Going Full Circle: Biochars from Ag Waste as Adsorbents for Environmental Remediation

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Using Carbon to Achieve Chesapeake Bay (and Watershed Water Quality Goals and Climate Resiliency: The Science, Gaps, Implementation Activities and Opportunities

Agriculture Residues - The Driving Force

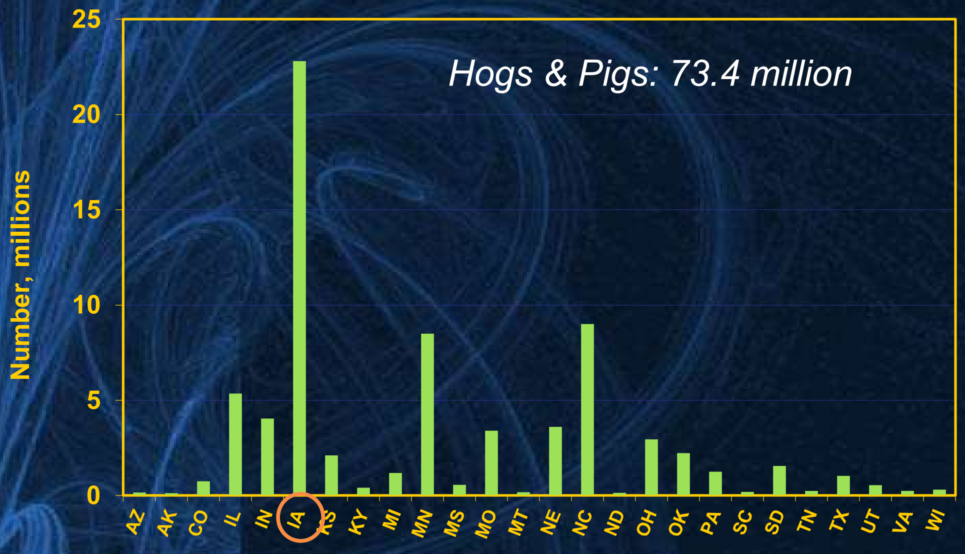
- *How much* is animal agriculture leaving behind?
  - Poultry, swine and cattle produce over 5 times the waste of the U.S. human population
  - ~ 175 million tons of manure produced each year
  - 129, 176 M DMT available from forestry & agriculture for bioenergy & bio-products

The leftovers of our Agriculture…

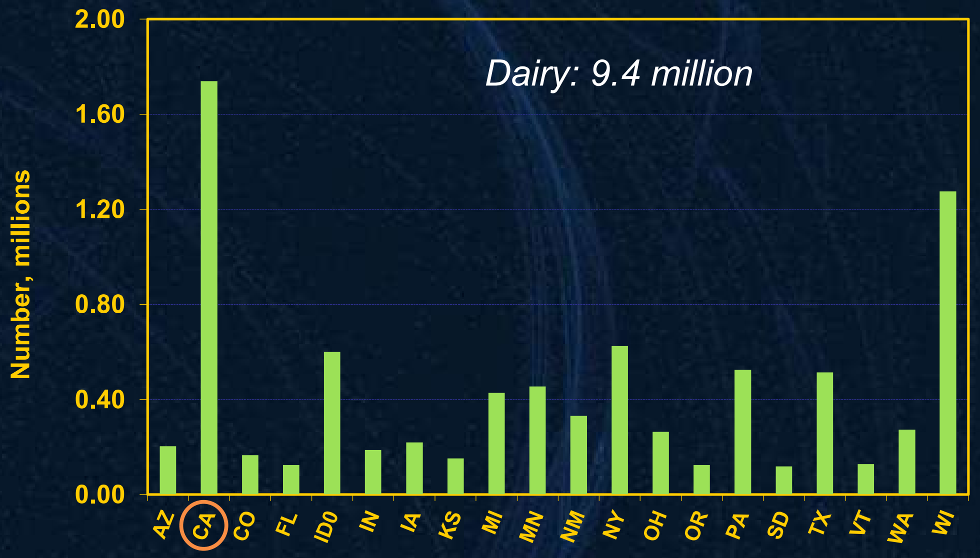
- Out of 3.6 million miles of rivers and streams in the U.S., farming impairs water quality to some degree
- Excess nutrients from fertilizing lawns, gardens, and farms, pollution from urban sources, wastewater, septic systems, and stormwater runoff all contribute to the Chesapeake Bay pollution
- Increase in public and regulatory concern from the impact of animal waste on quality of life and the environment

Production by States

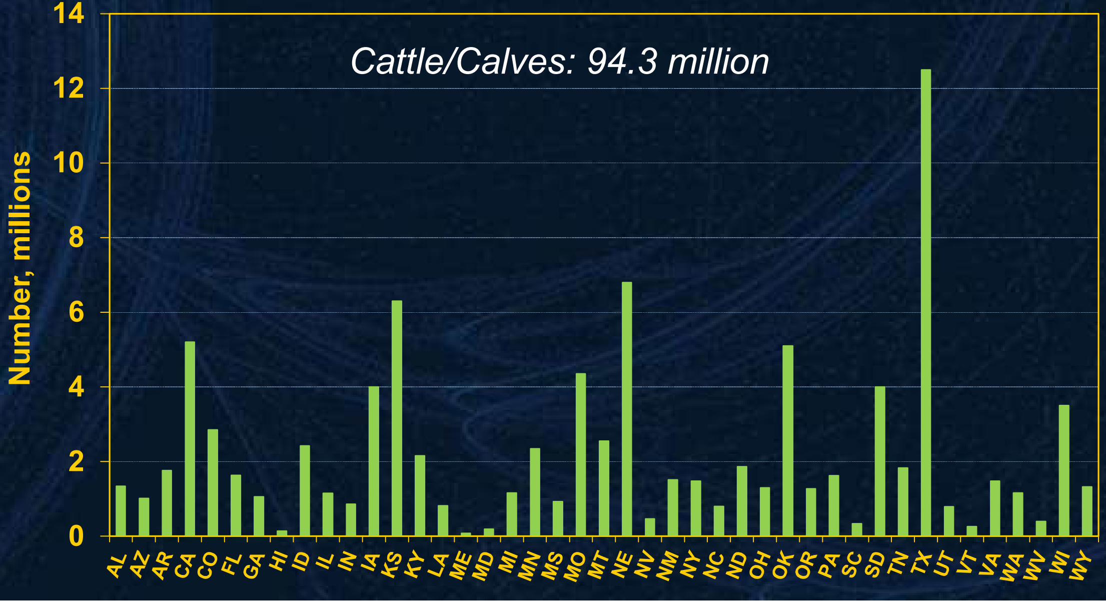
2017-18



Hogs & Pigs: 73.4 million



Dairy: 9.4 million

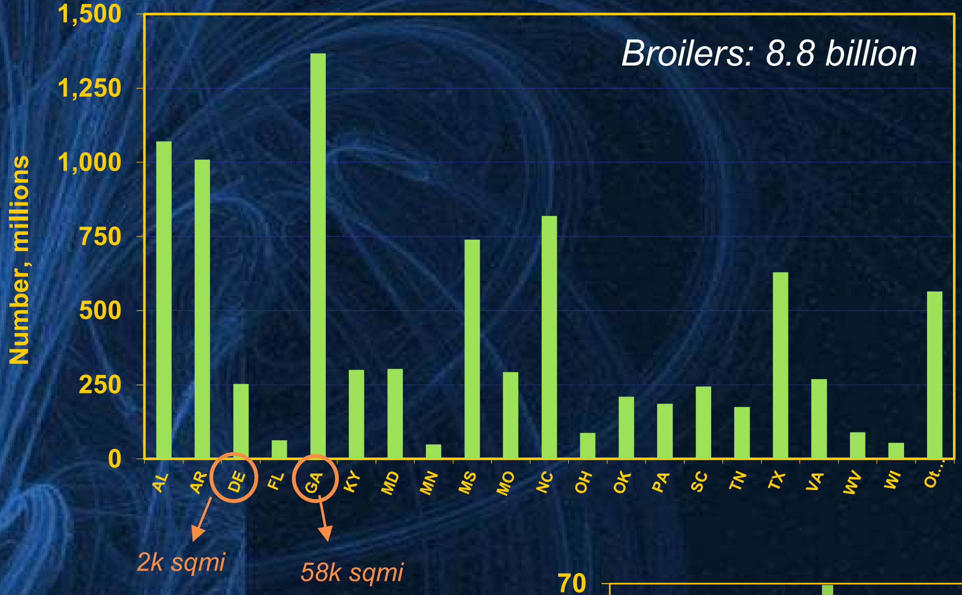


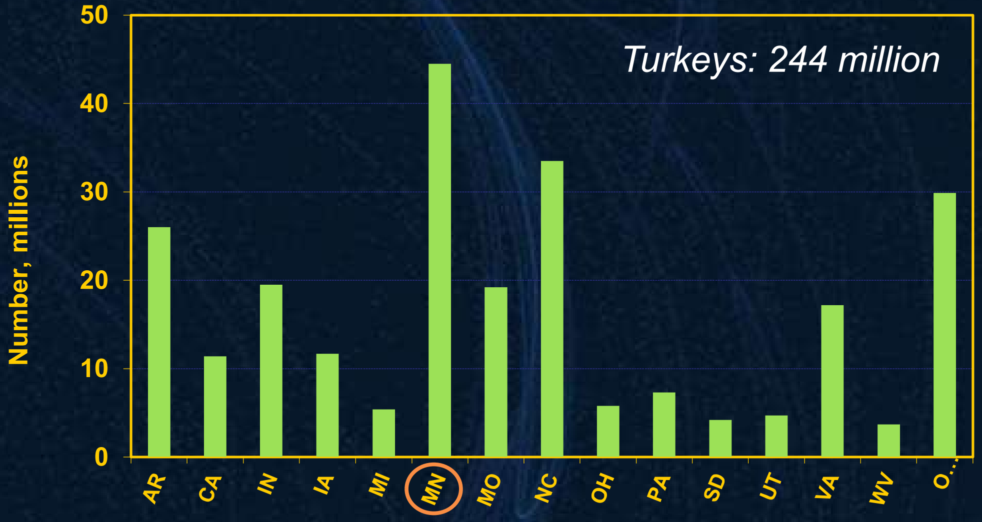
Cattle/Calves: 94.3 million

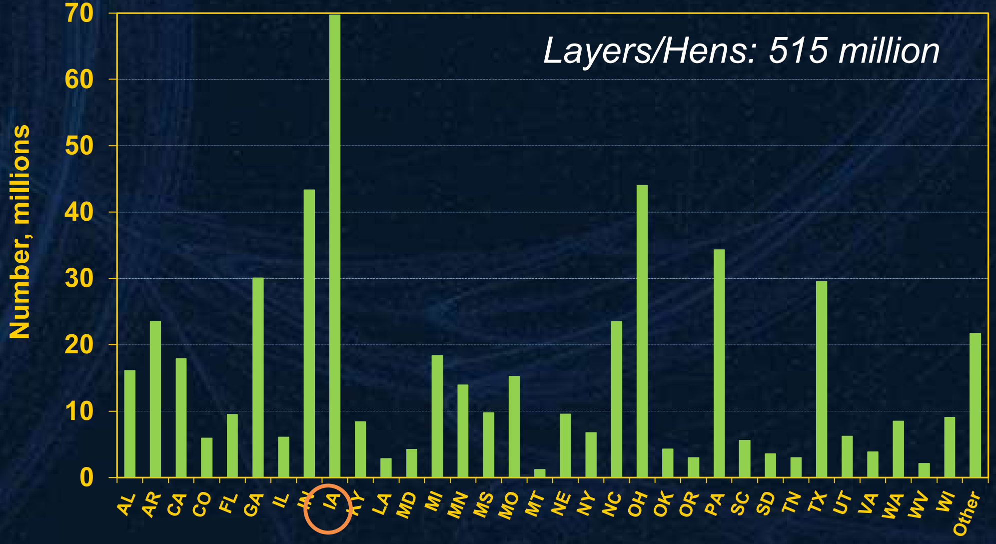
USDA, National Agricultural Statistics Service

