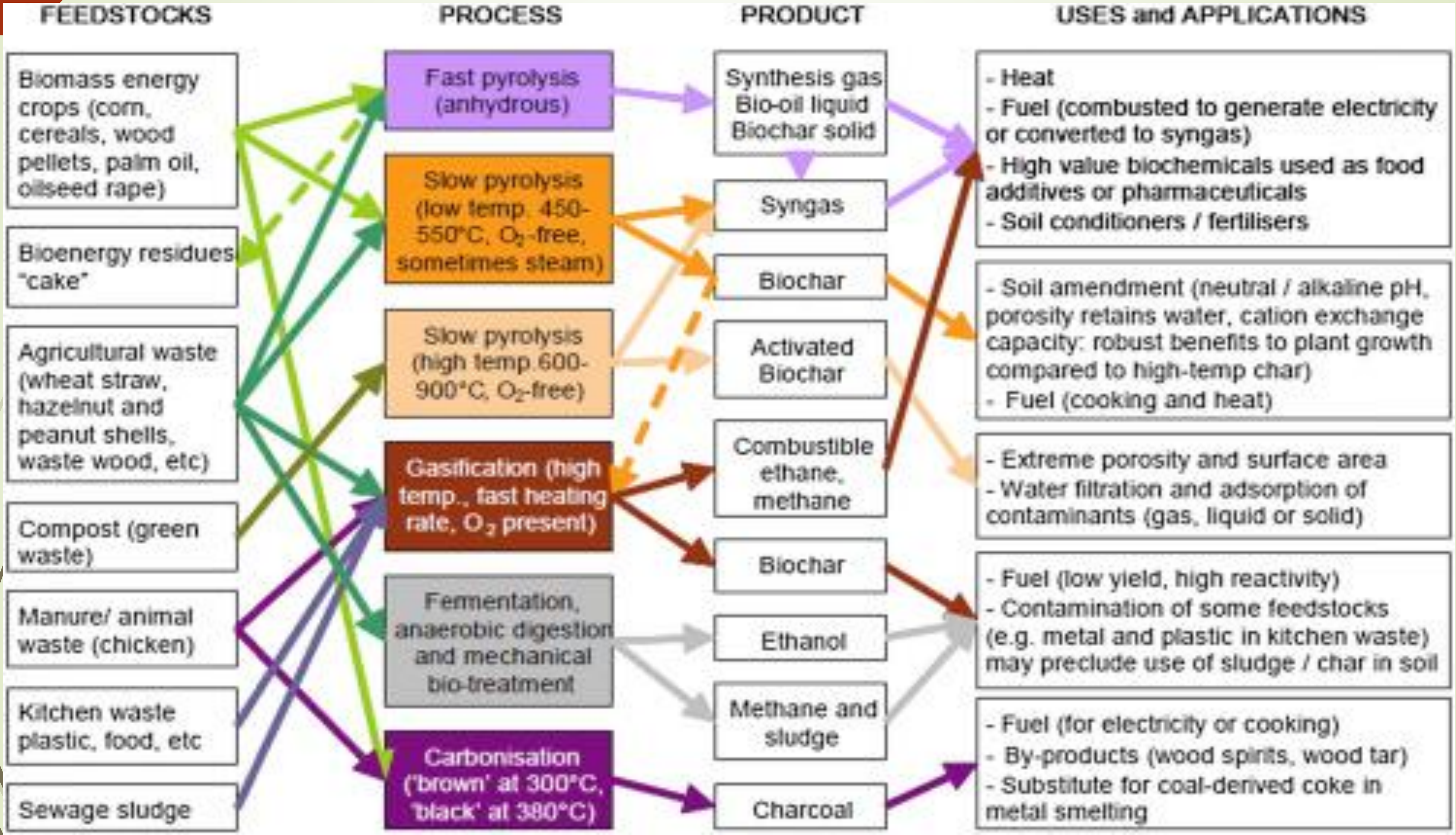
Biochar is an organic charcoal that has an incredible range of environmental benefits - removing heavy metals from soils, enriching farmland, filtering groundwater, sequestering carbon from the carbon cycle that causes global warming..

Biochar & Carbon Sequestration

Cornell University estimates that producing biochar from biomass could sequester carbon equivalent to 12% of global CO_2 emissions - on par with emissions from the global transport sector.

Biochar sequesters carbon by converting it into a stable element of the soil that can stay in the ground for millennia.

Summary Of Thermal Conversion Processes In Relation To Common Feedstocks, Typical Products, And Potential Applications



(Sohi et al., 2010).

Biochar & Activated Carbon

Both are excellent adsorbents!

- Biochar is porous, inexpensive and readily available for use as adsorbent, typically having large surface area to remove contaminants.
- Activated carbon is traditionally made from coal and has very high carbon content.
- Activated carbon has a very high surface area; a teaspoon of activated carbon has surface area equivalent to a football field.

Biochar Vs. Activated Carbon

Biochar - shares adsorption properties with activated carbon.

