

Biochar: The Truth Behind the Research



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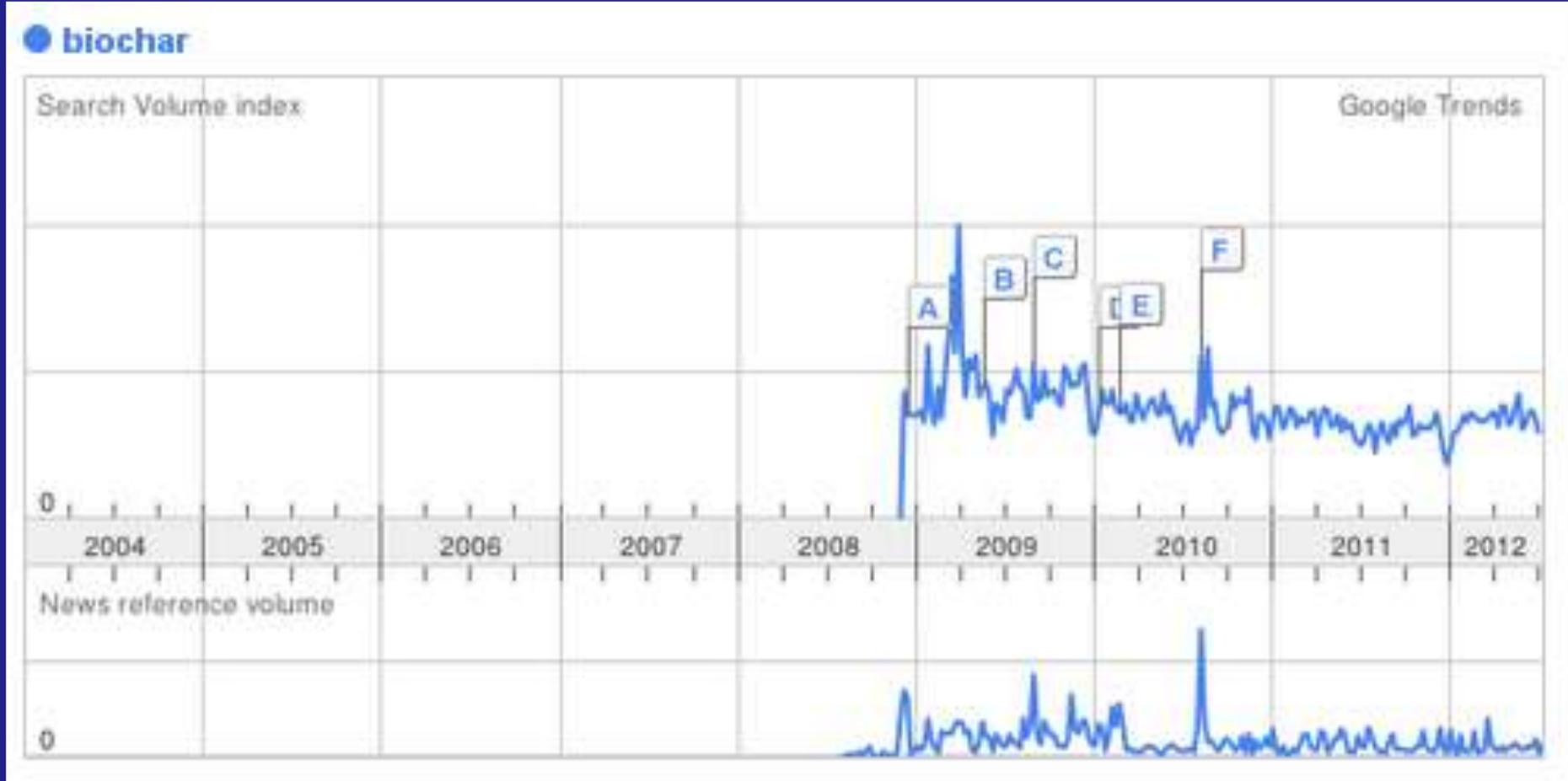
2012 Upper Midwest Regional Master Gardener Conference – July 21, 2012