Production by States

2017-18

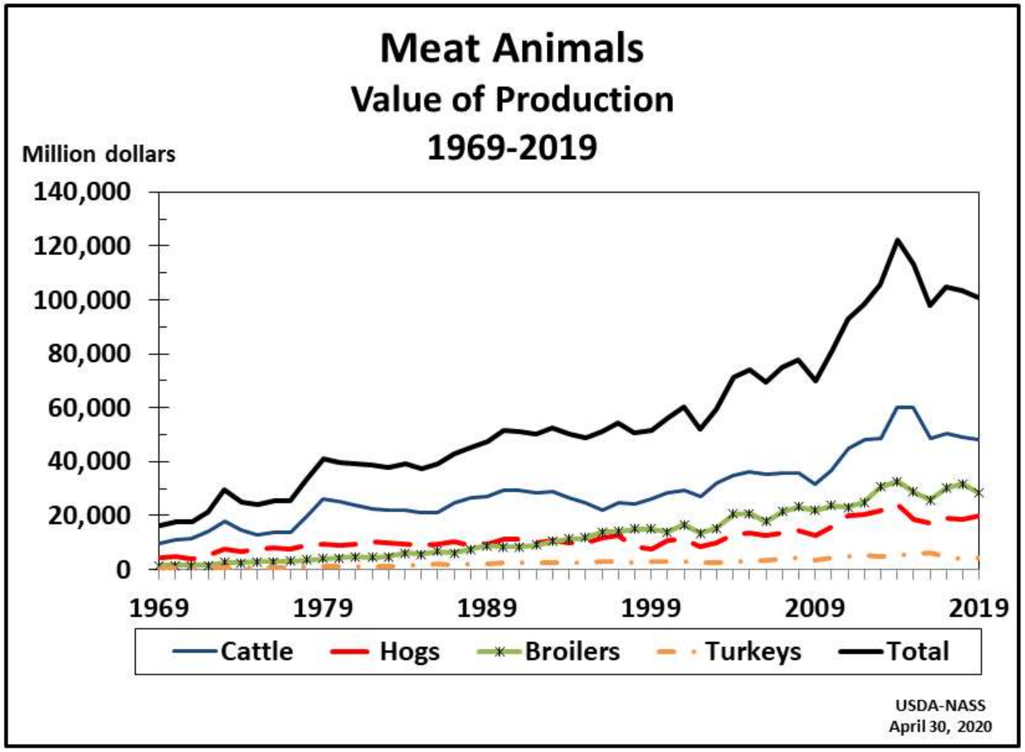


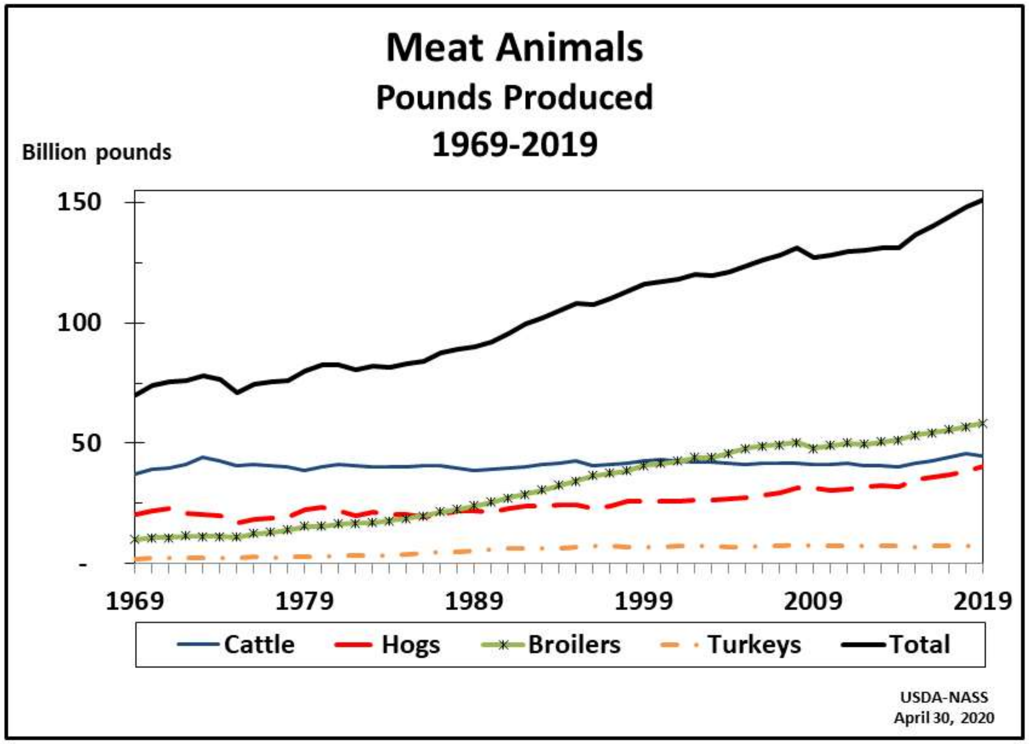




USDA, National Agricultural Statistics Service

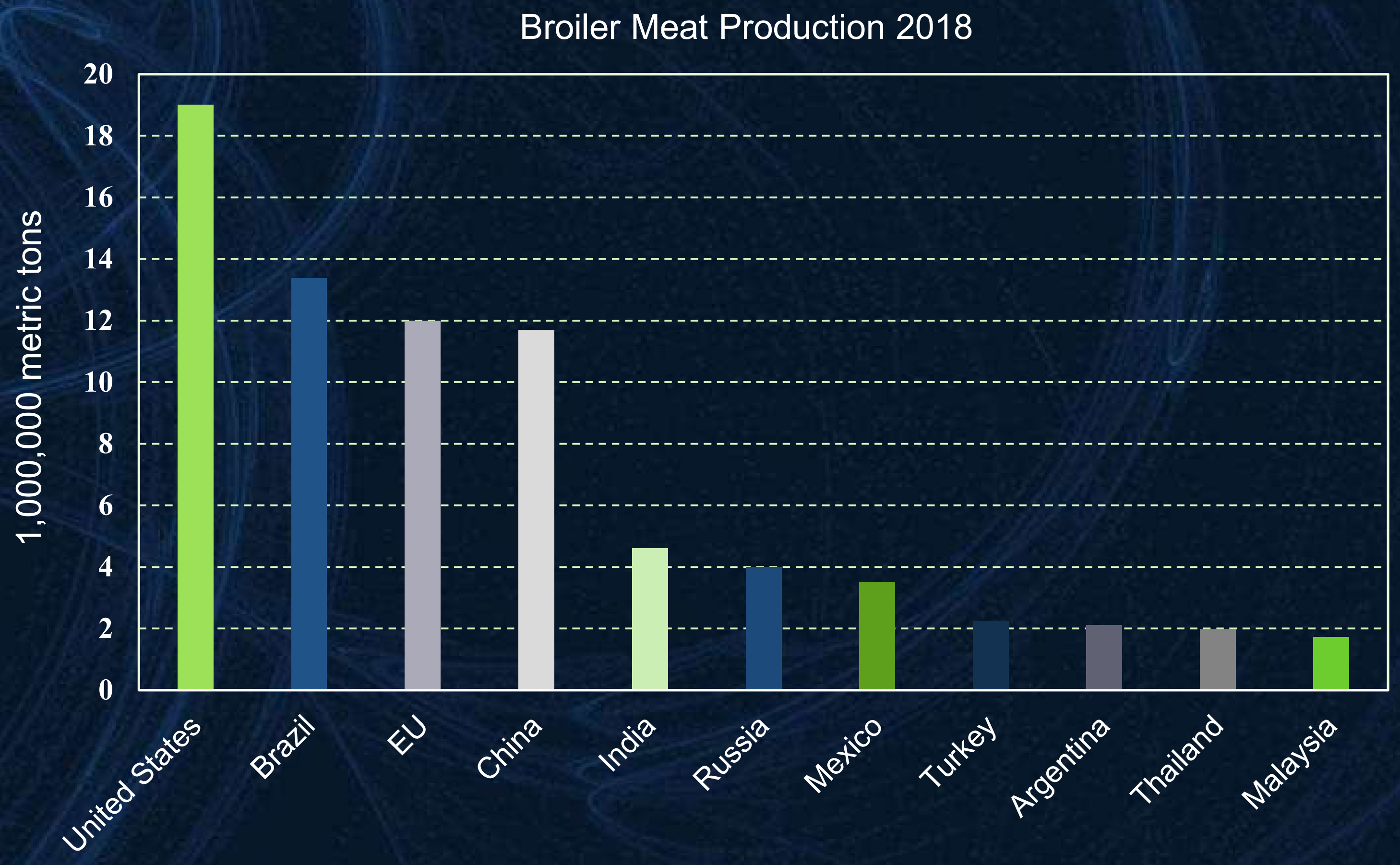
Meat Animals: Production & Value by Year, US





U.S. No1 Poultry Meat producer

World Total (2018): 92.5 M tons



Source: NASS 2018, Livestock branch

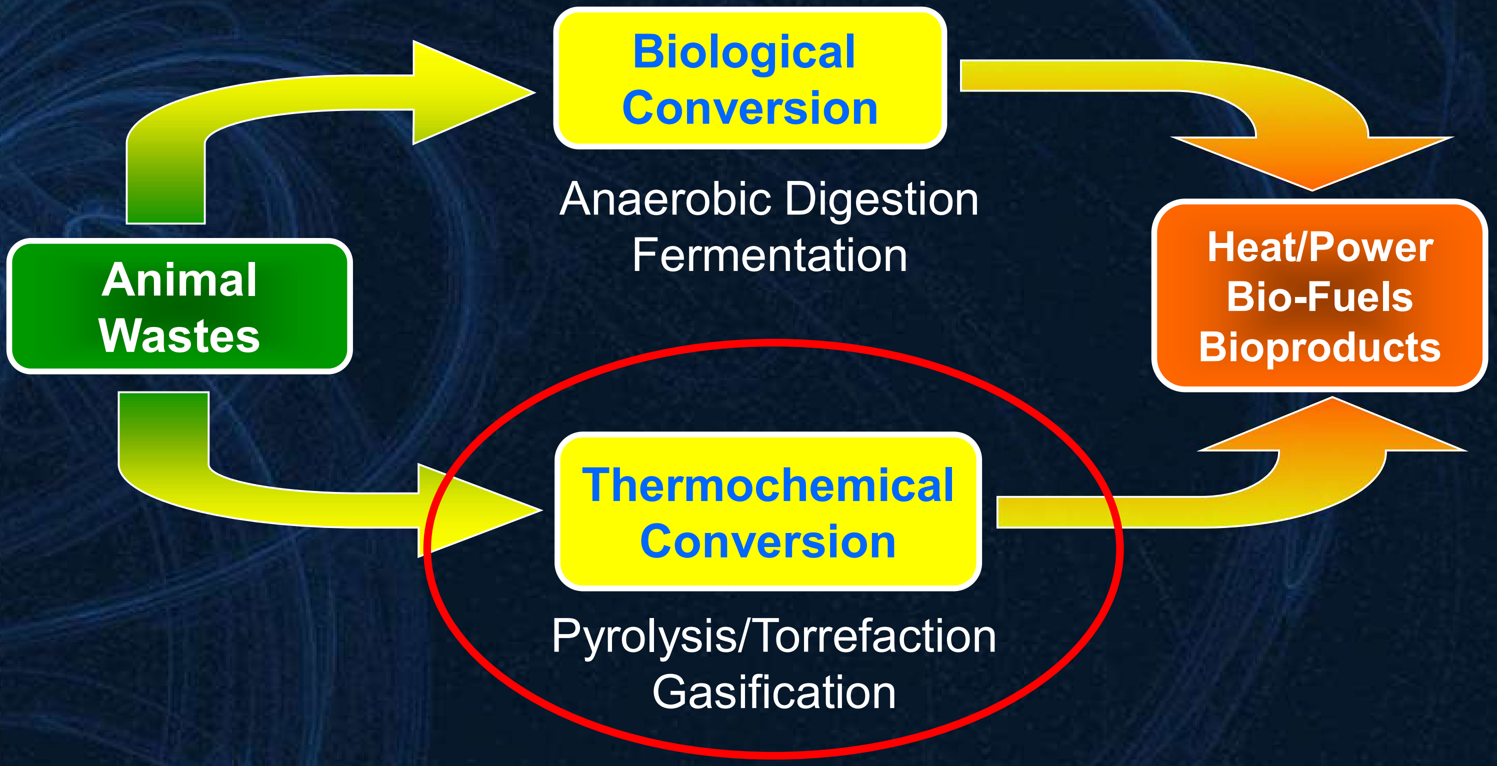
Agricultural Residuals

- Plentiful, cheap and renewable resources
- Contain intrinsic properties
- Land not an issue
- Liability to animal farmers and growers

Adding ⬇ *Value*

- Adding value by transforming agricultural residuals into biochars
- Help protect the environment and public health
- Solve a waste disposal problem

Energy Conversion Pathways



Animal Wastes

Biological Conversion

Anaerobic Digestion
Fermentation

Thermochemical Conversion

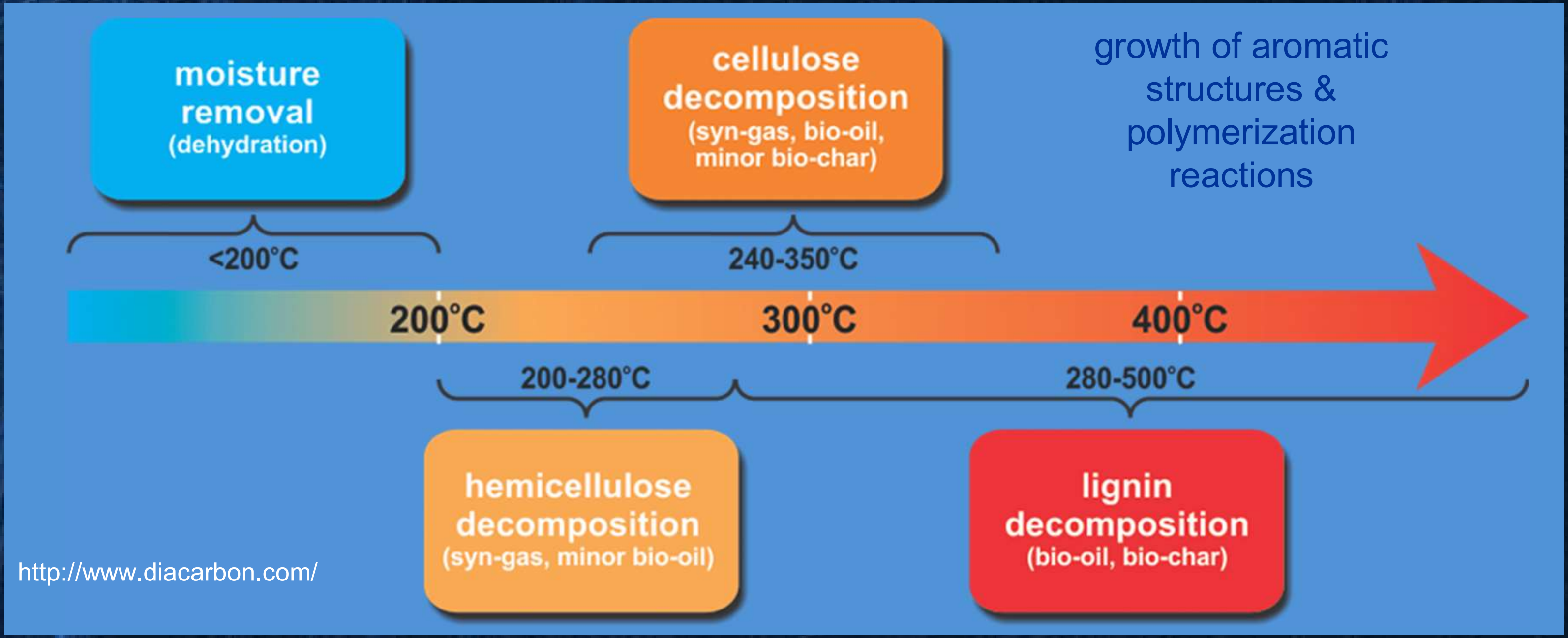
Pyrolysis/Torrefaction
Gasification

Heat/Power
Bio-Fuels
Bioproducts

- Thermal decomposition of feedstock: growth of aromatic structures and polymerization reactions
- Pyrolysis (pyro = heat, lysis = breaking apart), fast or slow pyrolysis
- Gasification (conversion of solid into gas), dry or wet gasification
- Combustion (burning of gas with O_2 to make H_2O and CO_2)

Pyrolysis

- Carbonization: C enrichment, porosity development as VM is removed
- Used as amendment to improve soil properties or sorbent for environmental stressors
- Biochar properties and application depend on feedstock and processing conditions



http://www.diacarbon.com/

- High heating rates > 200°C/s
- Endothermic reaction
- Maximize bio-oil production

← Slow

Fast →

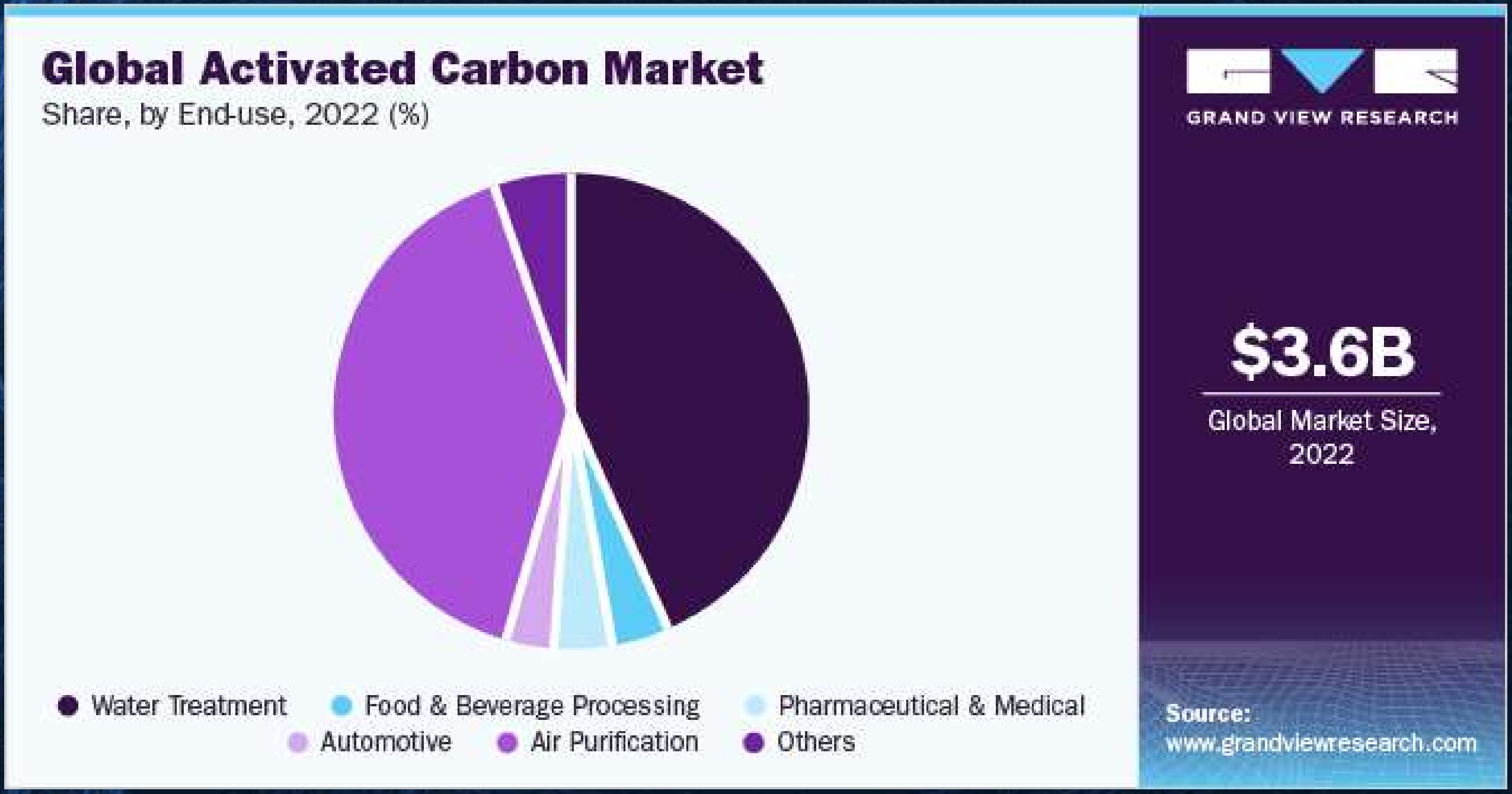
- Low heating rates, 0.01 to 2°C/s
- Exothermic reaction
- Maximize biochar production

Activated Carbon Market

- Common feedstock is coal, coconut shell, wood or peat.
- U.S. AC market estimated at 472,000 tons for 2022
- Global AC market estimated at 3 million tons, is predicted to double by 2030
- Total global market size valued at USD $3.62 billion for 2022
- Compound Annual Growth Rate of 2.6%
- There are no carbons with good metals adsorbing properties
- High-quality activated carbons are commonly expensive

Activated Carbon Market Size & Trends Analysis Report, 2030 (grandviewresearch.com)

Activated Carbon Market



Applications range from water treatment, air purification, food & beverage processing, medical & pharmaceuticals production, automotive emission canisters, etc.