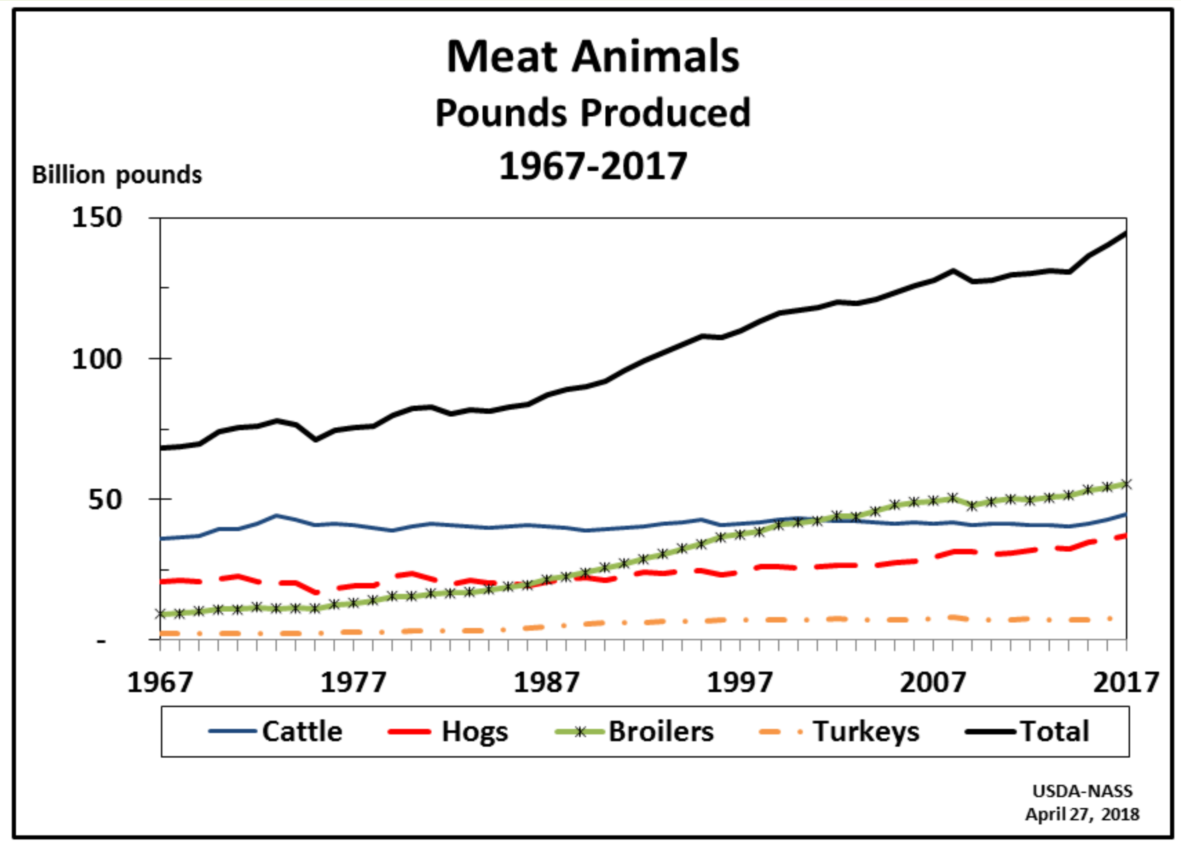
Biochar has a significant amount of ion exchange capacity, a property that is minimal or absent in traditional activated carbons.

Biochar is low density – as compared to higher density of AC. As soil amendment – provides great aeration, significant cation exchange capacity, and the ability to increase both nutrient uptake and soil fertility.

Drivers for Biochar Production

- Poultry, swine and cattle produce over 5 times the waste of the U.S. human population
- ~ 175 million tons of manure produced each year
- 129, 176 M DMT available from forestry & agriculture for bio-energy & bio-products
- Out of 3.6 million miles of rivers and streams in the U.S., farming impairs water quality to some degree in about 18% of the 0.7 million miles that states assessed
- Increase in public and regulatory concern from the impact of animal waste on quality of life and the environment

Agricultural Residuals



- Plentiful, cheap and renewable resources
- Contain intrinsic properties
- Land not an issue
- Liability to animal farmers, growers, refiners
- Concentrated in large amounts

- Adding value by transforming agricultural residuals into biochars via thermo-chemical conversion (pyrolysis)
- Help protect the environment and public health

Biochar Physico-Chemical Properties

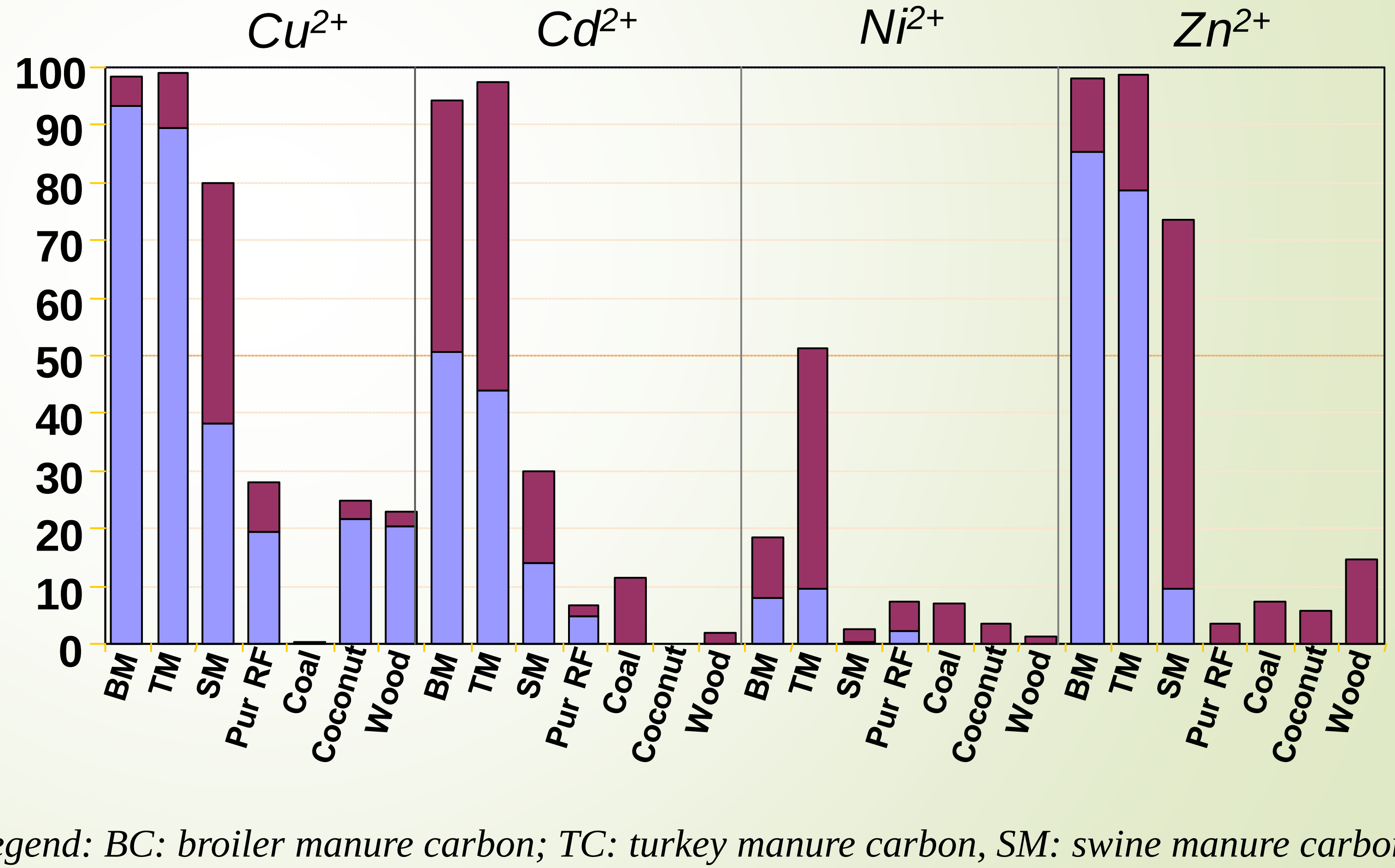
Sample	IY %	FY %	Ash %	BD g/cm³	S.A. m²/g	PM %	Ads %	pH	S.A. m²/g
Broiler manure	40	30	45.2	0.54	318	88	48.2	8.6	*395*
Broiler litter	41	34	49.2	0.60	238	90	29.5	8.1	*441*
Turkey manure	41	33	40.4	0.53	147	93	16.9	9.2	*394*
Turkey litter	42	35	43.5	0.57	179	93	30.9	8.1	*414*
Swine	38	31	56.9	0.59	92	40	14.1	6.8	*419*
Dairy	48	37	71.0	0.56	131	75	8.5	7.2	*318*
Coal	78	61	2.5	0.42	4	-	0.0	4.2	-
Coconut shell	28	28	1.8	0.61	35	24	0.0	6.6	*843*
Wood	25	24	1.4	0.38	301	93	0.0	5.1	*849*