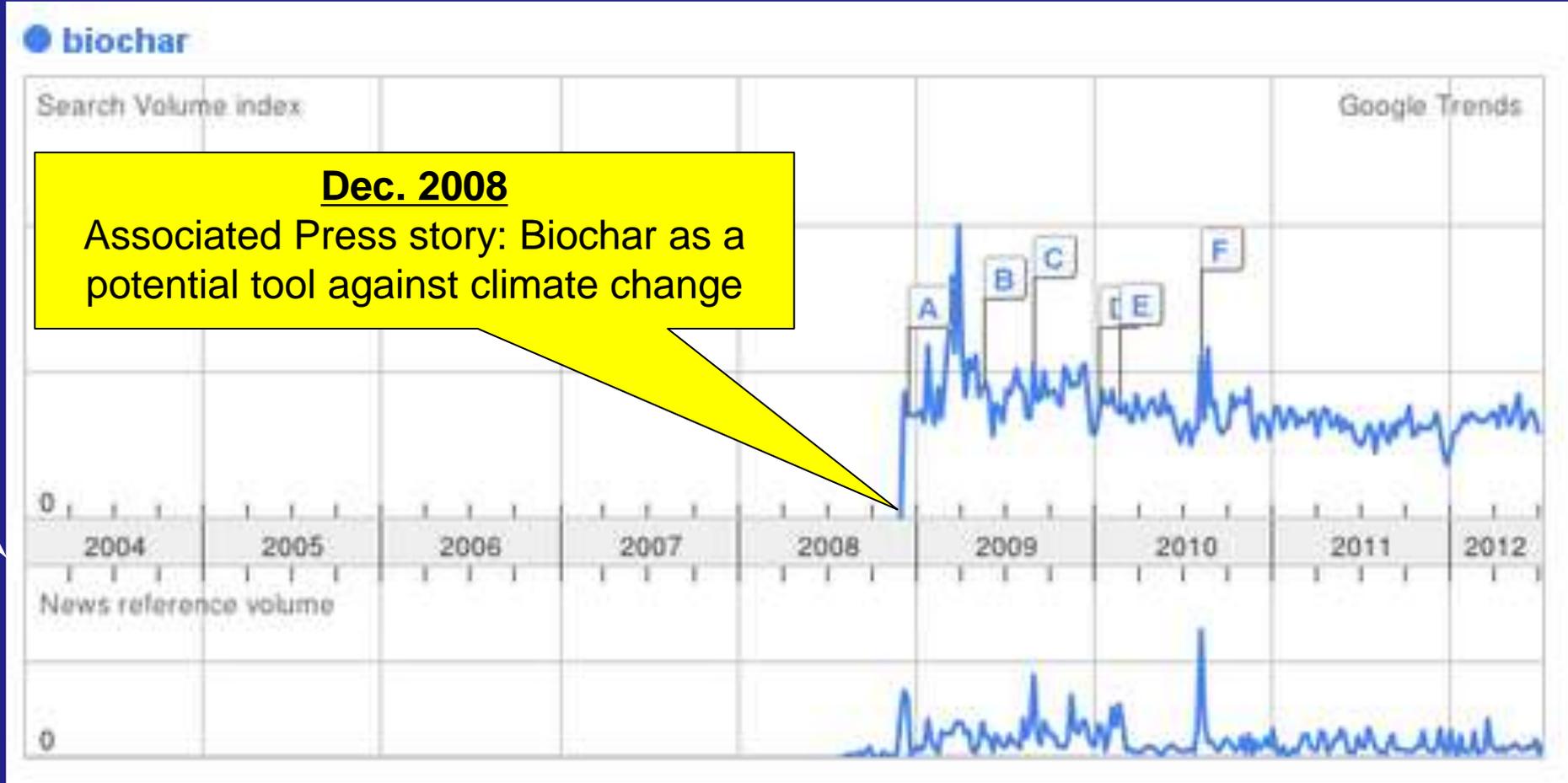
Step 1. Biochar: What is it ?