U.S. Activated Carbon History

- Carbon in use for 1000’s of years; impetus for large growth has been wartime uses with biggest launch of peace time use in the 70’s – enactment of environmental legislation – CAA, CWA, superfund
- Some growth since then with applications in water & waste treatment, remediation, pollution control & chemical operations
- Chinese sourced carbons in 90’s led to severe drop in market, reversed with tariff protection
- Exponential growth expected through legislation leading to new water-air pollution laws, limitations on released contaminant levels and new applications

Biochar Making

feedstock

10-20
%wb

Cross beater Mill

< 1 mm

Pellet Mill

3/16" dia
pellets

N_2

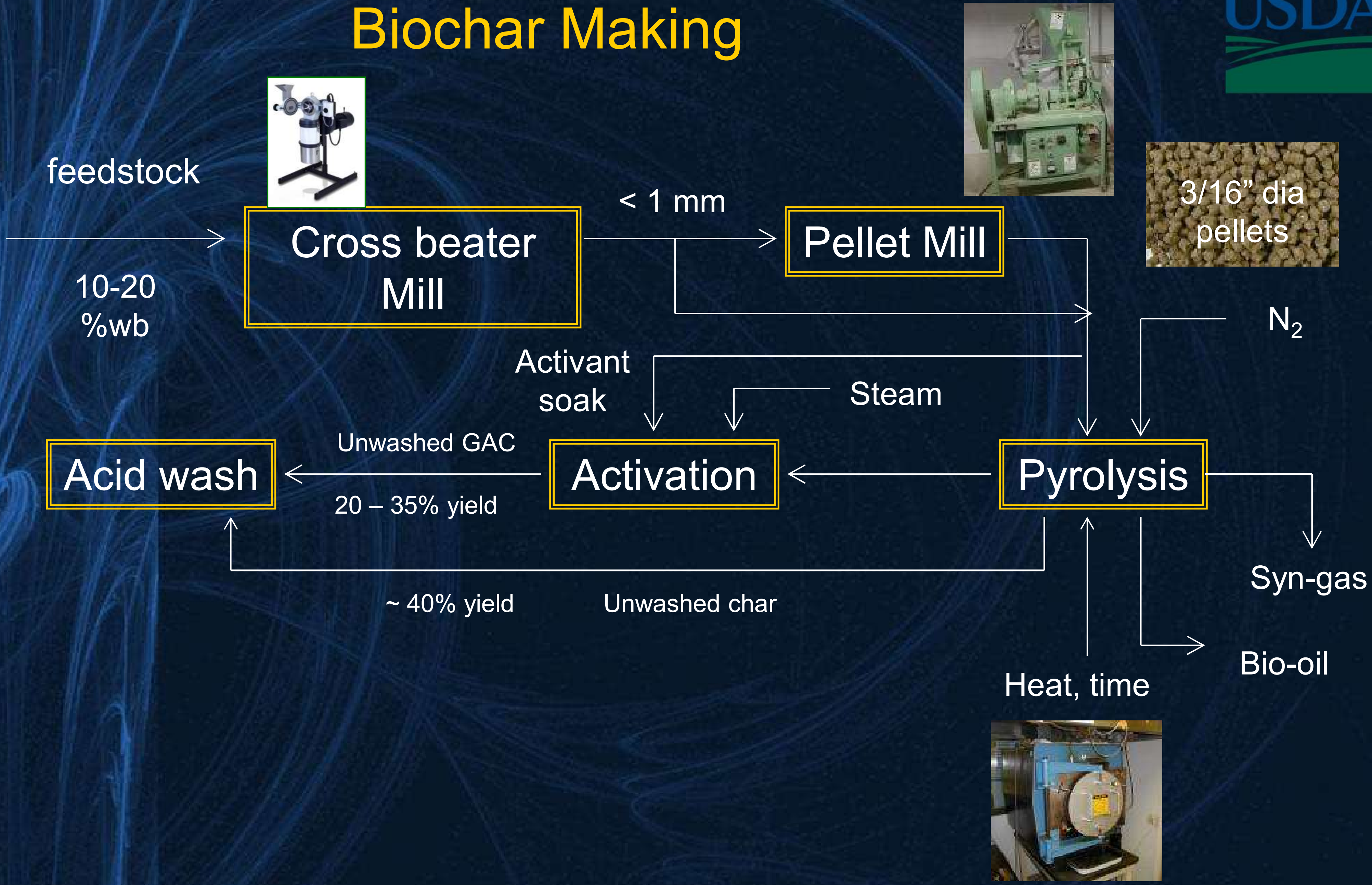
Pyrolysis

Syn-gas

Bio-oil

Heat, time

Biochar Making



feedstock

10-20 %wb

Cross beater Mill

< 1 mm

Pellet Mill

3/16" dia pellets

N_2

Activant soak

Steam

Acid wash

Unwashed GAC

20 – 35% yield

Activation

Pyrolysis

Syn-gas

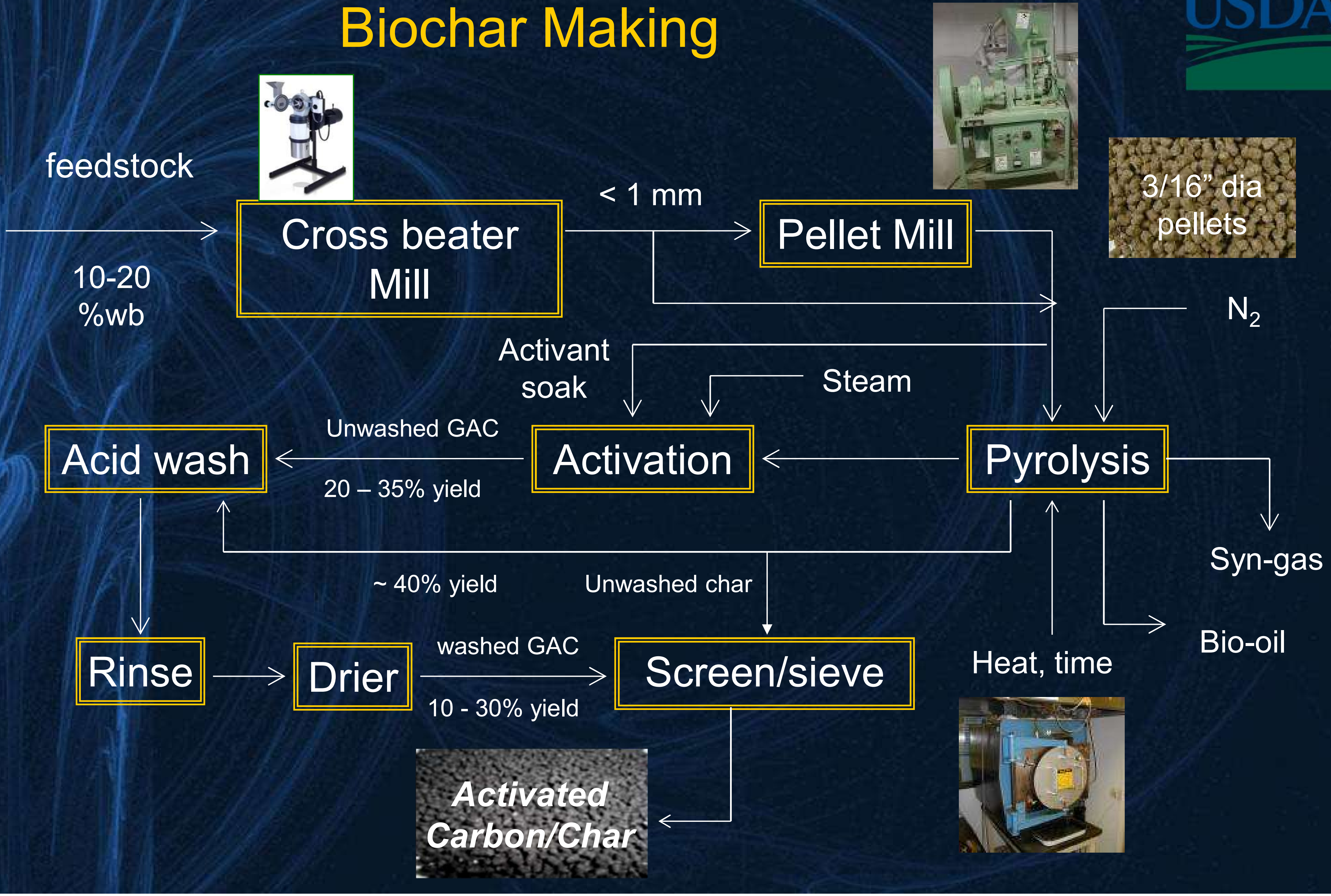
~ 40% yield

Unwashed char

Bio-oil

Heat, time

Biochar Making



feedstock

10-20 %wb

Cross beater Mill

< 1 mm

Pellet Mill

3/16” dia pellets

N_2

Activant soak

Steam

Acid wash

Unwashed GAC

20 – 35% yield

Activation

Pyrolysis

Syn-gas

~ 40% yield

Unwashed char

Bio-oil

Heat, time

Rinse

Drier

washed GAC

10 - 30% yield

Screen/sieve

Activated Carbon/Char

Pellet Mill

Pelletized Manure

Furnace

Biochar/Activated Biochar Characterization

- Physical properties
  - Carbon yields, surface area, attrition resistance, bulk density, particle size distribution, SEM characterization

- Chemical properties
  - Total surface charge, pH, compositional analysis, ash content, X-ray analysis, NMR
- Adsorptive properties
  - Adsorption isotherms, kinetic studies, batch/column, multiple adsorbates/compounds

Comparison with other carbons

Sample	Sample Description
Our carbons	**Made from pelletized manure, steam activated under N_2**
Coal, coconut shell or wood based	Made from pelletized coal, ground coconut shells/sawdust, steam activated under N_2
PUR RF	Replacement Filter, coal derived, 10x20 mesh, originally in block form
Calgon F300	Filtrasorb 300, GAC by Calgon Carbon for removal of organic pollutants from munic/indust wastewaters. Made from bituminous coal
Norit Darco Hg	Powdered (<45 µm) activated carbon made from lignite coal

Biochar Physical Properties

700C Sample	IY %	FY %	Attrition %	BD g/cm^3	BET, m^2/g	PM %
Broiler cake	40	30	15.1	0.54	318	88
Broiler litter	41	34	14.4	0.60	238	90
Turkey cake	41	33	10.7	0.53	147	93
Turkey litter	42	35	9.2	0.57	179	93
Swine	38	31	21.3	0.59	92	40
Dairy	48	37	29.7	0.56	131	75
Coal	78	61	34.1	0.42	4	-
Coconut shell	28	28	20.5	0.61	35	24
Wood	25	24	23.4	0.38	301	93

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

Biochar Physical Properties

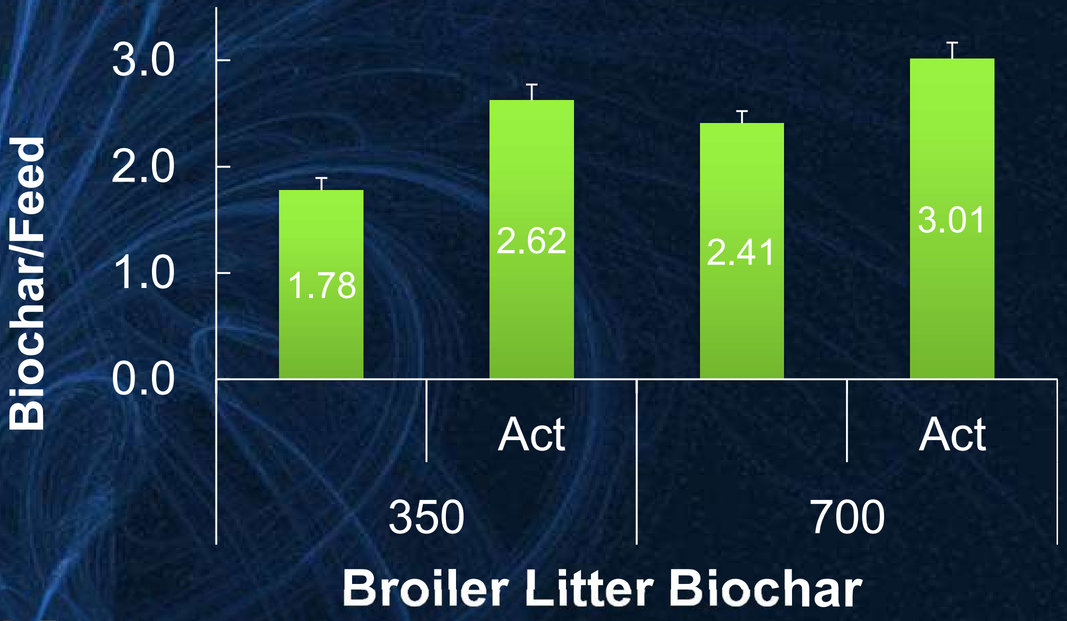
700C Sample	pH	% Ash	% C	% H	% N	% S	C, af
Broiler cake	8.6	45.2	43.9	1.02	2.84	0.35	80
Broiler litter	8.1	49.2					
Turkey cake	9.2	40.4	39.9	1.05	3.43	0.37	67
Turkey litter	8.1	43.5					
Swine	6.8	56.9	31.4	0.33	1.80	0.01	73
Dairy	7.2	71.0	25.2	0.15	1.08	0.00	87
Coal	4.2	2.5	86.8	1.08	1.85	0.06	89
Coconut shell	6.6	1.8	82.1	1.33	0.19	0.09	84
Wood	5.1	1.4	85.1	1.76	0.31	0.22	86

C, af: carbon content (%), ash free basis.

Activated Biochar Physical Properties

	Yield %	Surface Area m^2 / g	Attrition %	pH
Broiler Litter	22.7	441	17.9	7.9
Broiler Cake	11.0	395	24.0	8.2
Turkey Litter	21.1	414	20.0	8.0
Turkey Cake	16.4	394	25.8	8.1
Swine	17.0	419	20.6	6.9
Dairy	26.8	318	22.1	9.0
PUR RF	-	474	32.0	6.4
Coal	70.0	0	13.8	4.9
Coconut Shell	22.7	843	22.3	3.1
Wood	17.9	849	15.6	2.9

Element Enrichment

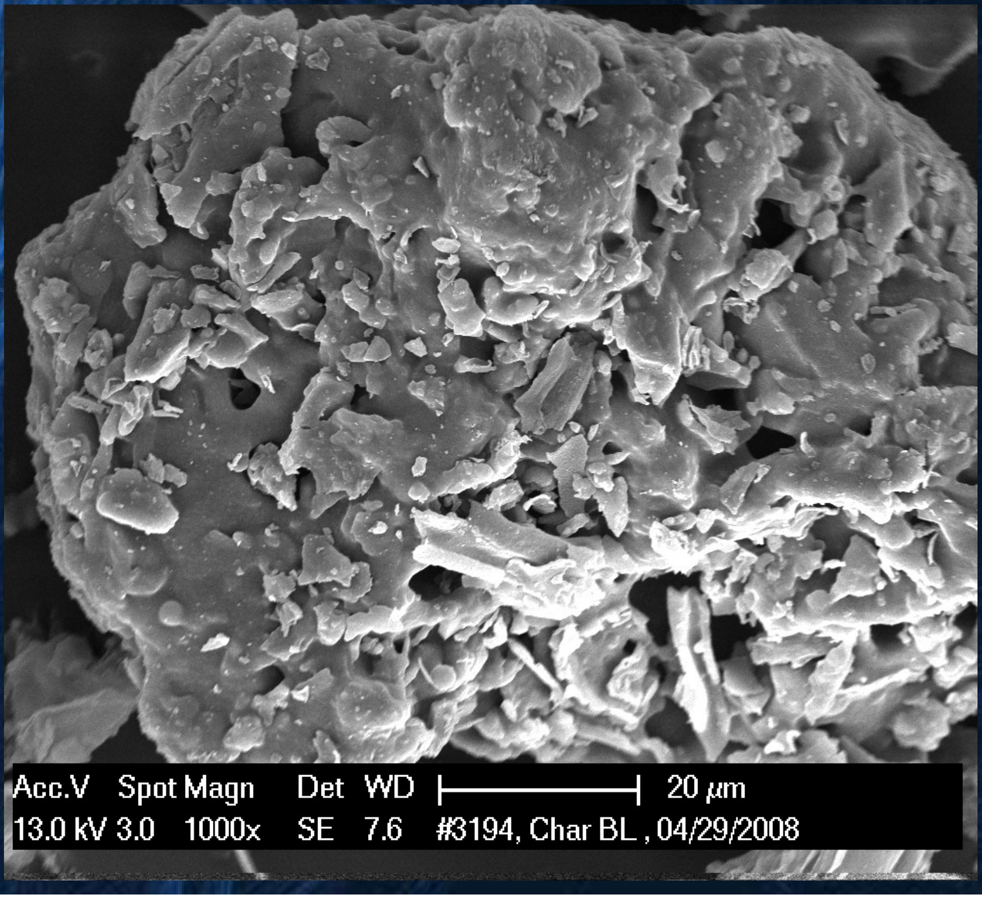


Pyrolysis	T (ºC)	C	N	O
		----- *% wt* -------		
Broiler Litter	-	38	3.4	40
Slow	350	42	3.8	24
		34	**1.8**	**19**
	700	39	2.3	19
		32	**1.3**	**23**
Fast	450	22	1.9	31
		14	**0.6**	**30**