Steam activation (last S.A. column)

IY: initial yield before acid washing; FY: final yield after acid washing; BD: bulk density; SA: Surface Area; PM: Percent of surface area in micropores.

Heavy Metal Adsorption (%)

	Sample	Cu^{2+}	Cd^{2+}	Ni^{2+}	Zn^{2+}
Single	Broiler manure	95.4	83.2	6.6	89.8
	Broiler litter	95.0	82.3	5.1	90.9
	Coal	0.0	12.8	0.5	2.6
	Coconut shell	3.1	13.5	0.0	0.5
	Wood	6.3	13.3	0.0	1.8
Competition	Broiler manure	71.1	18.8	3.8	23.7
	Broiler litter	66.1	18.1	3.6	25.2
	Coal	0.6	0.3	0.7	1.0
	Coconut shell	0.2	0.9	0.7	3.8
	Wood	4.0	0.0	0.0	2.4



Legend: BC: broiler manure carbon; TC: turkey manure carbon, SM: swine manure carbon

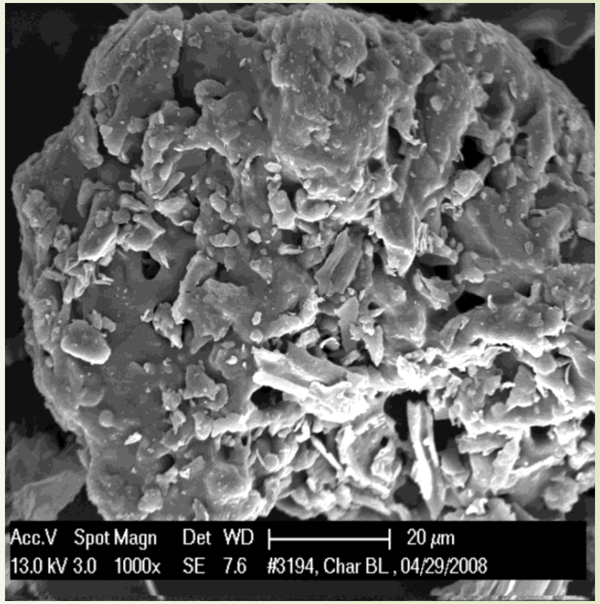
Biochar vs. Activated Carbon

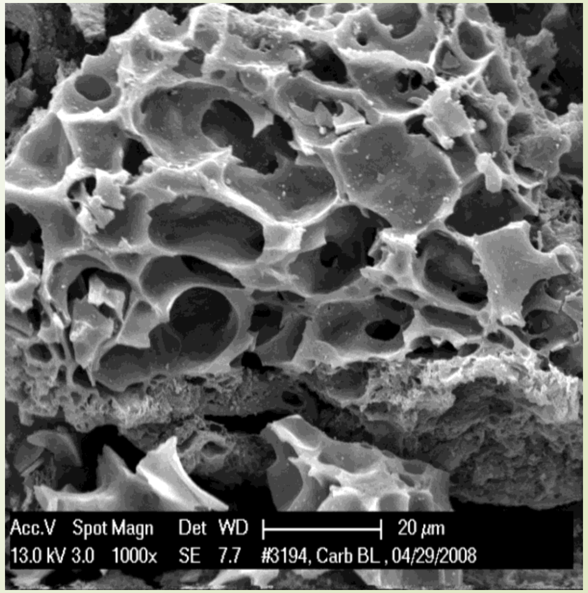
EPA discharge limits

	mg/L daily max	mg/L avg/mo
Cu	1.00	0.23
Cd	0.73	0.16
Zn	1.20	0.27

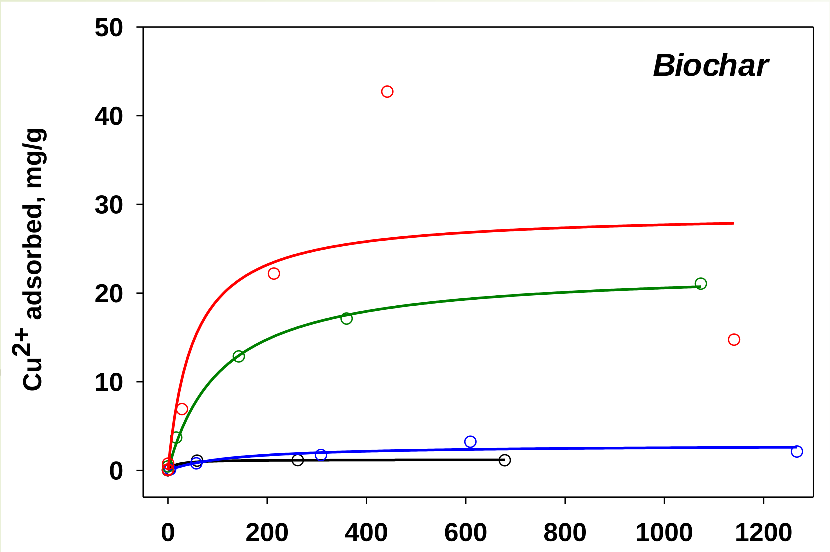
(mg/g)	Cu^{2+}	Cd^{2+}	Ni^{2+}	Zn^{2+}
BL carbon	77.0	122.9	3.7	86.9
BL biochar	36.9	50.5	14.8	47.2
BM carbon	123.8	149.8	26.5	126.5
BM biochar	57.8	71.9	5.9	63.1
TL carbon	110.4	161.9	32.2	113.4
TL biochar	38.6	69.8	9.4	47.6
TM carbon	99.0	165.9	78.7	109.3
TM biochar	21.1	51.3	14.5	40.6
Coal	0.0	6.0	7.7	2.0
Coconut Shell	0.0	4.8	7.9	6.4
Wood	0.0	3.0	11.9	3.0