Biochar – Google Trend Reports



Biochar – Google Trends



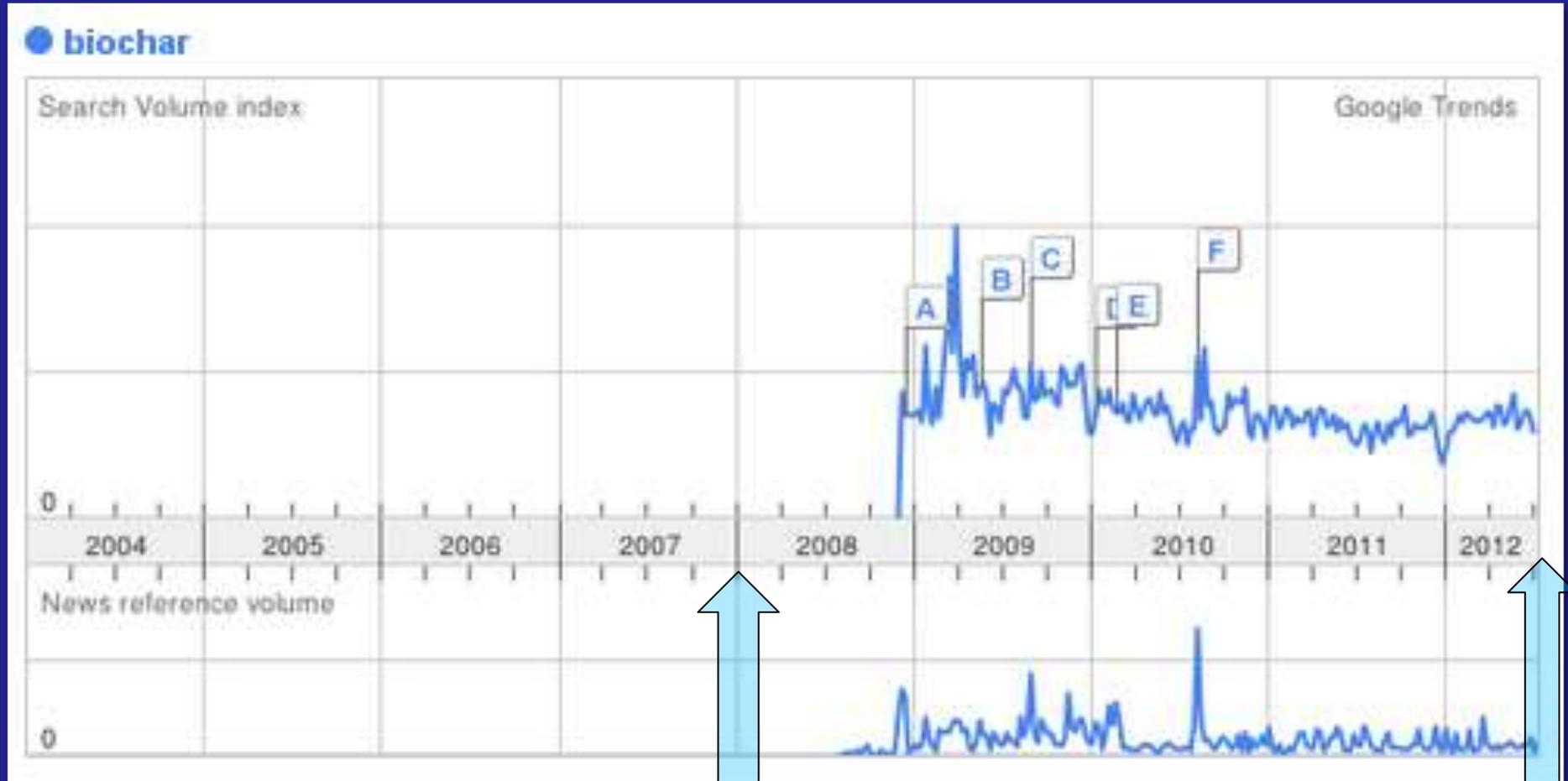
1998

First use of biochar in the scientific literature

1985

First reference of using biomass for climate abatement

Biochar – Google Trends Reports



Jan 2008
285 results

July 2012
2.87 million results

Biochar – Google Trends

Regions



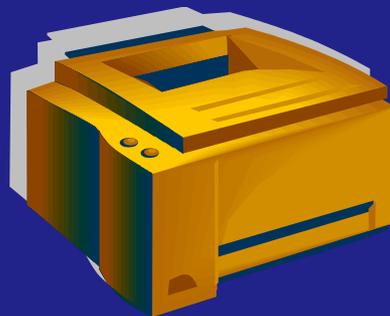
Biochar – Google Trends (US)

Subregions



Biochar: Form of Black Carbon

- *Black carbon* is the range of solid residual products resulting from the chemical and/or thermal conversion of any carbon containing material (e.g., fossil fuels and biomass) (Jones et al., 1997)



Formation of Black Carbon: “Pyrolysis”

- ⇒ **Pyrolysis** is the chemical decomposition of an organic substance by heating
 - ⇒ Main Characteristic:
 - Does not involve reactions with oxygen
 - Typically in the absence of oxygen

Formation of Black Carbon: “Pyrolysis”

- ⇒ **Pyrolysis** is the chemical decomposition of an organic substance by heating
 - ⇒ Does not involve reactions with oxygen
- ⇒ Pyrolysis is also used in everyday activity –