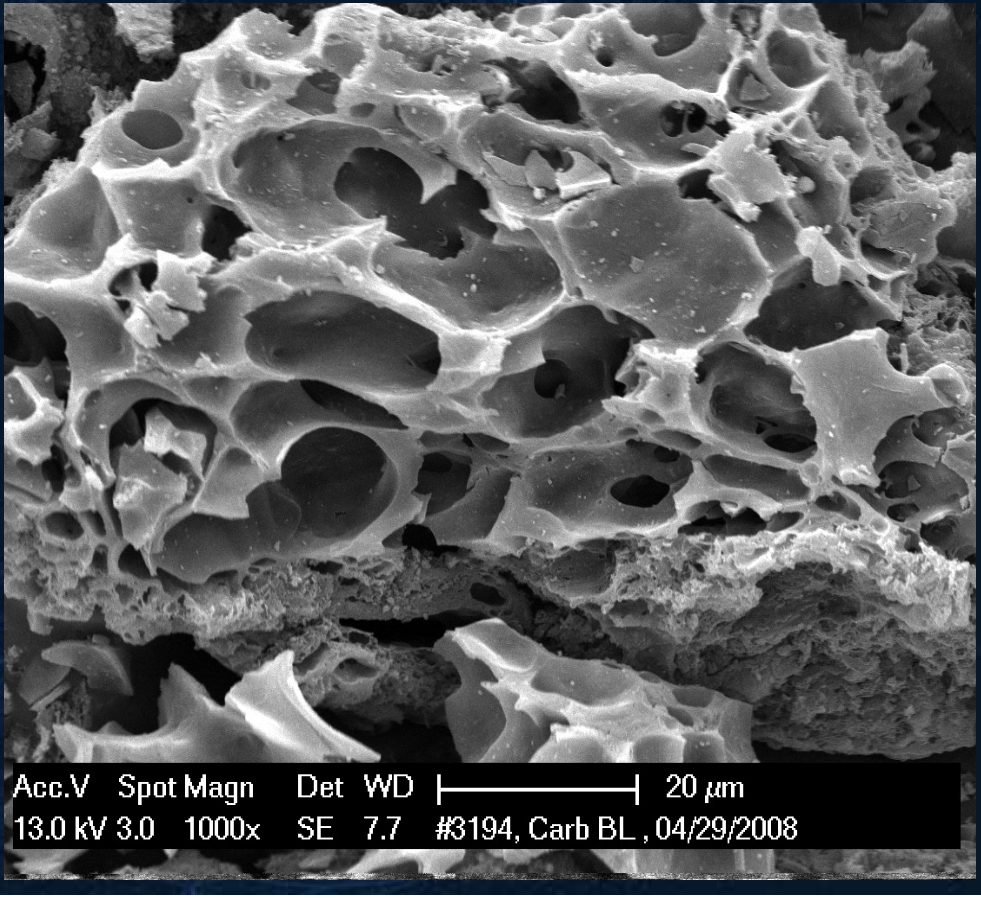
Bold numbers in rows indicate activated biochar

Broiler Litter Micrographs

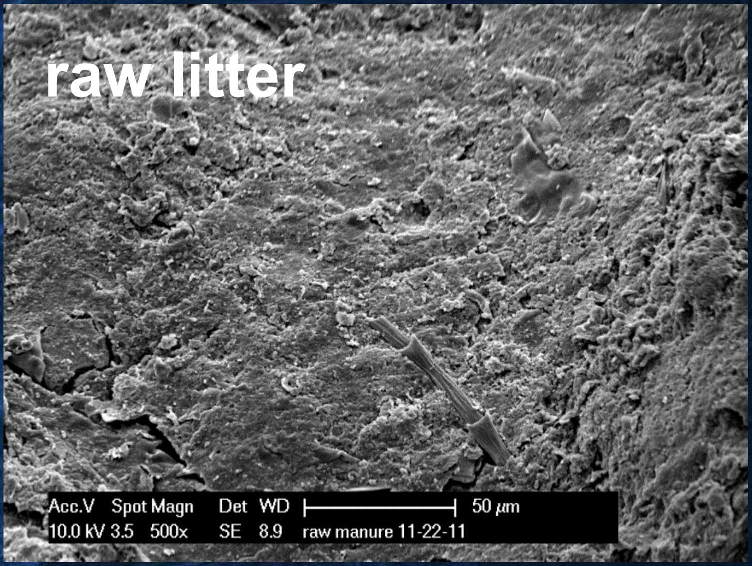
Biochar



Activated Biochar



Broiler Litter Micrographs

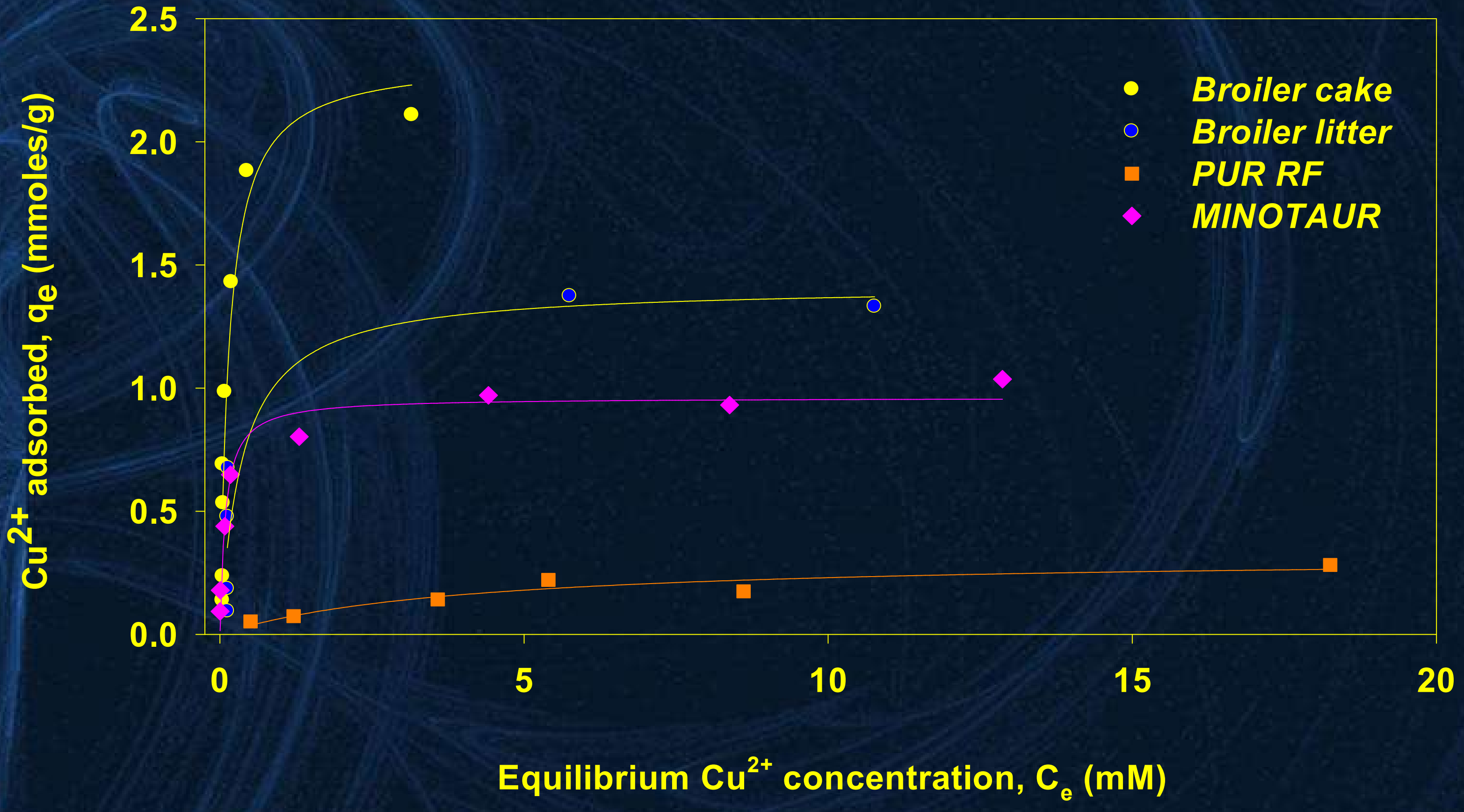

raw litter


unwashed


rinsed


washed

Adsorption Isotherms



0.25 g carbon placed in 25 ml solutions of $CuCl_2.2H_2O$ at 1, 2, 5, 7, 10, 15, 20, and 25 mM for 24 hr.

Activated Biochar Metal Ion Adsorption

(mmoles/g)	Cu^{2+}	Cd^{2+}	Ni^{2+}	Zn^{2+}
Broiler Litter	1.20	1.09	0.06	1.33
Broiler Cake	1.90	1.33	0.42	1.94
Turkey Litter	1.65	1.44	0.86	1.73
Turkey Cake	1.42	1.48	1.34	1.67
Duck Manure	0.55	0.34	0.06	0.49
Swine	0.61	0.51	0.07	0.58
Dairy	0.33	0.12	0.07	0.15
PUR RF	0.28	0.15	0.00	0.15
Coal	0.08	0.30	0.05	0.04
Coconut Shell	0.29	0.02	0.04	0.06
Wood	0.26	0.00	0.02	0.14

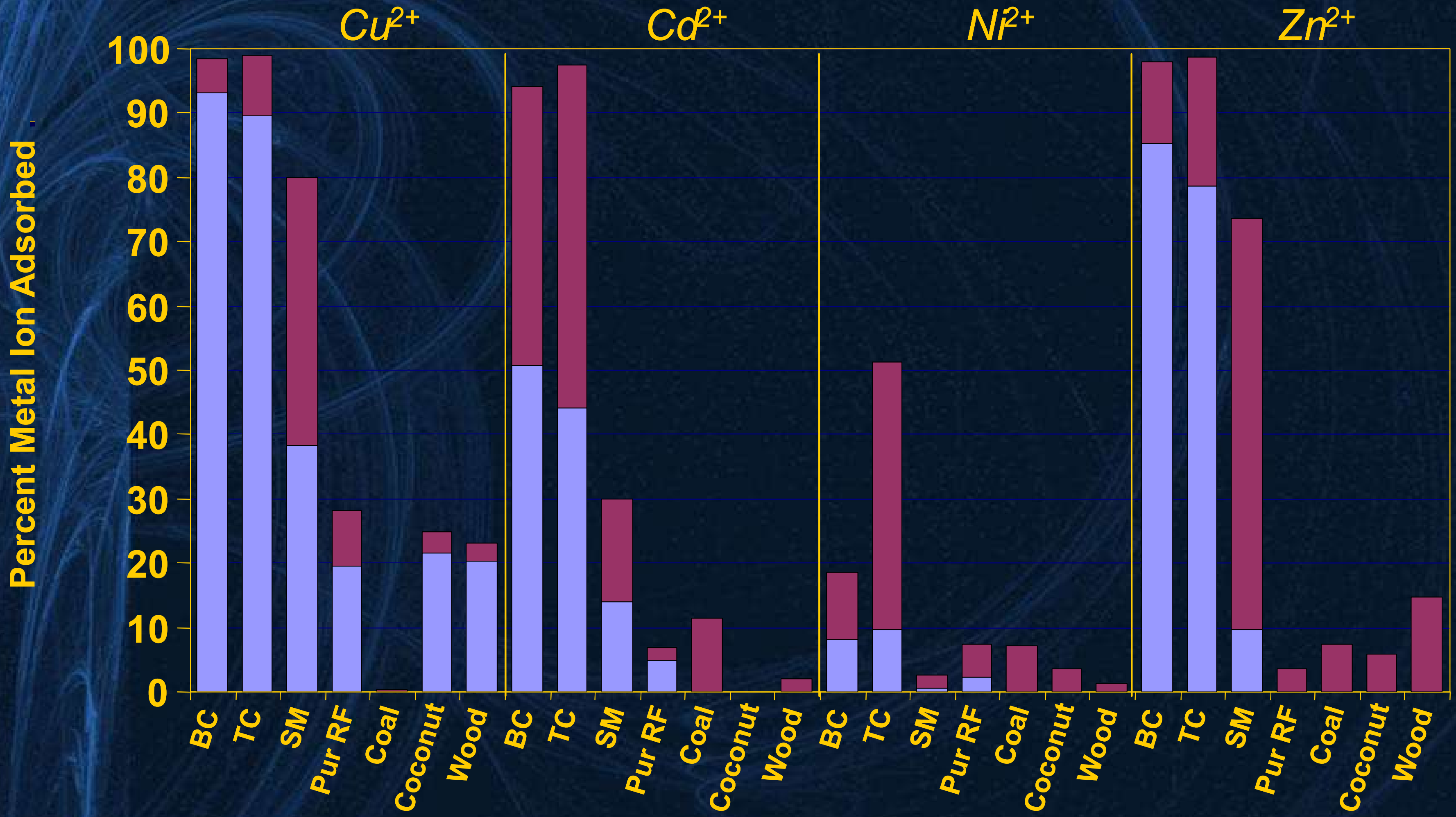
Activation Comparison

(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
BC carbon	123.8	149.8	26.5	126.5
BC char	57.8	71.9	5.9	63.1
TL carbon	110.4	161.9	32.2	113.4
TL char	38.6	69.8	9.4	47.6
TC carbon	99.0	165.9	78.7	109.3
TC char	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

EPA discharge limits

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

Competition Study – Activated Biochar



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

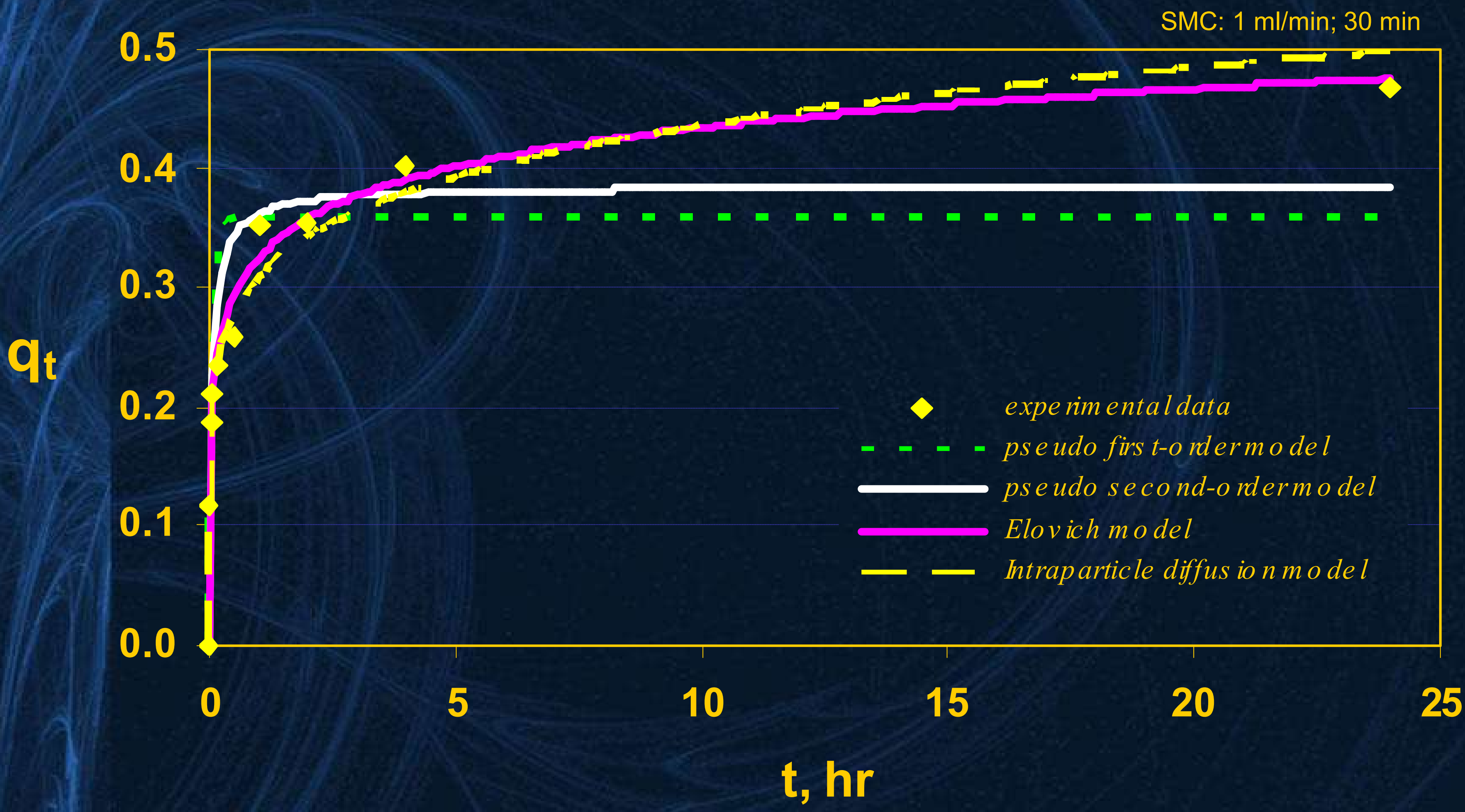
Competition Study - Biochars

	Sample	Cu^{2+}	Cd^{2+}	Ni^{2+}	Zn^{2+}
Single	Broiler cake	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 cake	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