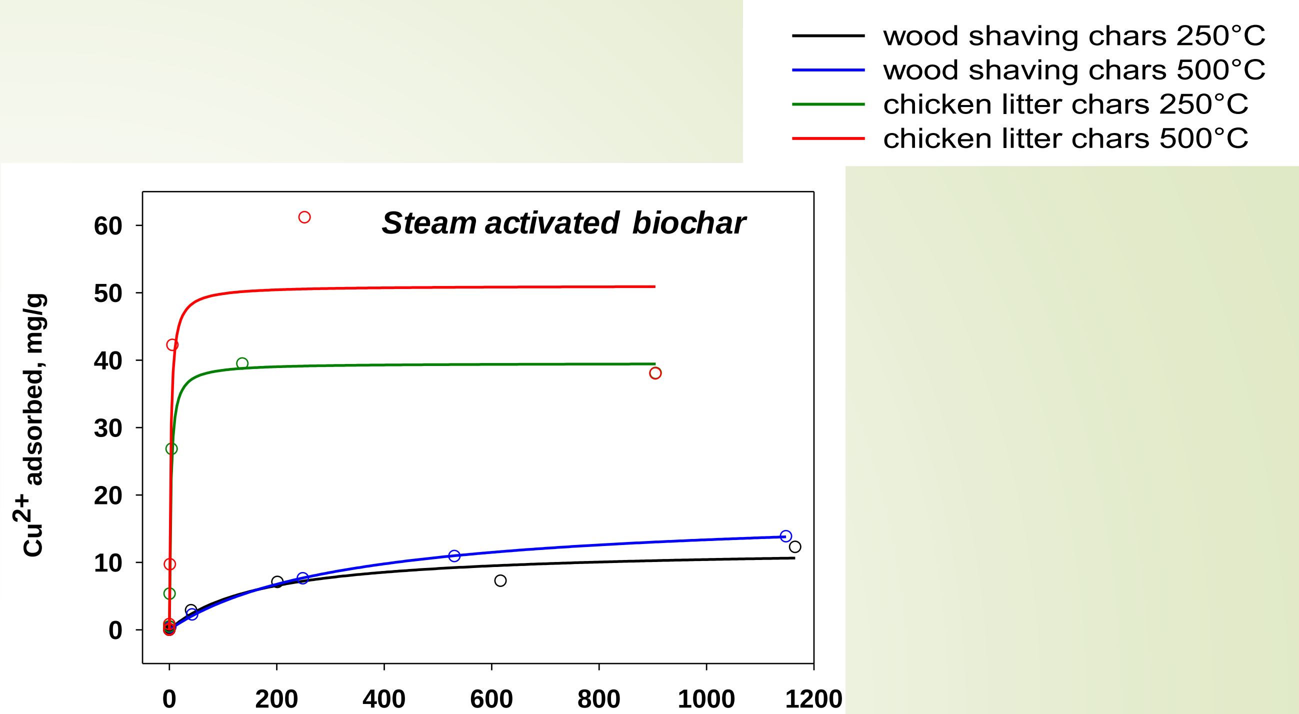
BL: Broiler litter, BM: Broiler manure; TL: turkey litter, TM: Turkey manure

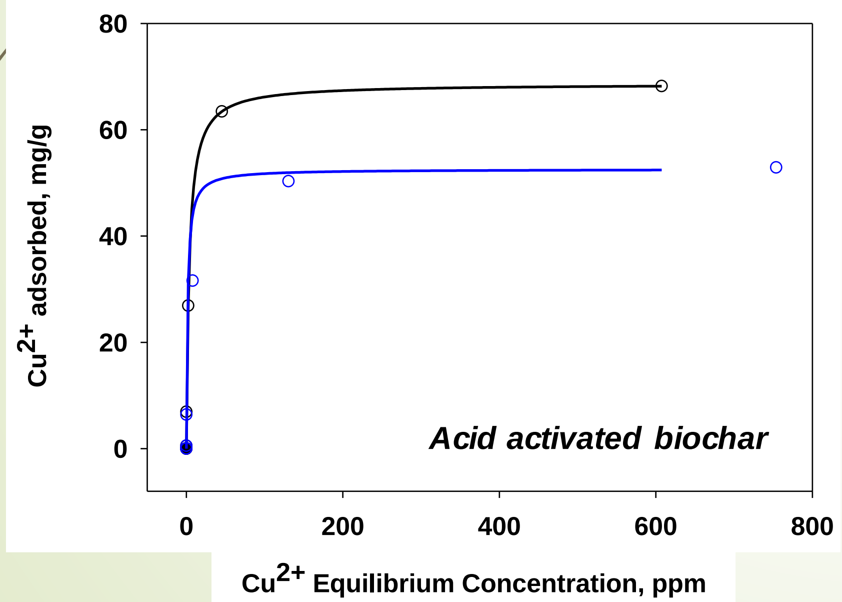




Feedstock Differences







Feedstock	Sample	SC meqH⁺/g	Q_o mg/g	BET m²/g	P mg/g
Wood 250°C	Biochar	1.57	1.22	0.03	0.32
	Steam act	0.00	12.2	**573**	1.34
	Acid act	**3.00**	**68.6**	**851**	3.76
Wood 500°C	Biochar	0.37	2.89	0.0	1.55
	Steam act	0.00	17.7	511	1.81
	Acid act	**2.11**	**52.9**	538	3.61
Chicken litter 250°C	Biochar	1.28	22.8	0.5	16.7
	Steam act	0.06	39.5	592	34.9
Chicken litter 500°C	Biochar	0.22	29.1	1.6	25.3
	Steam act	**0.00**	**51.0**	420	35.7

SC: total negative surface charge; Q_o: Adsorption capacity for copper ion; BET: surface area; P: phosphorous content