Cooking → roasting, baking, frying, grilling

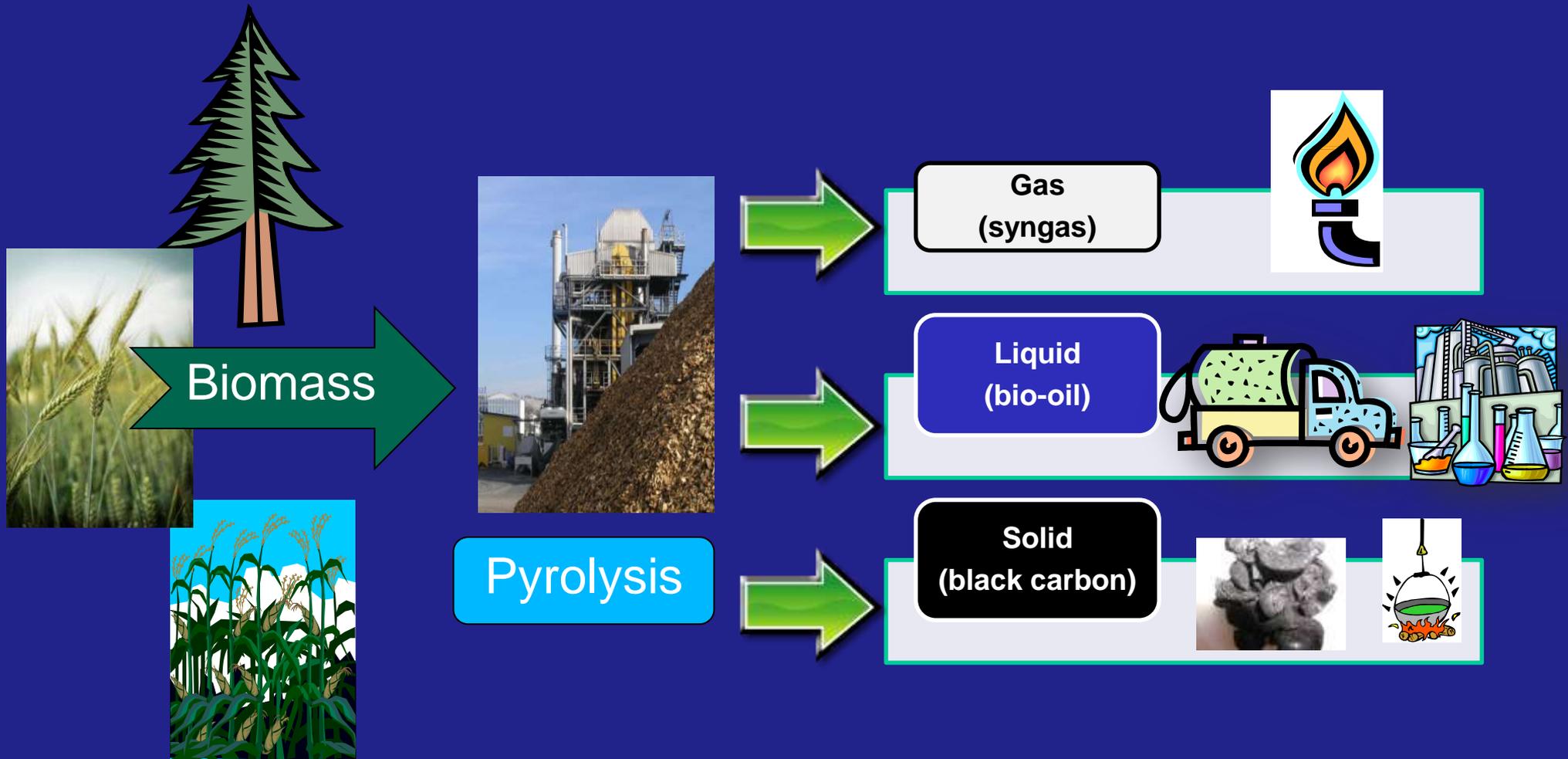


Formation of Black Carbon: “Pyrolysis”

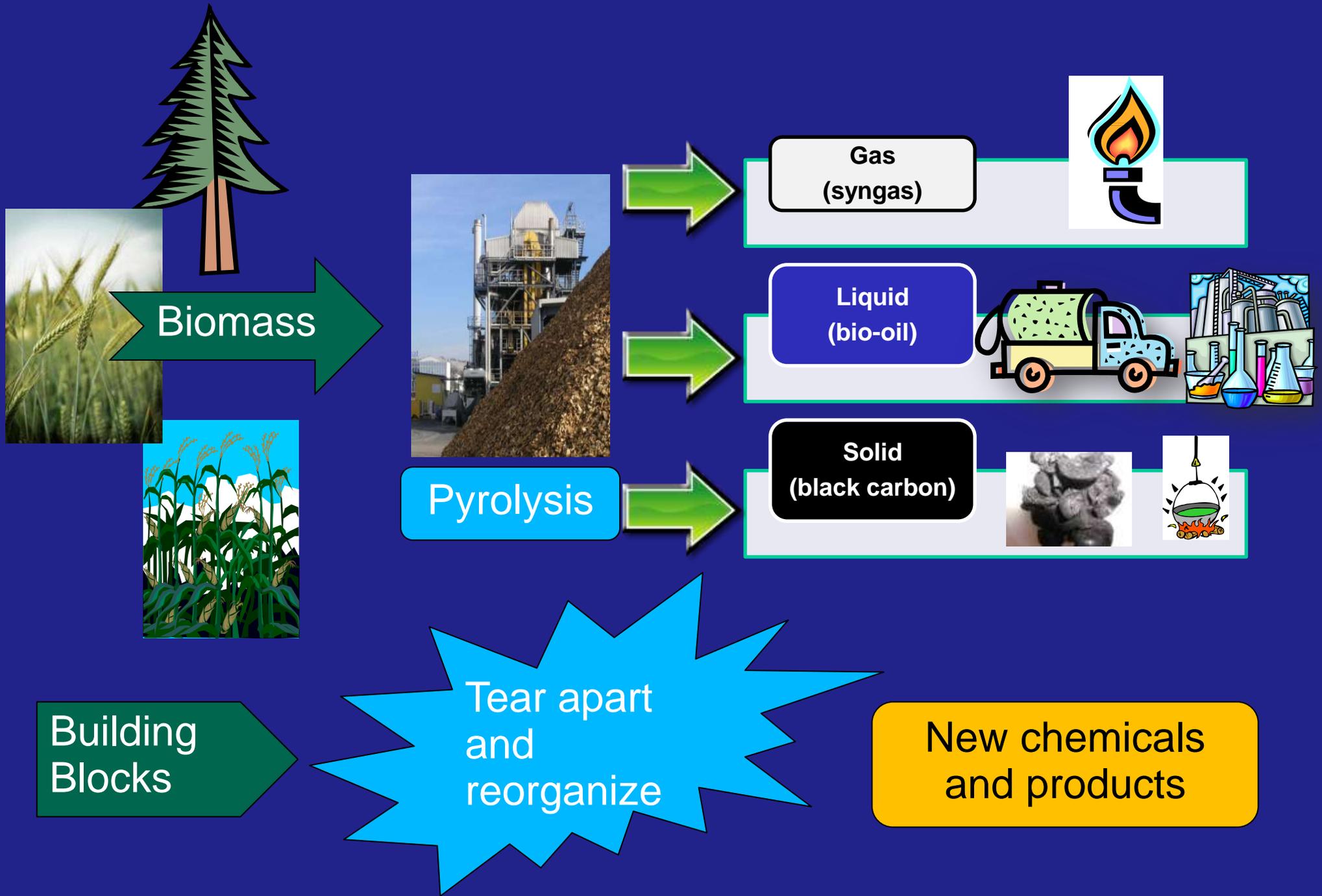
- **Pyrolysis** is the chemical decomposition of an organic substance by heating
 - Does not involve reactions with oxygen
- Pyrolysis is also used in everyday activity –
- Also occurs in lava flows and forest/prairie fires