Comparison with other Adsorbents

Sample	Activation Method	Surface area (m^2/g)	Cu^{2+} ads. (mmoles/g)
Pecan shells	Steam	894	0.29
Pecan shells	Acid/air oxid	682	1.10
Broiler cake	Steam	481	1.90
Broiler litter	Steam	377	1.20
RO 3515	Steam	920	0.27
F-400	Steam	960	0.22

Adsorption Kinetics



$$q_t = q_e\left(1 - e^{-k_1 t}\right)$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t$$

$$q_t = \frac{1}{\beta}\ln(\alpha\beta) + \frac{1}{\beta}\ln t$$

$$\log R = \log k_{id} + a \log t$$

Elemental Composition (g/100g)

Manure
Activated biochar

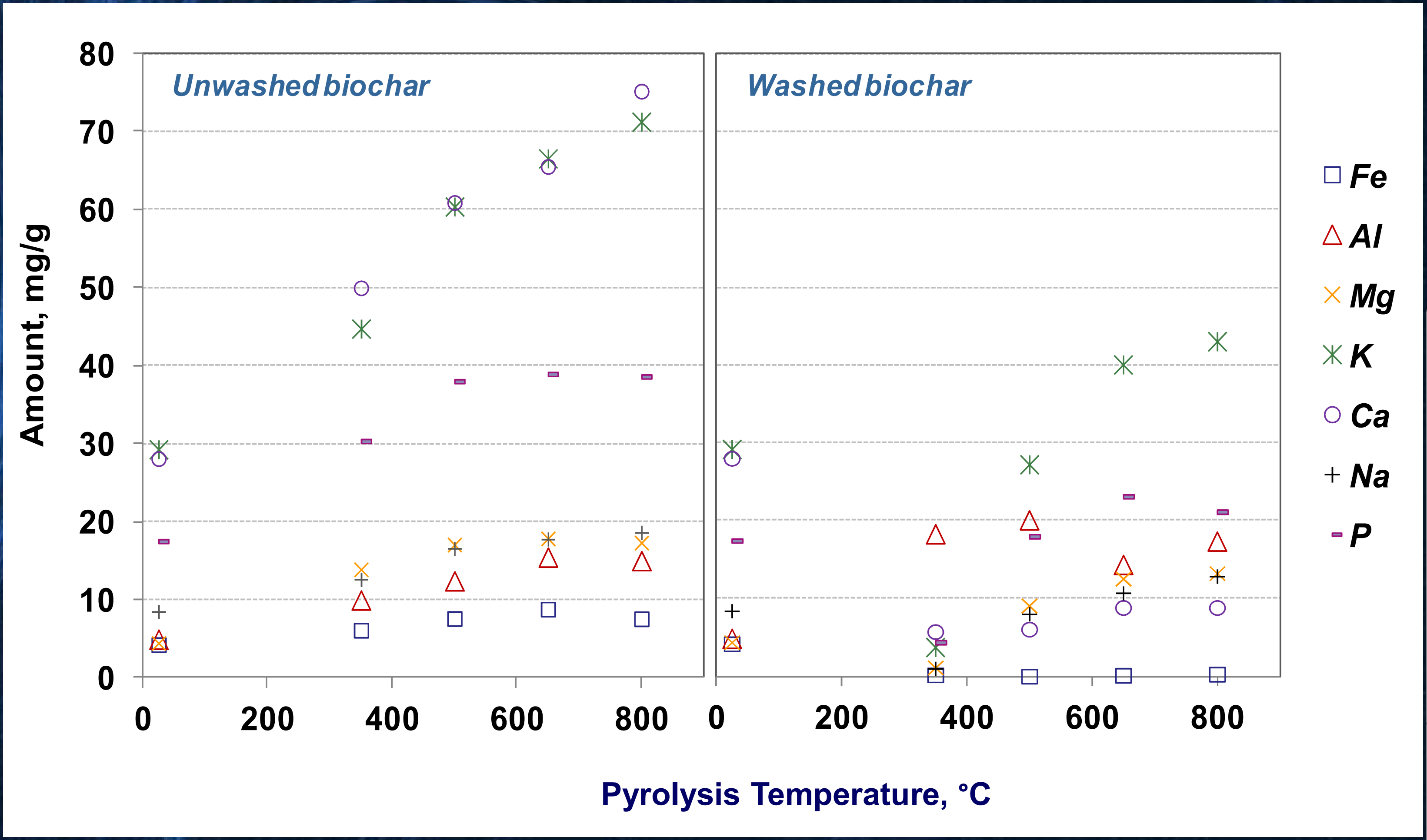
	C	N	K	S	P
Broiler Litter	**34.4**	**3.26**	**3.83**	**0.67**	**1.66**
	25.8	*0.75*	*3.00*	*0.64*	*4.80*
Broiler Cake	**32.6**	**3.62**	**5.34**	**0.83**	**1.94**
	17.2	*0.60*	*5.80*	*0.80*	*7.30*
Turkey Litter	**34.9**	**3.84**	**2.75**	**0.61**	**2.26**
	32.6	*1.12*	*4.09*	*0.93*	*7.88*
Turkey Cake	**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*

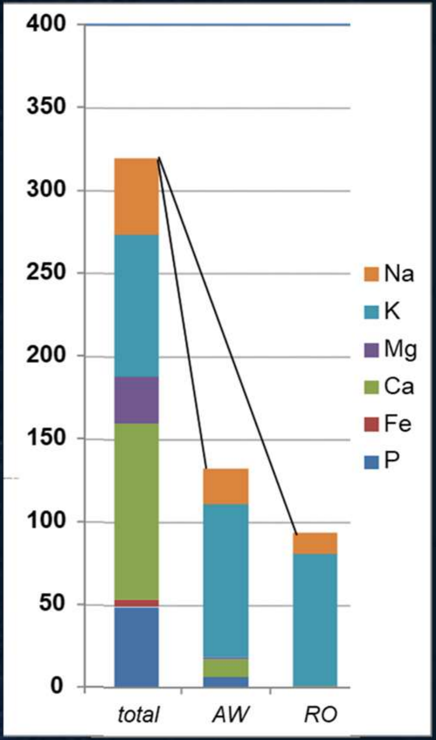
3.68

biochar

4.92

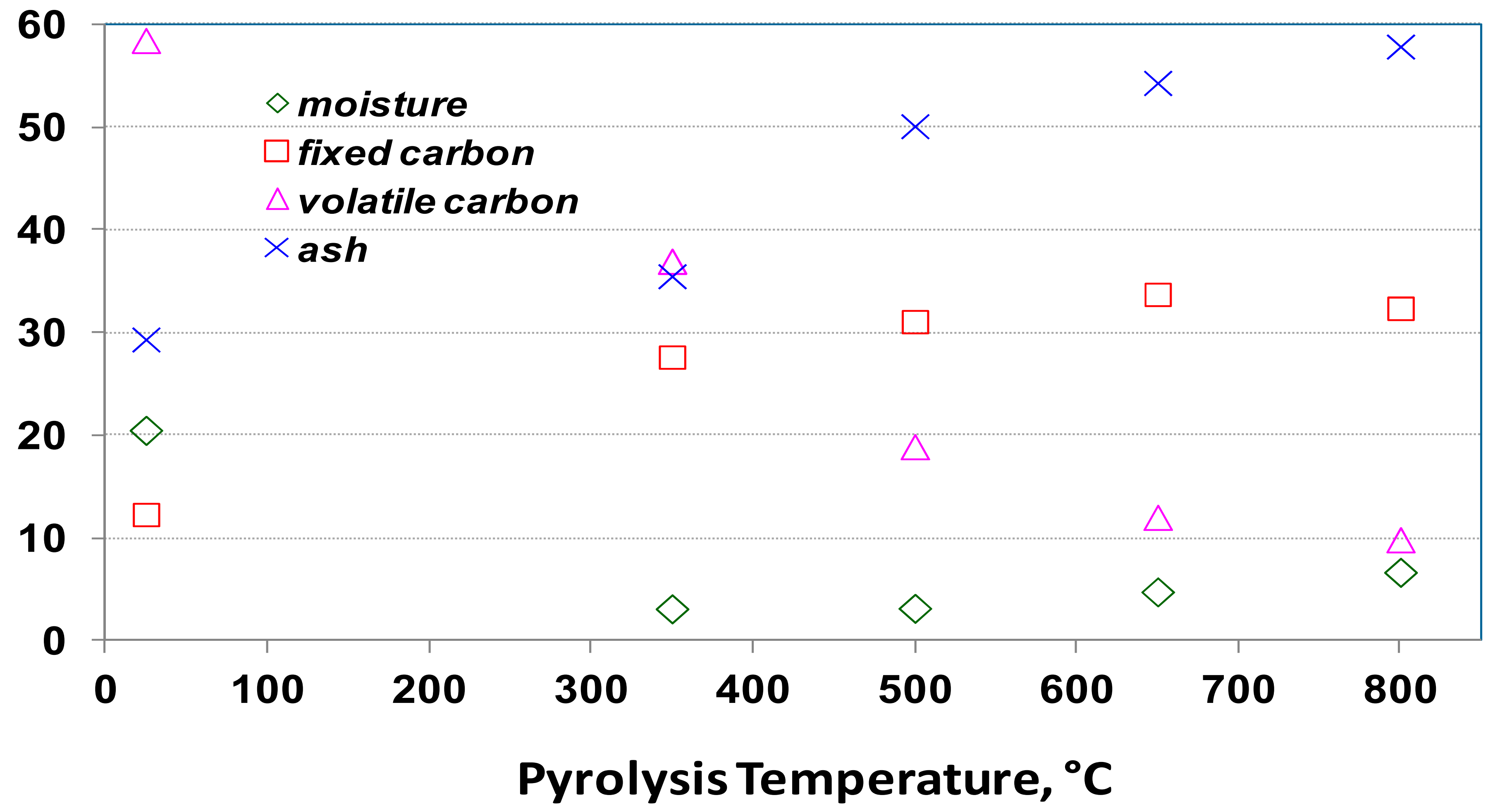
Elemental Composition Function of PT





AW and RO: amounts removed by acid washing or rinse only treatments: selective element leaching

Proximate Analysis
Effect of Temperature



Feedstock: Forest versus Ag

- Pine wood shavings, broiler litter
- Pyrolysis at 250°C and 500°C
- Steam activation at 800°C, 45 min, 3ml/min flow rate
- Acid activation at 450°C under air, 30% H_3PO_4, 1:1 ratio
- Base activation at 450°C under air, 5M KOH, 1:1 ratio
  - Biochars and steam activated Biochars not rinsed
  - Acid and base activated biochars rinsed in hot water

Feedstock: Forest versus Ag

Source	Product	Act. yield %	BET m^{2}/g	pH	Surf. charge meq H+/g
Wood shavings 250°C	Biochar		0.03	5.3	**1.57**
	Steam act	36.0	**573**	8.8	0.00
	Acid act	36.8	**851**	2.5	**3.00**
	Base act	45.8	27	6.7	0.36
Wood shavings 500°C	Biochar		0.0	5.6	0.37
	Steam act	76.7	511	8.1	0.00
	Acid act	64.9	538	2.2	**2.11**
	Base act	53.2	360	6.7	0.04
Chicken litter 250°C	Biochar		0.5	8.2	1.28
	Steam act	31.8	592	10.5	0.06
	Base act	58.6	122	-	0.70
Chicken litter 500°C	Biochar		1.6	8.7	0.22
	Steam act	68.5	420	10.9	0.00
	Base act	65.1	118	7.7	0.00

Proximate Analysis: Forest versus Ag (%)

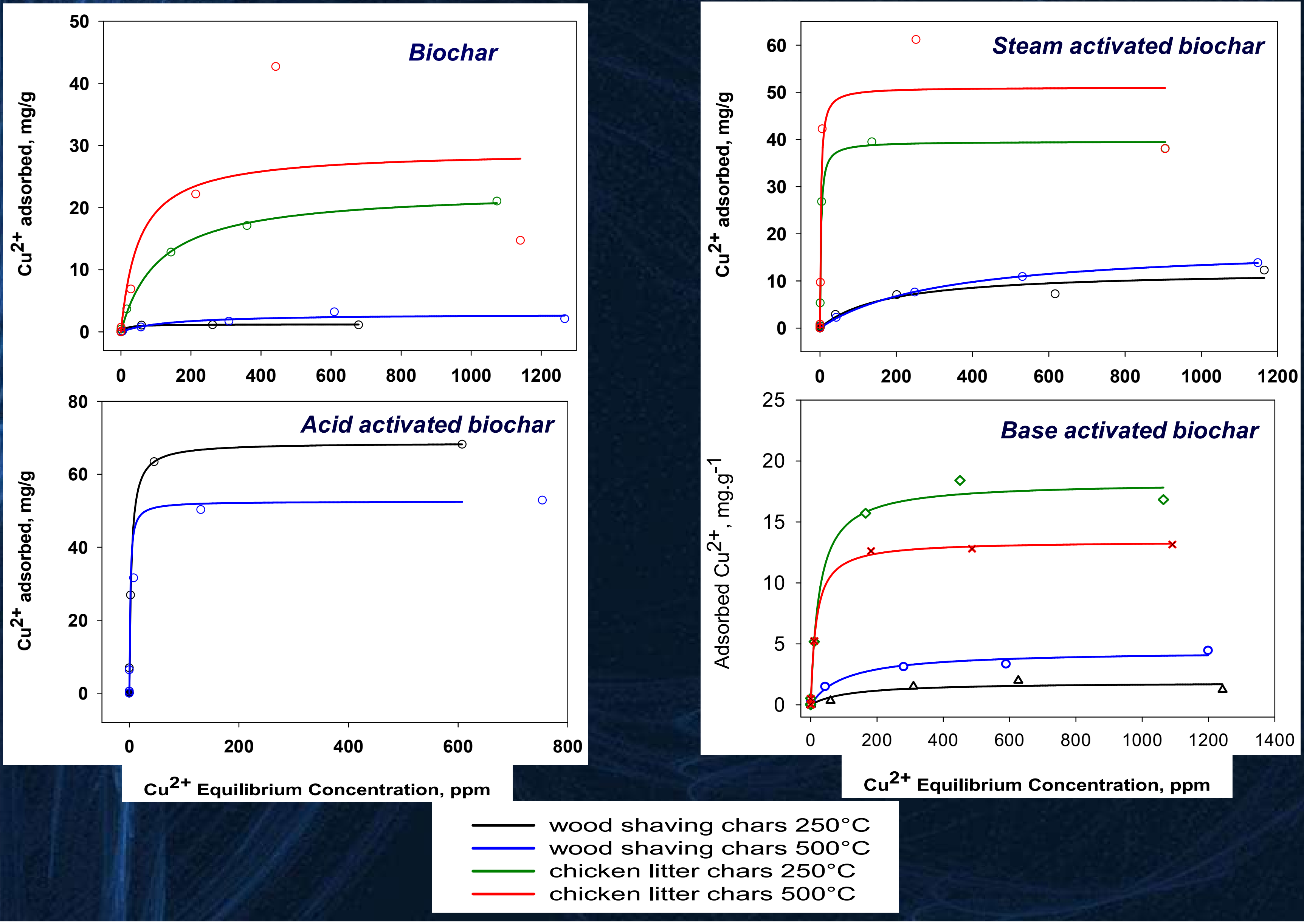
Source	Product	MC	Volatile Matter	Fixed C	Ash
raw	Feedstock	4.6 41.4	56.9 70.6	40.0 17.8	3.1 11.6
250°C	Biochar	4.0 3.6	59.1 59.5	38.3 27.0	2.6 13.5
	Steam act	1.9 1.5	6.0 7.3	88.4 44.7	5.6 48.0
	Acid act	3.1	35.8	57.8	6.4
	Base act	3.4 2.2	19.9 22.1	77.6 55.7	2.6 22.1
500°C	Biochar	7.7 4.4	14.2 21.8	80.3 38.1	5.6 40.1
	Steam act	1.6 1.1	6.3 7.0	87.1 37.8	6.6 55.2
	Acid act	2.4	30.2	62.8	7.1
	Base act	3.3 4.8	12.1 20.8	82.0 40.1	5.9 39.2

wood shavings litter

Elemental Analysis, mg/g

Source	**Product**	**P**	**Fe**	**Ca**	**Mg**	**K**
Wood shavings 250°C	Feedstock	**0.61**	2.93	4.57	2.15	4.91
	Biochar	0.32	4.72	2.57	1.57	3.87
	Steam act	1.34	4.37	7.93	4.37	12.7
	Acid act	3.76	4.03	2.23	0.71	0.36
Wood shavings 500°C	Biochar	1.55	9.66	12.0	5.06	12.1
	Steam act	1.81	6.03	14.2	5.97	17.5
	Acid act	3.61	7.45	4.16	1.56	0.22
Chicken litter 250°C	Feedstock	**16.7**	2.77	44.2	10.1	39.3
	Biochar	11.2	4.86	34.2	8.2	42.5
	Steam act	**34.9**	10.0	136	24.8	130
Chicken litter500°C	Biochar	29.5	7.89	102	18.2	95.9
	Steam act	29.5	10.6	106	19.7	117