Elemental composition (g/100 g)

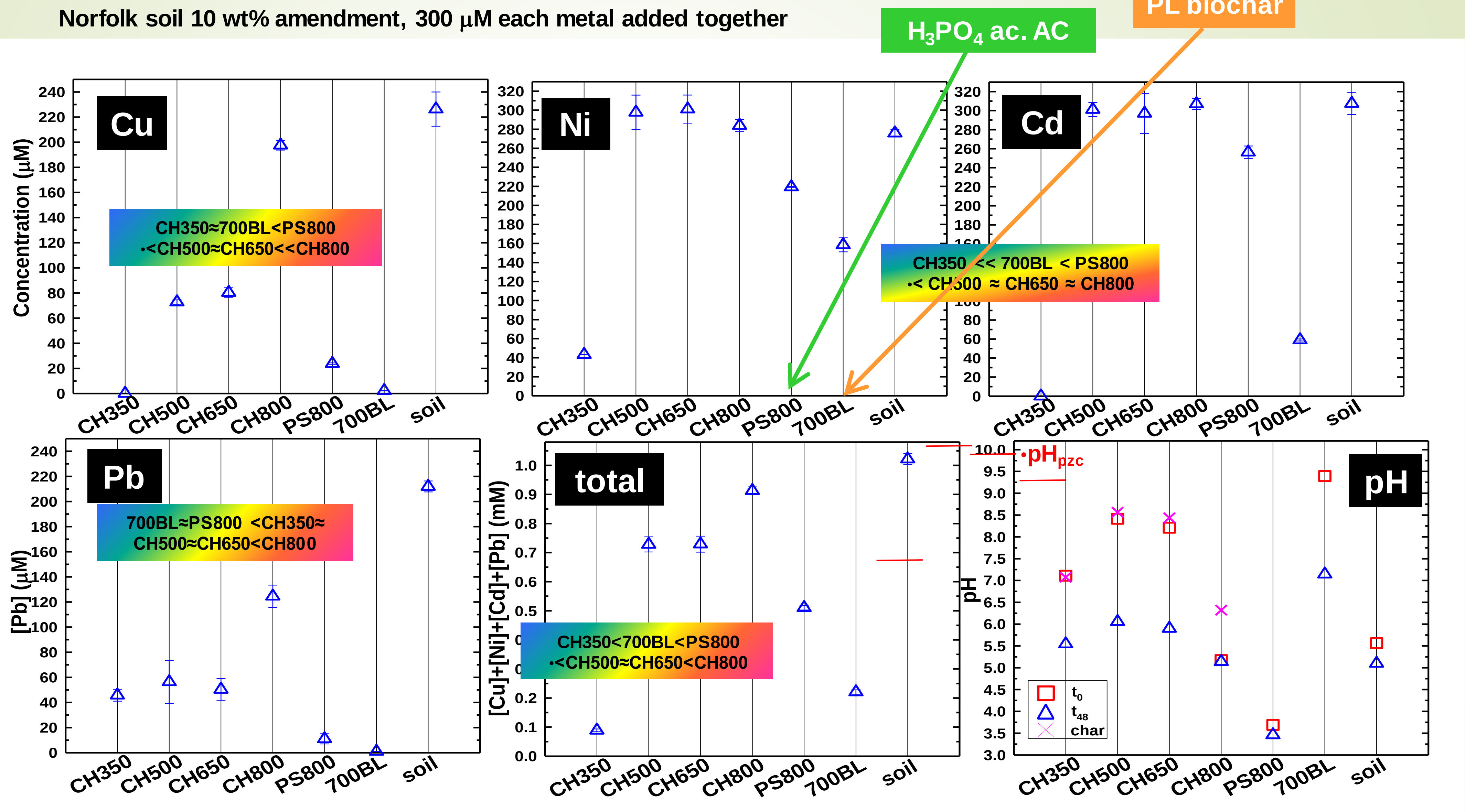
manure (bold values) / *activated carbon* (italic values)

	C	N	K	S	P
Broiler Litter	**34.4**	**3.26**	**3.83**	**0.67**	**1.66**
	25.8	*0.75*	*3.00*	*0.64*	*4.80*
Broiler Manure	**32.6**	**3.62**	**5.34**	**0.83**	**1.94**
	17.2	*0.60*	*5.80*	*0.80*	*7.30*
Turkey Litter	**34.9**	**3.84**	**2.75**	**0.61**	**2.26**
	32.6	*1.12*	*4.09*	*0.93*	*7.88*
Turkey Manure	**35.4**	**4.82**	**2.88**	**0.66**	**2.04**
	30.5	*1.40*	*4.59*	*1.46*	*7.40*
Swine	**41.5**	**4.21**	**1.81**	**0.42**	**1.85**
	39.9	*1.48*	*1.67*	*0.27*	*5.20*
Dairy	**30.3**	**3.01**	**1.46**	**0.50**	**1.29**
	28.8	*0.69*	*0.83*	*0.50*	*2.70*

biochar: P — Broiler Litter *3.68*; Broiler Manure *4.92*

Sample	Activation Method	Surface Area m^2/g	Cu^{2+} Adsorption (mmoles/g)
Pecan shells	Steam	894	0.29
Pecan shells	Acid/Oxid	682	1.10
Broiler manure	Steam	481	1.90
Broiler litter	Steam	377	1.20
RO 3515	Steam	920	0.27
F-400	Steam	960	0.22

Poultry Litter biochar: among the most effective for Cu, Ni, Cd, Pb retention in soils



Estimated Cost of Production

Lima et al. (2008)