Overview of Pyrolysis



Overview of Pyrolysis



Wide Spectrum of Pyrolysis

Both temperature and time factors:

- High temperature pyrolysis
→ gasification (>800 °C) {+ O₂}

- “Fast” or “Slow” pyrolysis (300-600 °C)
 1. Fast pyrolysis
60% bio-oil, 20% biochar, and 20% syngas
Time = seconds

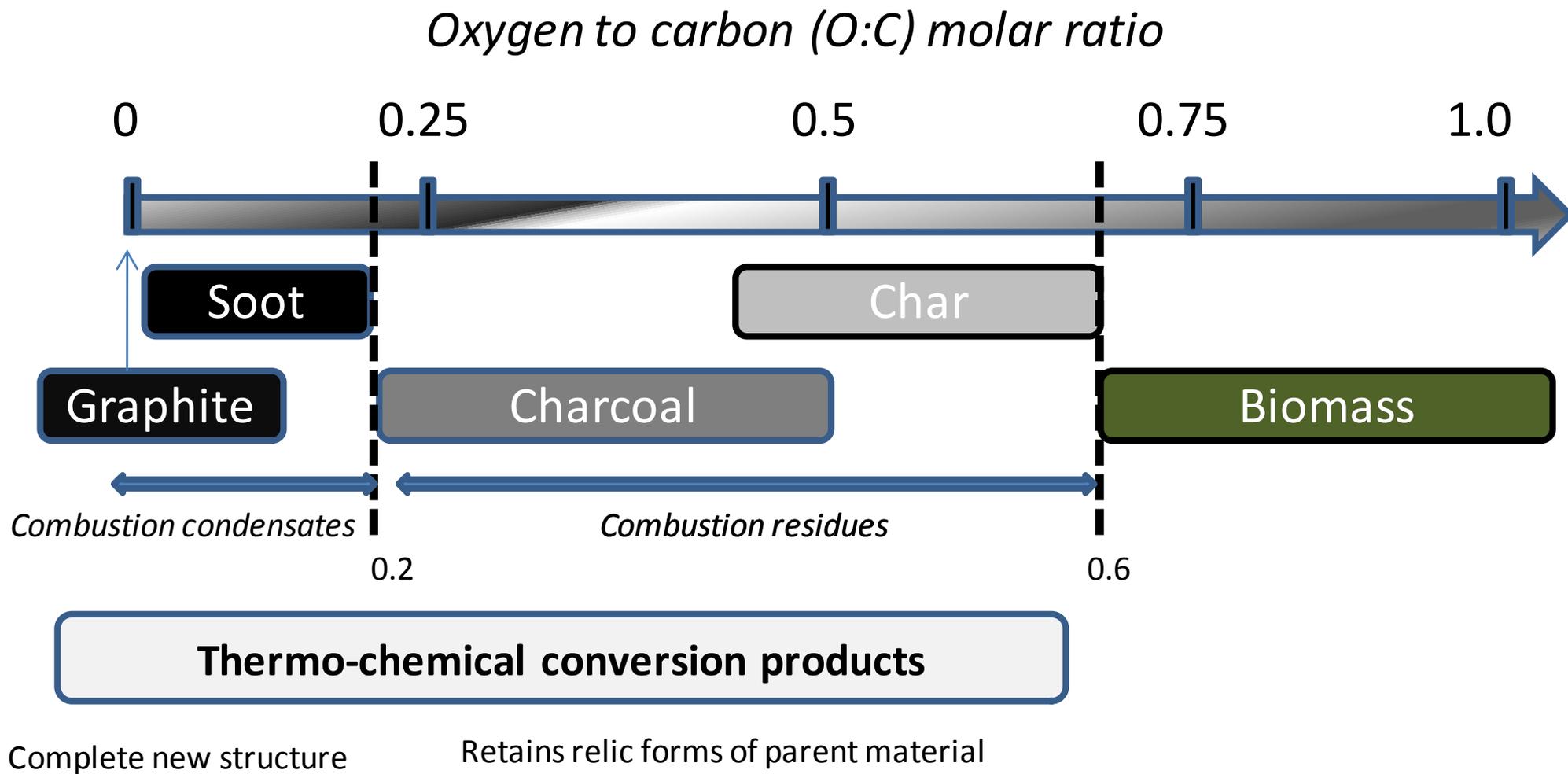
 2. Slow pyrolysis
Can be optimized for char production
(>40% biochar yields)
Time = hours



Others Ways to Make Black Carbon



Black Carbon "Spectrum"



Adapted from Hedges et al., 2000; Elmquist et al., 2006; Spokas, 2010

Problem → Lack of nomenclature uniformity

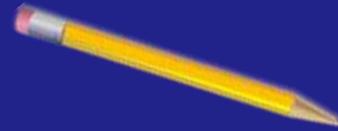
(Jones et al., 1997)

Black Carbon Use

- We have used black carbon in the past...and currently



Cave Drawings
(>10,000 to 30,000 BC)



Pencils



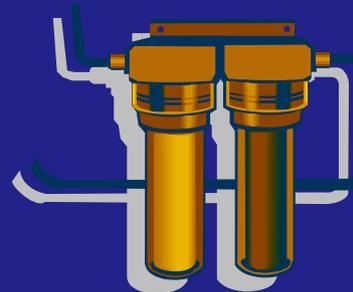
Used as fuel
(3000-4000 BC)



Charcoal production
(15th century)



Water filtration
(2000 BC)



Activated Charcoal
Filtration Today

Biochar: New purpose not a new material

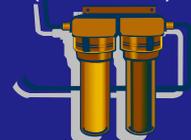
Cave Drawings
(>10,000 to 30,000 BC)



Used as fuel
(3000-4000 BC)



Water filtration
(2000 BC)



Charcoal production
(15th century)



Climate Change Mitigation
(1980's)



➤ What is new?