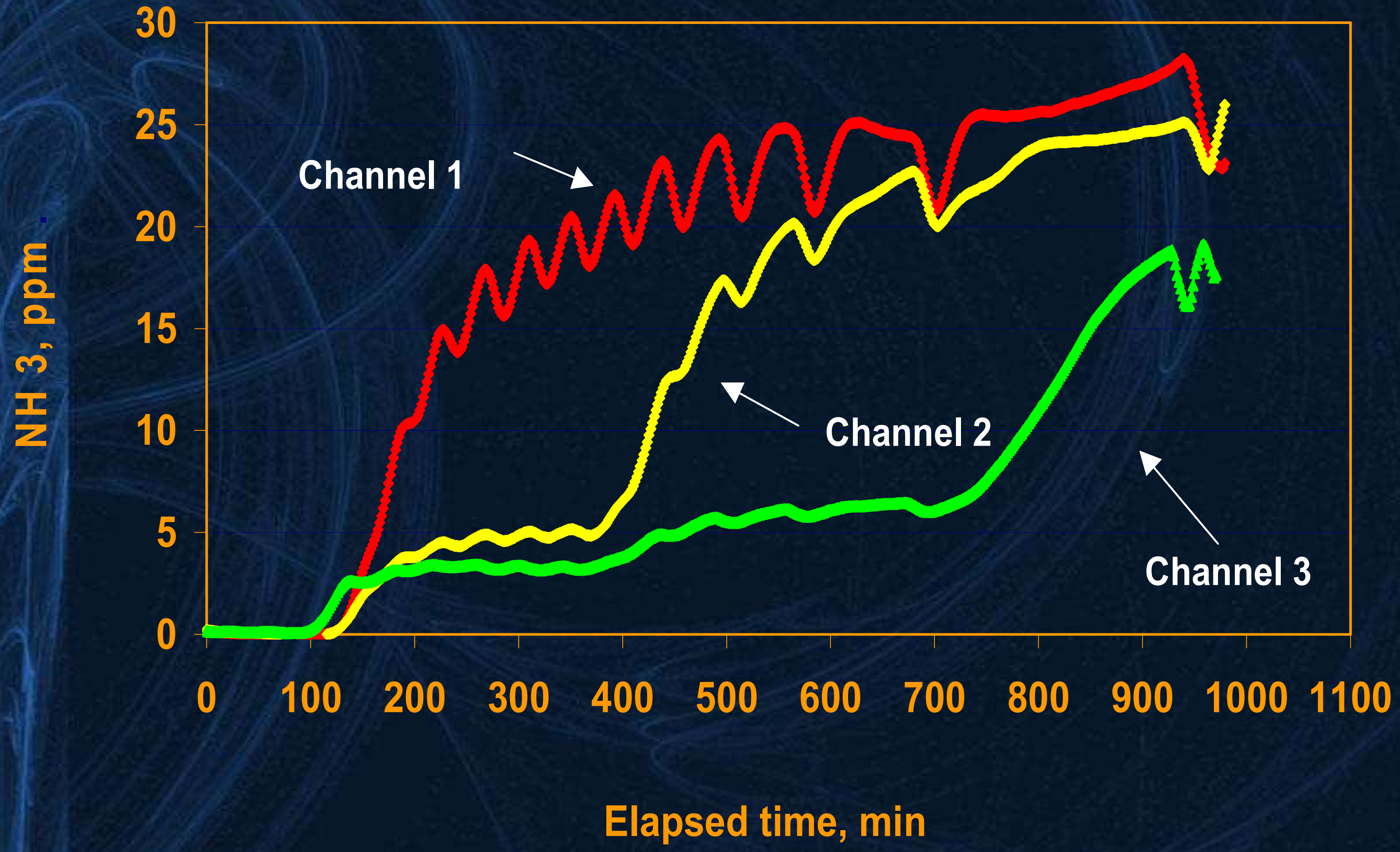
Isotherm Plots

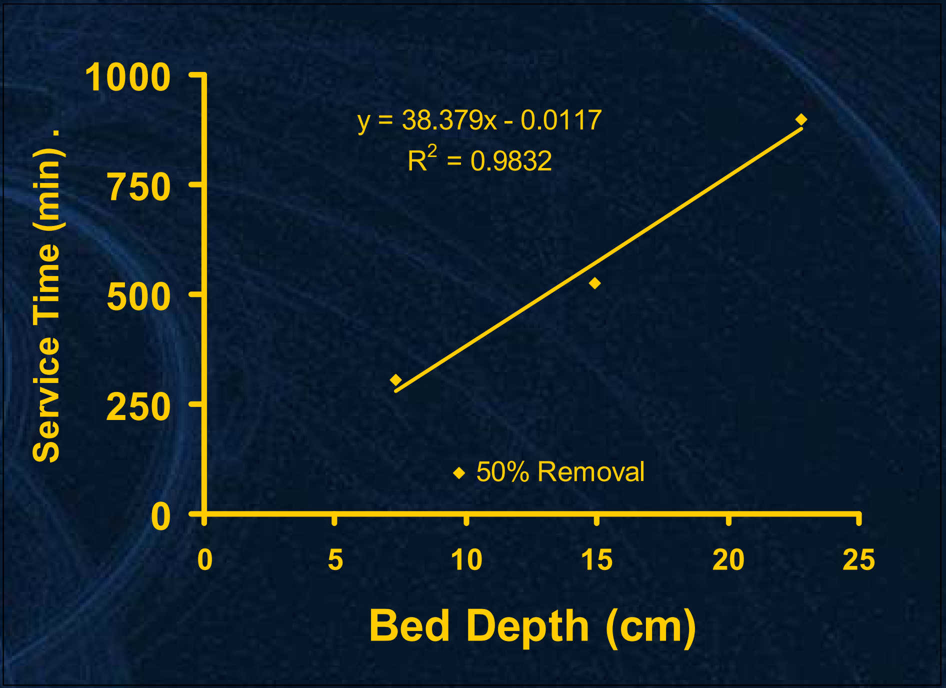


Isotherm Coefficients

Feedstock	Product	SC, meq H^+/g	Q_o, mg/g	R^2	P-value
Wood shavings 250°C	Biochar	1.57	1.22	0.984	<0.0001
	Steam act	0.00	12.2	0.936	<0.0001
	Acid act	**3.00**	**68.6**	0.992	<0.0001
	Base act	0.36	1.84	0.961	0.0006
Wood shavings 500°C	Biochar	0.37	2.89	0.886	0.0020
	Steam act	0.00	17.7	0.999	<0.0001
	Acid act	**2.11**	**52.9**	0.989	<0.0001
	Base act	0.04	4.42	0.976	<0.0001
Chicken litter 250°C	Biochar	1.28	22.8	0.998	<0.0001
	Steam act	0.06	39.5	0.992	<0.0001
	Base act	0.70	18.2	0.994	<0.0001
Chicken litter 500°C	Biochar	0.22	29.1	0.691	0.0210
	Steam act	**0.00**	**51.0**	0.908	0.0004
	Base act	0.00	13.4	0.998	<0.0001

3-chamber NH_3 adsorption

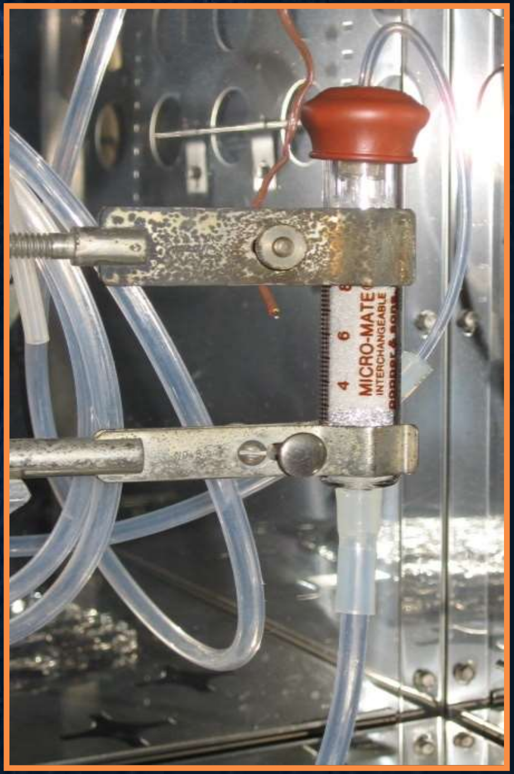


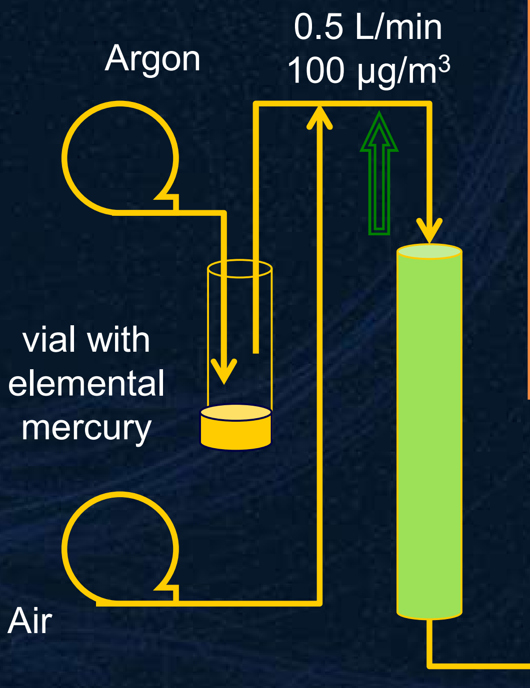


Column #	Cumulative bed depth (cm)	Service time (min) @ breakthrough
1	7.3	303
2	14.9	527
3	22.8	897

Hg Experimental Set-up

- 2021 U.S. mercury emissions at 16 metric t/yr
- Simulated flue gas with elemental Hg_0 at ~100 $\mu g/m^3$ flowing through bed of sand and pulverized biochar held in 150°C oven, samples taken from inlet & outlet and injected into mercury analyzer
- Feedstock: cotton seed hulls, broiler litter, lignin, nutshells
- 350-800°C, 150°C increments