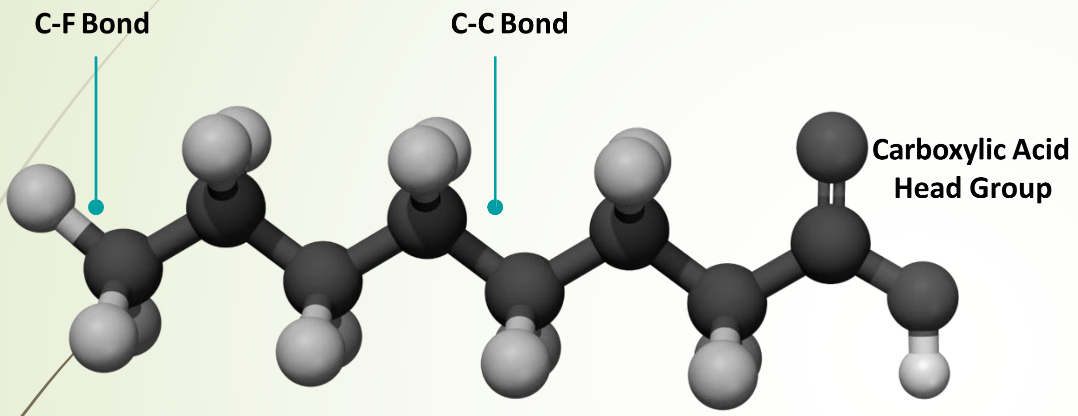
- Based on a feed rate of 44,000 lbs/day (22 t).
- Poultry litter obtained from various farmers at $5.00/ton. Litter is transported for 10 miles to the processing facility at a cost of $25.00 per ton.
- Processing facility converts poultry litter into biochar on a continuous basis 24 hr/day and 330 day/yr.
- Based on equipment costs and operating expenses.
  - Production costs include utilities, operating & maintenance, labor & supplies, facility overhead charges and amortization of the cost to build the manufacturing plant over a 10-yr period.

Potential Market Size

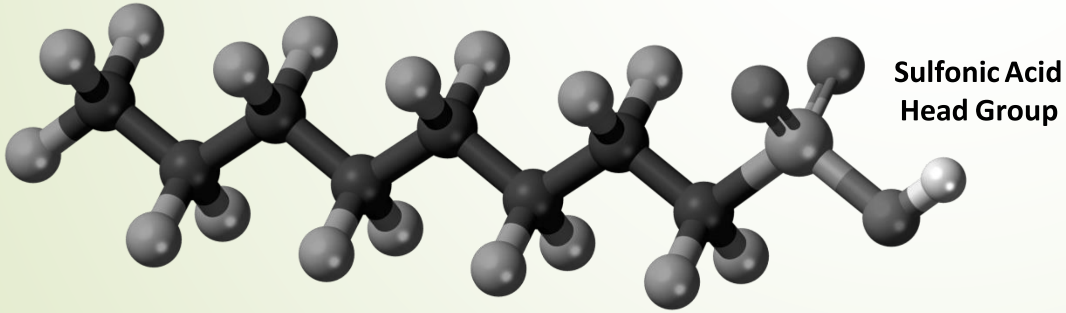
- Depends on local availability of manure
- Small manufacturing facility
  - 11 t/d (3500 t/yr); 20 broiler houses
- Medium to Large manufacturing facility
  - 50 t/d (16,000 t/yr); 100 broiler houses
- Plentiful amount !!
  - 0.35 – 0.7 M t/yr manure => 25-50% AC market, biochar needs?
- *Location, Location, Location …*
  - Delmarva Peninsula (1.2 M T/yr)
  - Perdue AgriRecycle, Seaford, MD (2500hp mills, 30 T pellets/hr)
  - GA, AL, MS => 1/3 U.S. broilers supply

	Treatment	$/lb	Yield, %
Biochar	unwashed	$0.32	40.5
Activated	unwashed	$0.43	30.0
Biochar	washed	$0.38	33.5
Activated	washed	$0.65	21.6

PFAS Molecular Characteristics



PFOA MOLECULE



PFOS MOLECULE

CHEMICALLY STABLE

- Carbon Chain backbone
- C-F Bond

RELATIVELY HIGH MOLECULAR WEIGHT

TYPICALLY LOW VAPOR PRESSURE

EASILY INFILTRATES INTO GROUNDWATER & SOIL

BIOACCUMULATES IN ORGANISMS

Source – Calgon PFAS Webinar

REMOVING PFAS FOR 15 YEARS

OUR EXPERIENCE WITH PFAS REMOVAL

- Granular Activated Carbon (GAC), Ion Exchange Resin (IX), and CCC's Equipment Line are proven treatment solutions for PFAS removal
- Over 50 installations for PFAS removal across the United States
- Offer complete solution including activated carbon, equipment, on-site installation and exchange services, reactivation, and financing

GAC

Proven products and solutions for drinking water, wastewater, remediation and POET

Carbon reactivation to thermally destroy PFAS and enable the reuse of activated carbon

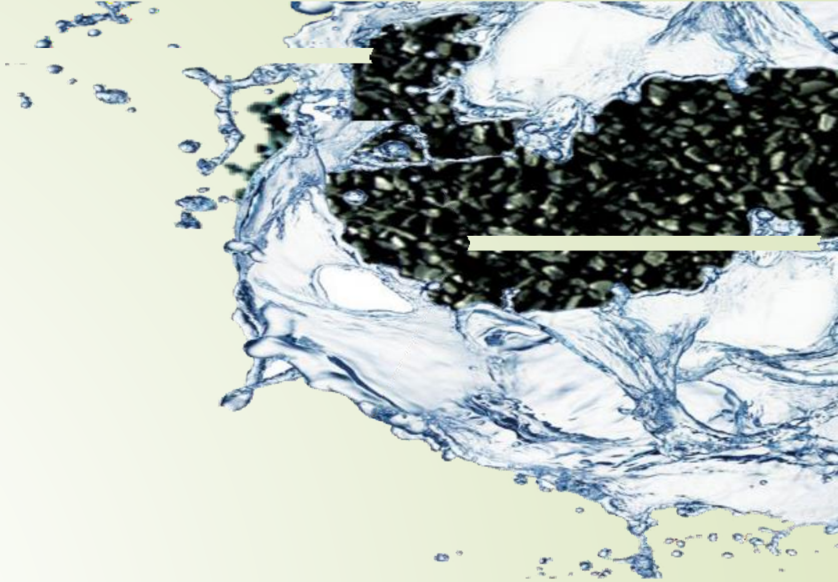
Unrivaled technical service

Laboratory & field testing for tailored solutions

Applications Engineers and R&D team dedicated to solving customer problems

Source – Calgon PFAS Webinar

GAC TAKEAWAYS



GAC IS EFFECTIVE AND PROVEN FOR PFAS REMOVAL

- Long chain
- Short chain
- Precursor/replacement compounds

NOT ALL PRODUCTS ARE CREATED EQUAL

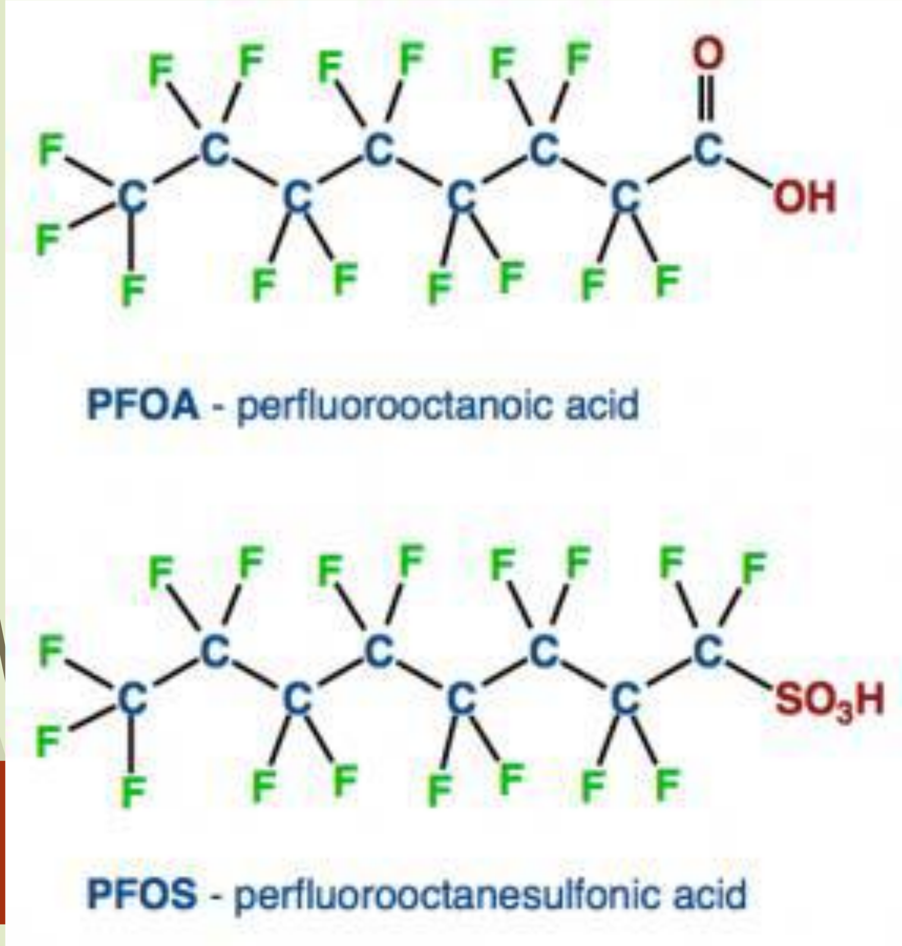
- Base material influences performance
- Water quality influences performance

TESTING IS REQUIRED FOR ACCURATE TECHNOLOGY COMPARISON

- Utility specific
- Performance influences economics

Source – Calgon PFAS Webinar

Biochars for PFAS treatment?



- PFAS used in many applications from weather resistant cooking, non-stick cookware, food wrappers and fire-fighting foam to electronics.
- They have relatively high molecular weight, they infiltrate in groundwater and soil easily. And bioacumulate in organisms.
- PFAS are chemically stable having a carbon chain backbone as well as C-F bonds.
- Granular Activated Carbons have been proven as treatment solutions for PFAS removal, for both short and long chain compounds.
- Just like with other remediation applications, the feedstock will influence the performance as well as the presence of other contaminants during treatment.
- Not all PFAS are created equal so effectiveness of treatment is dependent on chemical characteristics.
- Existing technologies also allow for thermal destruction of PFAS
- Economics: treatment cost and performance need to be combined to determine which product is more desirable.

Gasification – One of the most efficient technologies to produce biochar.

- **Gasification** is an oxygen-starved process, with the balance of fuel and air kept to produce mostly CO. Typically target a temperature of between 1200 and 1600 degrees F. inside of the gasifier. If there is a desire to increase this temperature, it can easily be done by either increasing the amount of air, or decreasing the amount of fuel. Can easily maintain 1800 degrees F (1000 degrees C) in the gasifier – temp which completely destroys PFAS bonds.

Gasification Technology - One of the most efficient technologies to produce biochar and destroy PFAS.