Argon

0.5 L/min
100 $\mu g/m^3$

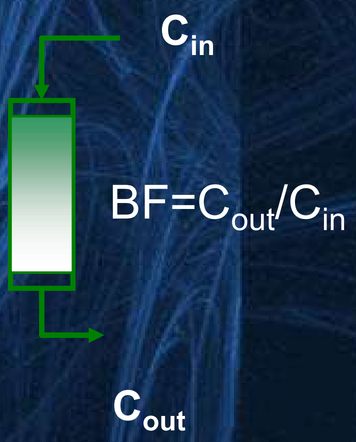
vial with
elemental
mercury

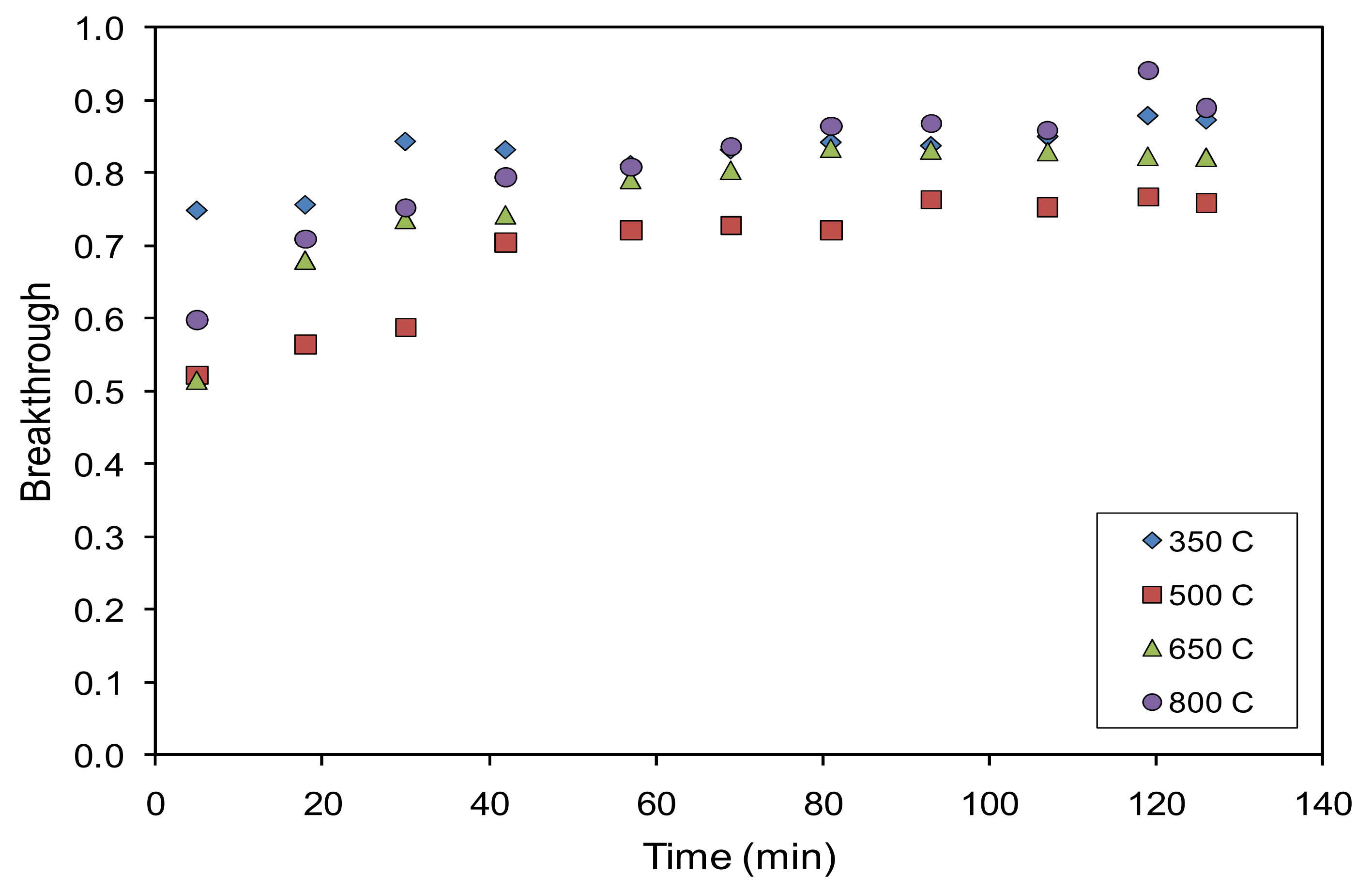
Air

10 g sand
20 mg carbon
13 mm ID x 47 mm L
0.5 s EBRT

Results of Mercury Removal

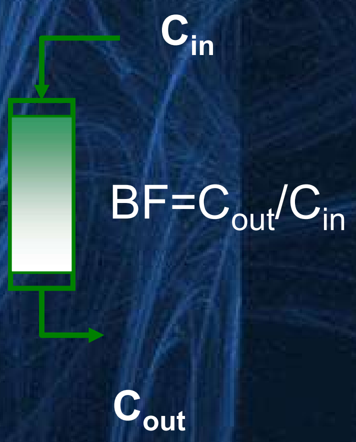
Unwashed cotton seed hull chars





Results of Mercury Removal

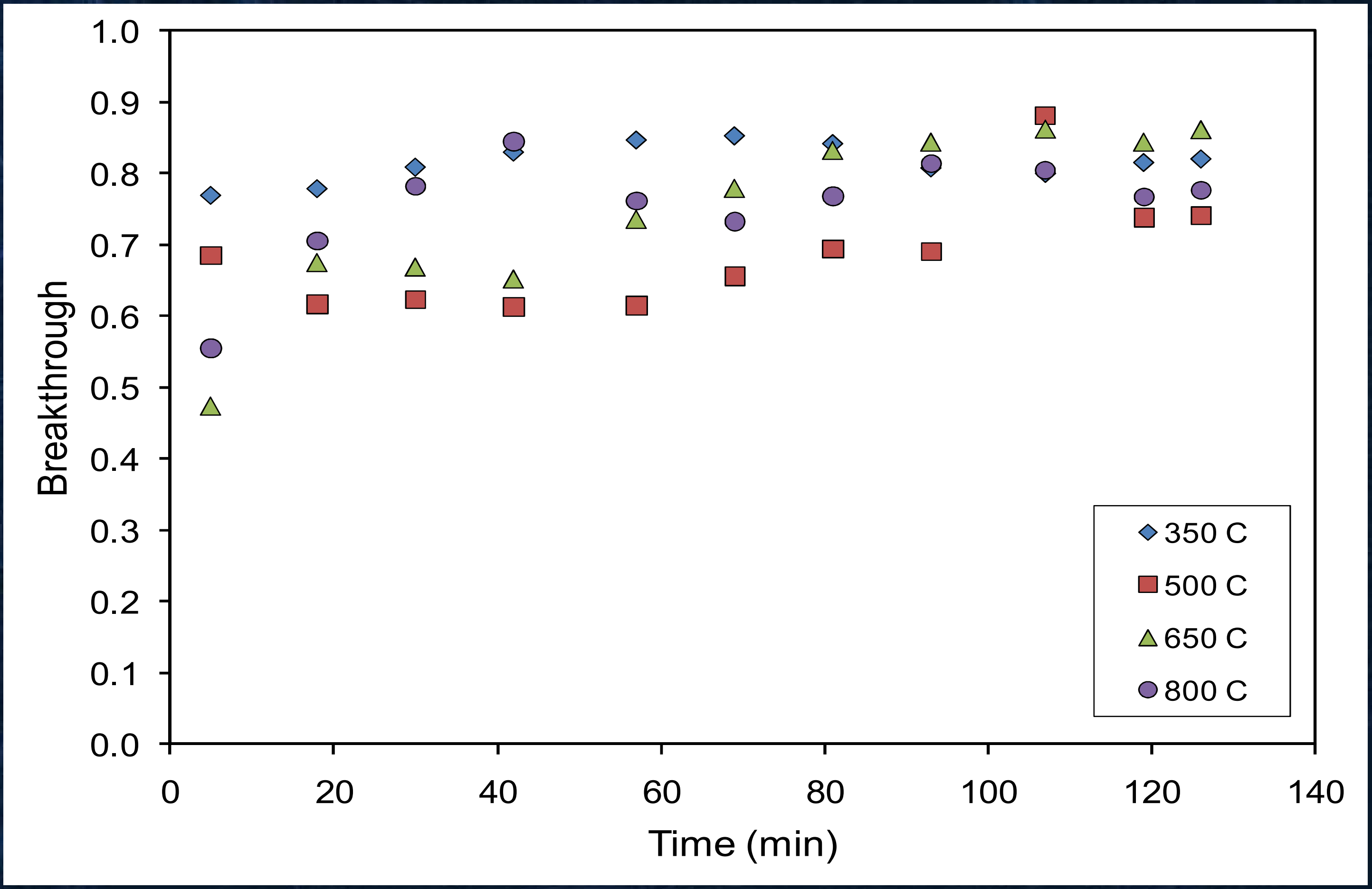
<u>Washed</u> cotton seed hull chars



C_{in}

$BF=C_{out}/C_{in}$

C_{out}



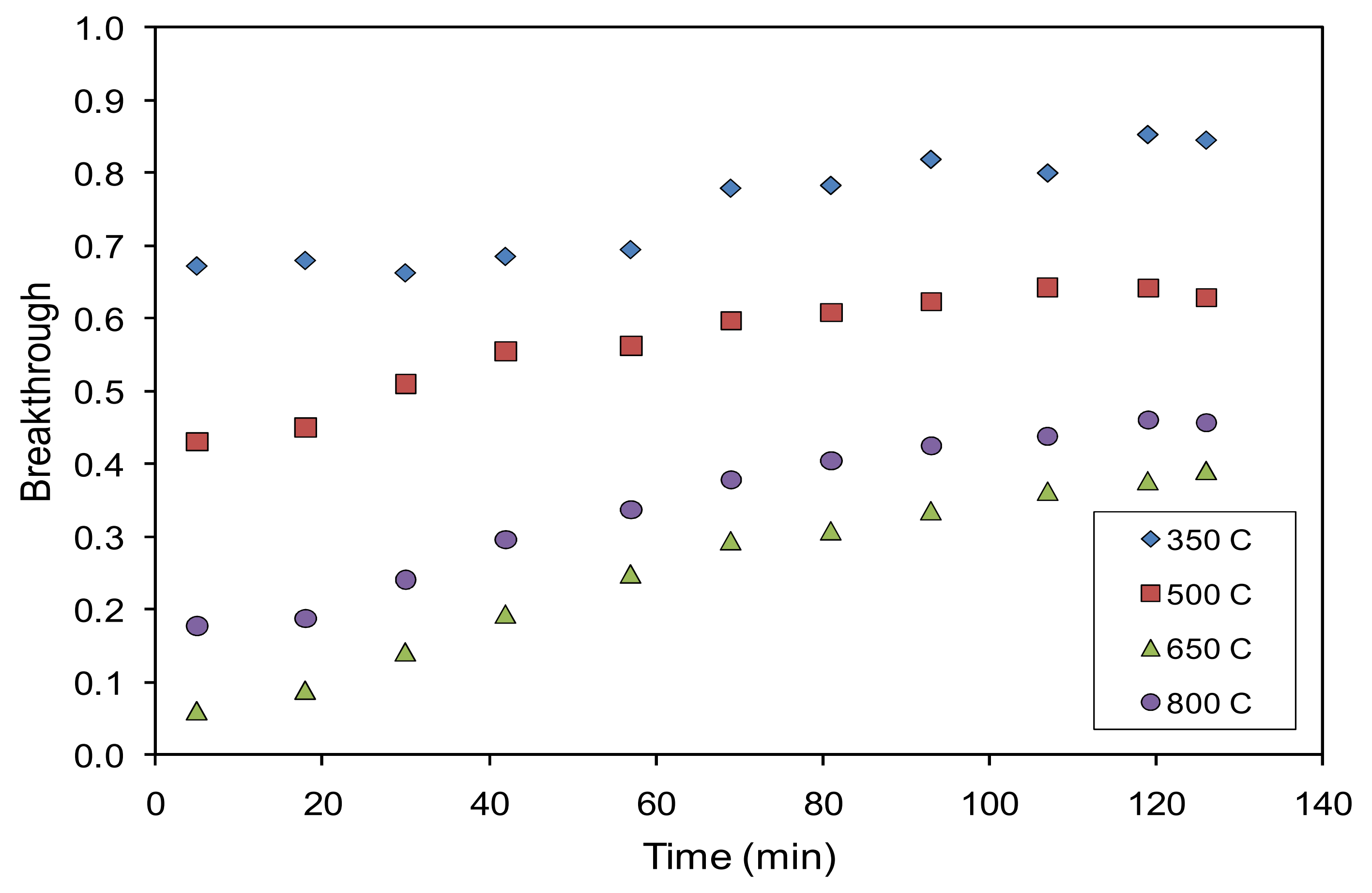
Results of Mercury Removal

Unwashed broiler litter char

C_{in}

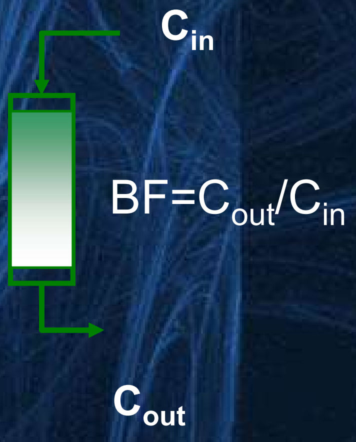
BF=C_{out}/C_{in}

C_{out}



Results of Mercury Removal

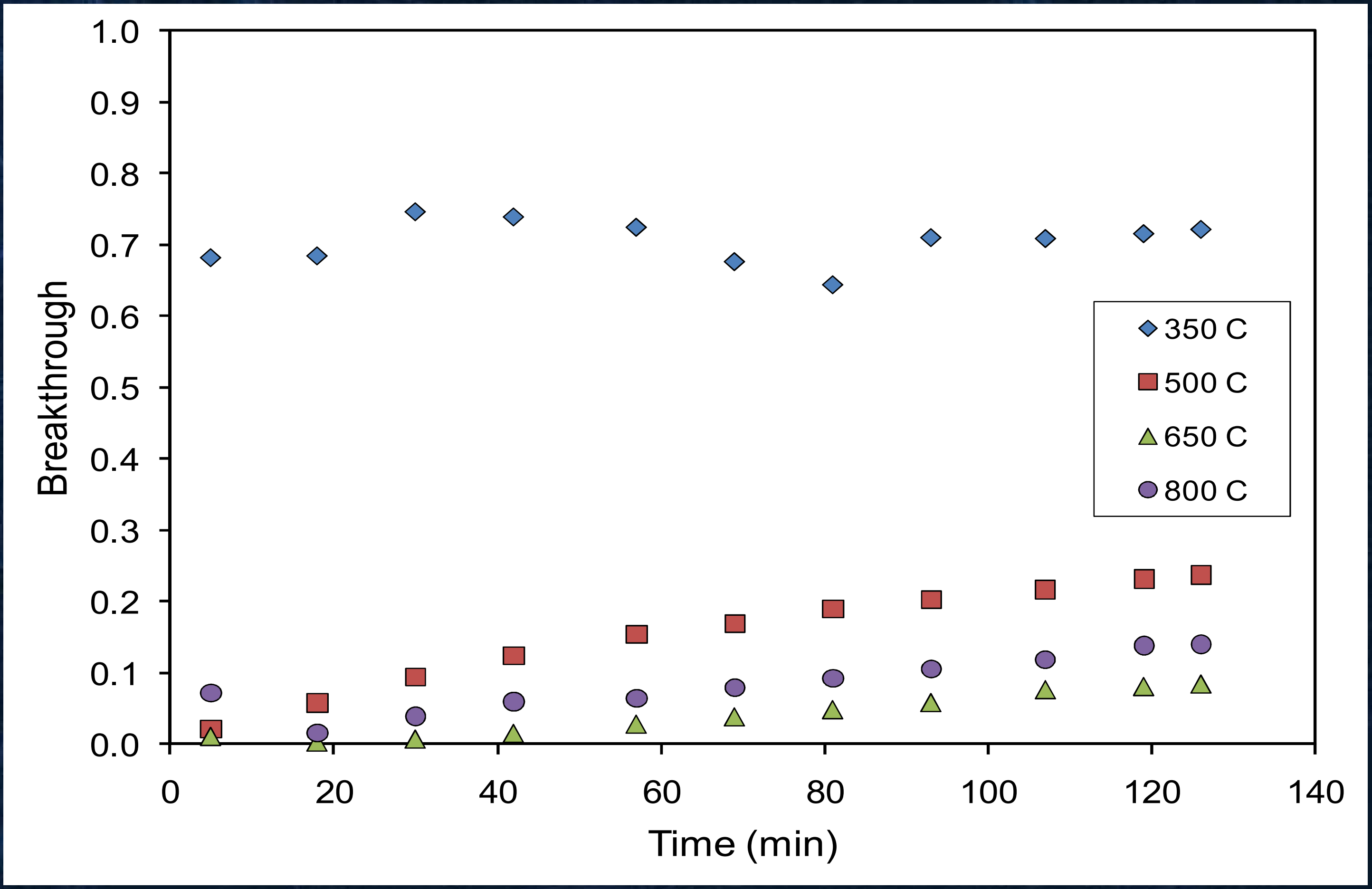
Washed broiler litter char



C_{in}

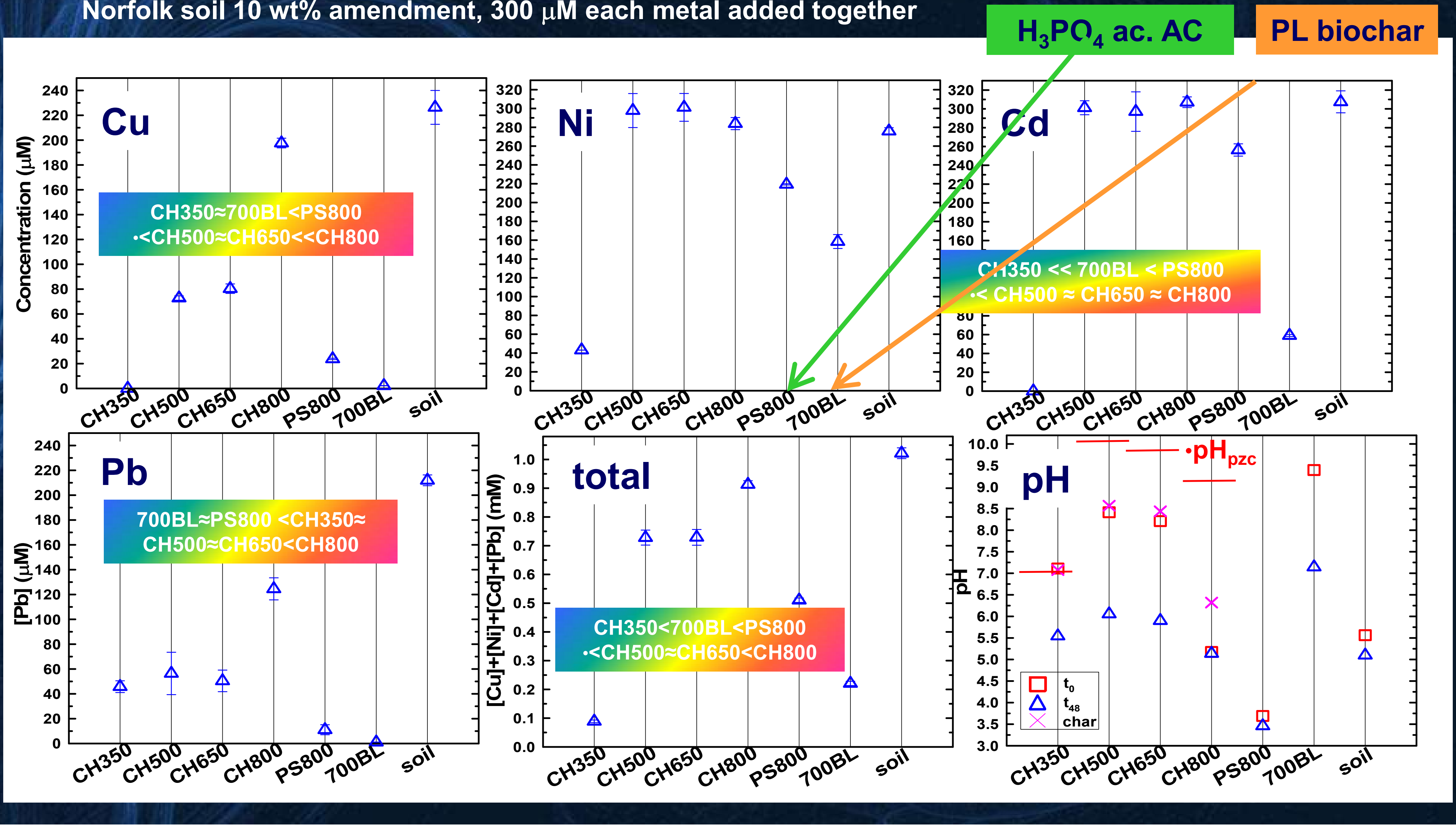
$BF=C_{out}/C_{in}$

C_{out}



Poultry litter char: among the most effective for Cu, Ni, Cd, Pb retention in soils