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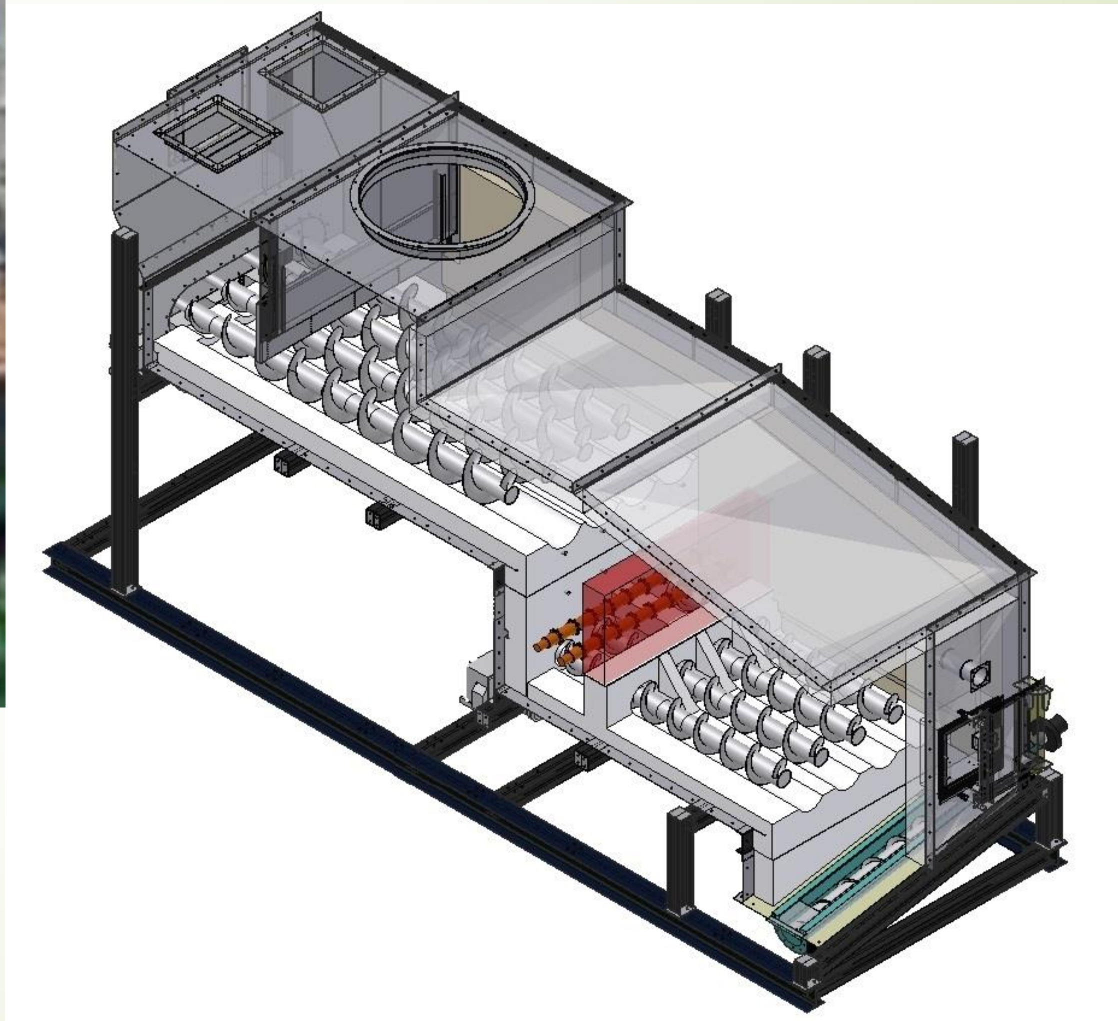
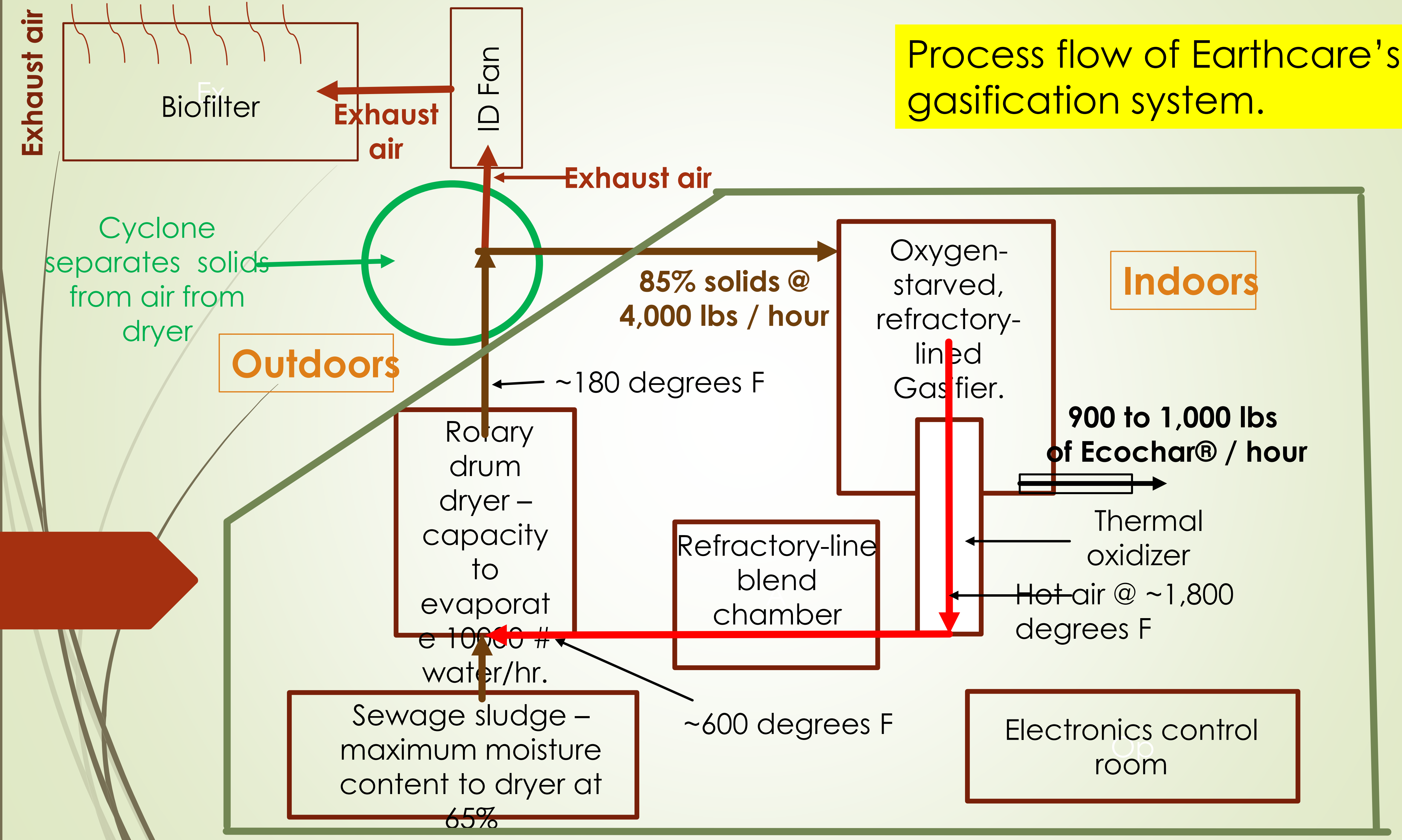
WDG plant in Nebraska

Coaltec Gasifier



Process flow of Earthcare's gasification system.



Biochar has been used for many years as a soil amendment.

But it is Much More than that.

FINAL THOUGHTS…

The integration of carbon production with waste management that can be beneficially reused to eliminate harmful and pervasive toxic pollutants, such as nutrients, pathogens and PFAS, promises a new carbon era supporting circular economies and a resilient planet.

The biomass waste stream is most abundant worldwide. Current disposal practices are GHG heavy (e.g. incineration) and/or pose adverse impacts to food, water, ecosystems and public health.

This represents threats to environment and human health along with tremendous economic losses.

A more profitable and resilient approach is the thermal conversion of waste biomasses to produce renewable fuels and eco-friendly biochars, which have yet to realize their true potential in the global, multi-commodity carbon market .

THE INGENUITY OF BIOCHAR & RELATED TECHNOLOGIES FOR EMERGING TOXICS, SOIL & WATER HEALTH, CLIMATE RESILIENCY & CIRCULAR ECONOMIES

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MICHAEL MCGOLDEN, PRESIDENT & CEO, ECOCHAR, LLC

QUESTIONS?