Norfolk soil 10 wt% amendment, 300 μM each metal added together



H_3PO_4 ac. AC

PL biochar

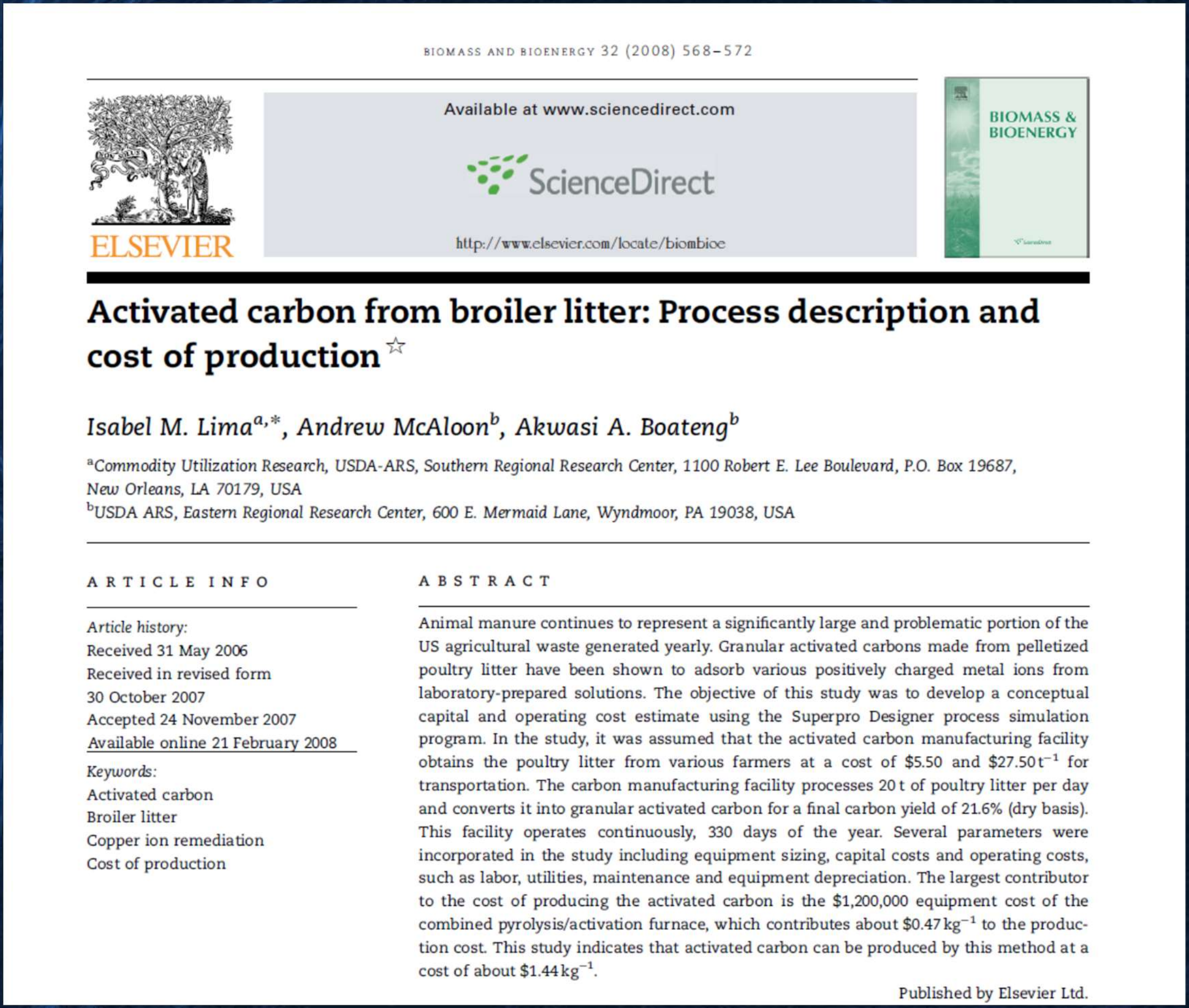
CH350≈700BL<PS800 •<CH500≈CH650<<CH800

CH350 << 700BL < PS800 •< CH500 ≈ CH650 ≈ CH800

700BL≈PS800 <CH350≈ CH500≈CH650<CH800

CH350<700BL<PS800 •<CH500≈CH650<CH800

•pH_{pzc}



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BIOMASS & BIOENERGY

Activated carbon from broiler litter: Process description and cost of production ☆

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ABSTRACT

Animal manure continues to represent a significantly large and problematic portion of the US agricultural waste generated yearly. Granular activated carbons made from pelletized poultry litter have been shown to adsorb various positively charged metal ions from laboratory-prepared solutions. The objective of this study was to develop a conceptual capital and operating cost estimate using the Superpro Designer process simulation program. In the study, it was assumed that the activated carbon manufacturing facility obtains the poultry litter from various farmers at a cost of \$5.50 and \$27.50 t^{-1} for transportation. The carbon manufacturing facility processes 20 t of poultry litter per day and converts it into granular activated carbon for a final carbon yield of 21.6% (dry basis). This facility operates continuously, 330 days of the year. Several parameters were incorporated in the study including equipment sizing, capital costs and operating costs, such as labor, utilities, maintenance and equipment depreciation. The largest contributor to the cost of producing the activated carbon is the \$1,200,000 equipment cost of the combined pyrolysis/activation furnace, which contributes about \$0.47 kg^{-1} to the production cost. This study indicates that activated carbon can be produced by this method at a cost of about \$1.44 kg^{-1}.

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Estimated cost of production for a broiler litter-based adsorbent

- Based on a feed rate of 44,000 lbs/day (22 t).
- Based on a product yield of 21.6% or a daily output of 3,360 kg (7,390 lbs) of product.
- Poultry litter is obtained from various farmers at a cost of $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 activated carbon on a continuous basis 24 hr/day and 330 day/yr.

Estimated cost of production for a broiler litter-based adsorbent

- Based on equipment costs and operating expenses.
  - Production costs include utilities, operating & maintenance, labor & supplies, facility overhead charges, & amortization of the cost to build the manufacturing plant over a 10-yr period.
  - Costs do not include profit. Profit would have to cover sales and marketing expenses, distribution costs and interest on the capital investment.
  - Facility dependent costs included depreciation (total capital costs spread over 15 years), maintenance, and several overhead charges calculated as a function of the projects capital cost.

Equipment Specification and Cost

Name	Size/Capacity	Cost ($)
Silo/Bin for litter holding	26.13 m^3	50,000
Mixer	3877.28 kg/hr	50,000
Mill	833.00 kg/h	17,000
Pelletization	833.00 kg/h	250,000
Furnace Pyrolisis/activation	17.33 m^2	1,200,000
Cooling (w/pyrolysis)	242.33 kg/h	0
HCL Store & Mix	3877.28 kg/hr	50,000
Mixer for carbon washing	4119.60 kg/hr	25,000
Water rinse	3902.12 kg/hr	15,000
Dewatering	4119.60 kg/hr	20,000
Drier	1.94 m^2	49,000
Silo/Bin for carbon storage	30732.80 L	50,000
Packaging	139.94 kg/hr	25,000
TOTAL		1,751,000

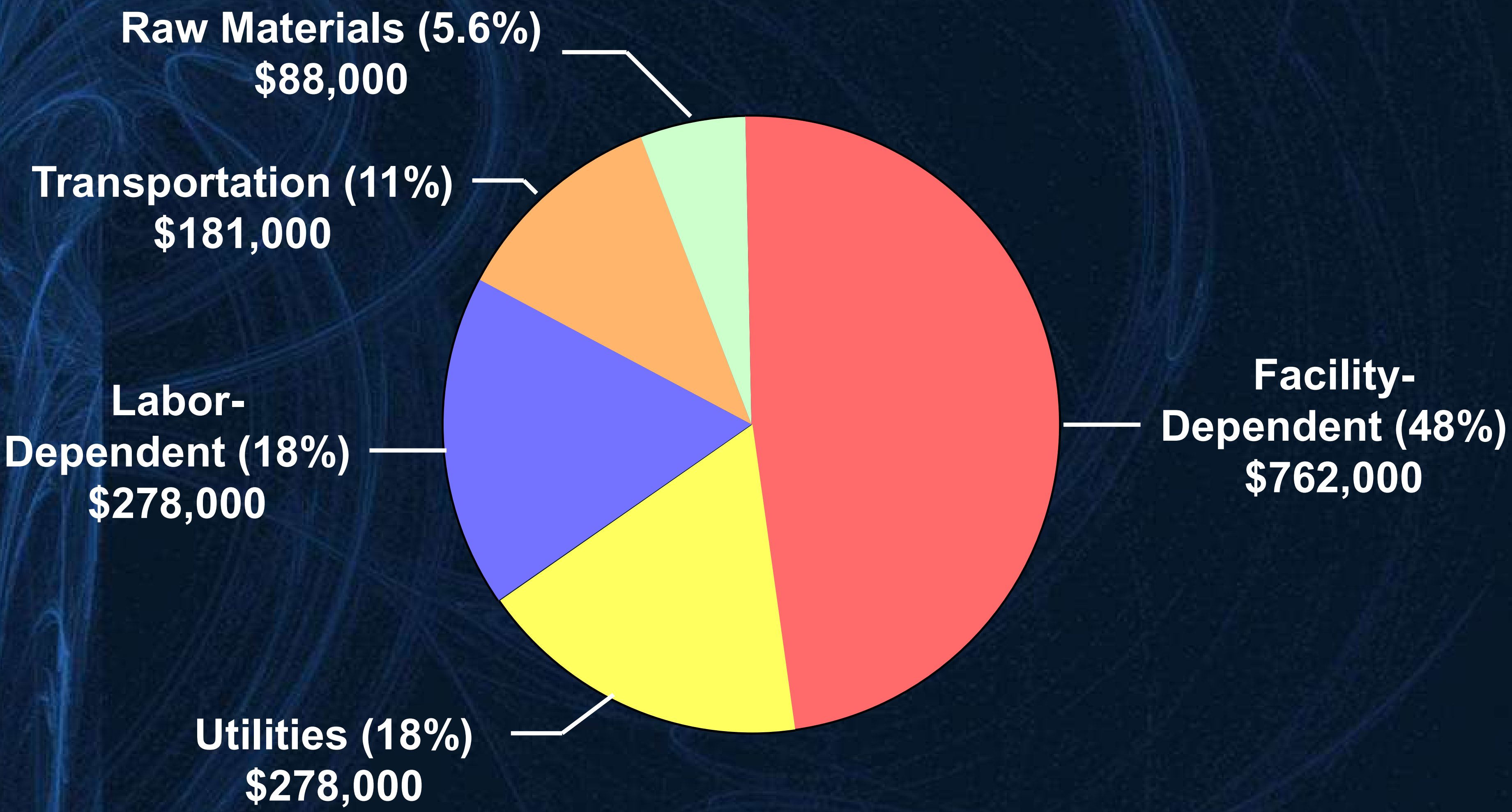
Labor, raw materials & utilities Cost

Labor Type	Unit Cost ($/hr)	Amount (hr)	Cost ($/yr)	%
Plant Workforce	23.47	8,320	195,000	70.12
Supervisor	40.00	2,080	83,000	29.88
TOTAL		10,400	278,000	100.00

Bulk Raw Material	Unit Cost ($/kg)	Amount (kg/yr)	Cost ($/yr)	%
Water	0.001	30,601,979	22,000	24.56
Poultry Litter	0.006	6,597,360	36,000	41.08
HCl	0.100	304,040	30,000	34.36
TOTAL		37,503,379	88,000	100.00

Utility	Amount/yr	Ref. Units	Cost ($/yr)	%
Electricity	3,532,117	kWh	176,606	63.53
Nat Gas	342,103	kg	98,868	35.56
Water	35,999,952	kg	2,520	0.91
TOTAL			277,993	100.00

Annual Operating Cost Breakdown (%)



Total Plant Direct Cost (TPDC)

- Total capital costs were developed from the equipment costs through the application of an installation factor of capital costs to equipment costs. [Capital costs = 3 times equipment costs].

Equipment Purchase Cost (pyrolysis/activation unit $1,200)	$ 1,751,000
Installation	$ 3,502,000
Total Capital Investment	$ 5,252,000
Operating Cost	$ 1,588,000/yr
Production Rate	1,108,356 kg /yr or 1,220 t/yr

Estimated cost of production for a broiler litter-based adsorbent

- Excluded from the capital costs were charges for environmental controls, land acquisition and site development, working capital and the cost of capital during construction.

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

Potential Market Size

- Depends on local availability of manure
  - Small carbon manufacturing facility
    - 11 t/d (3500 t/yr)
    - 20 broiler houses
  - Medium to Large Carbon 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
- *Location, Location, Location …*
  - Delmarva Peninsula (1.2 M T/yr)
  - Perdue Agri-recycle, Seaford, MD (2500hp mills, 30 T pellets/hr)
  - GA, AL, MS => 1/3 U.S. broilers supply

Summary

- Biochars and activated biochars produced by thermo-chemical conversion of organic feedstock such as animal manures proved to be excellent candidates for remediation applications (wastewater, air, soil).
- Carbons made from animal manure are extremely versatile in their use, possibly due to their high organic content and apparent intrinsic qualities.
  - High adsorption for Cu^{2+}, Cd^{2+}, and Zn^{2+} observed for the poultry and swine-based carbons.
  - Poultry litter biochars also performed well in Hg and NH_3 adsorption studies.
- Pyrolysis conditions, activation strategies and pre- and post-treatments can be manipulated to affect the properties of the resulting biochars and activated biochars.
- Biochar properties are feedstock dependent: surface area and surface charge play a role in adsorption; significant differences in metal uptake between plant versus manure-based biochars.

Summary

- Manure biochars, without being subjected to subsequent activation were able to adsorb up to 58 mg/g of Cu^{2+}, with a metal ion sequestering ability exceeding that of biochars from traditional feedstocks.
- Acid activation significantly improved metal ion adsorption for wood based biochars making them as effective as their chicken litter biochar counterparts.
- Copper ion uptake is affected by surface functionality via oxygen bearing groups added via acid activation.
- Functionality as measured by surface charge is not sufficient to explain why broiler litter biochars and steam activated biochars are superior to wood shavings in metal ion adsorption; for this feedstock, functionality could be related to phosphate containing groups.
- In Hg removal experiments, BL650°C biochar was the best performing by far, amongst other feedstocks (lignin, cotton seed hulls and nutshells).
- Ash significantly higher in manure biochars,40 to 70% as compared to 1.4 to 2.5% for plant biochars, selective elemental reduction via acid-wash.

Conclusions

- A cost analysis revealed that manure biochars can be produced for 32-38¢/lb ($0.65/lb for activated biochar), considerably lower than the purchase cost for comparable commercial materials and could be part of an attractive solution for farmers to dispose of their waste and the manufacturer in terms of profit.
- Key areas would include regions of concentrated poultry production close to sensitive environments such as the CB with explosive suburban development.
- Establishment of this product in the marketplace will benefit not only the manufacturer in terms of profit, but also the farmer by establishing a steady market for their waste.
- *The **key** is the **profitable reuse** of wastes for which farmers are liable and for which, the waste could be almost as valuable as the meat,*

  *– a true **Value-Added Product**.*
- *Its success will ultimately depend on the economic viability, environmental sustainability and consumer acceptance & the need for legislation.*

Multi-purpose

Climate Change Mitigation

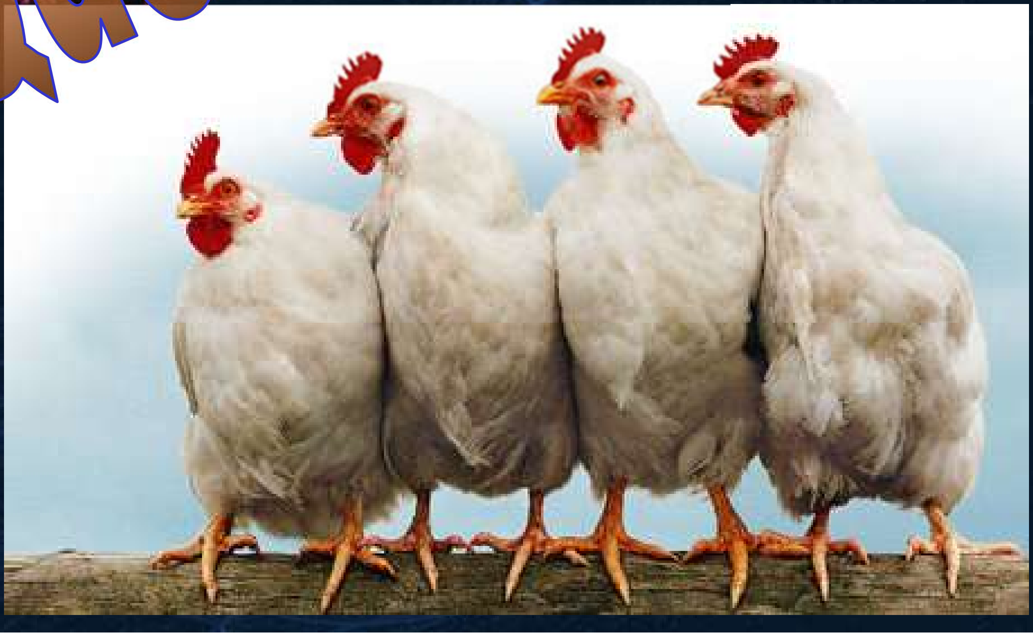
Energy Production

Soil Improvement

Waste Managment

Soil, Air, Water Remediation

Questions?



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