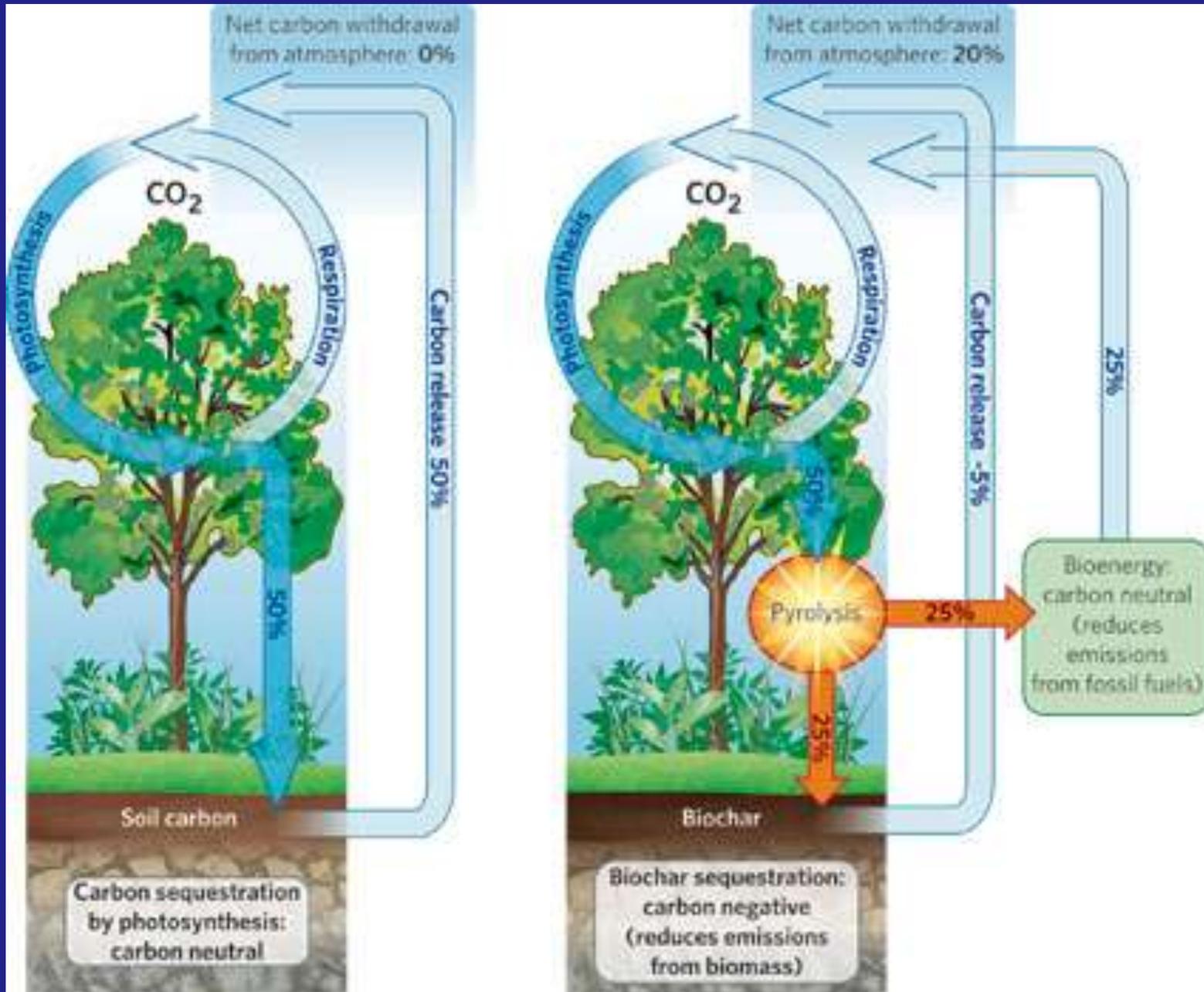
The use (or purpose) for the creation of charred biomass:

Atmospheric C sequestration

Dates to 1980's and early 2000's

(Goldberg 1985; Kuhlbusch and Crutzen, 1995; Lehmann, 2006)

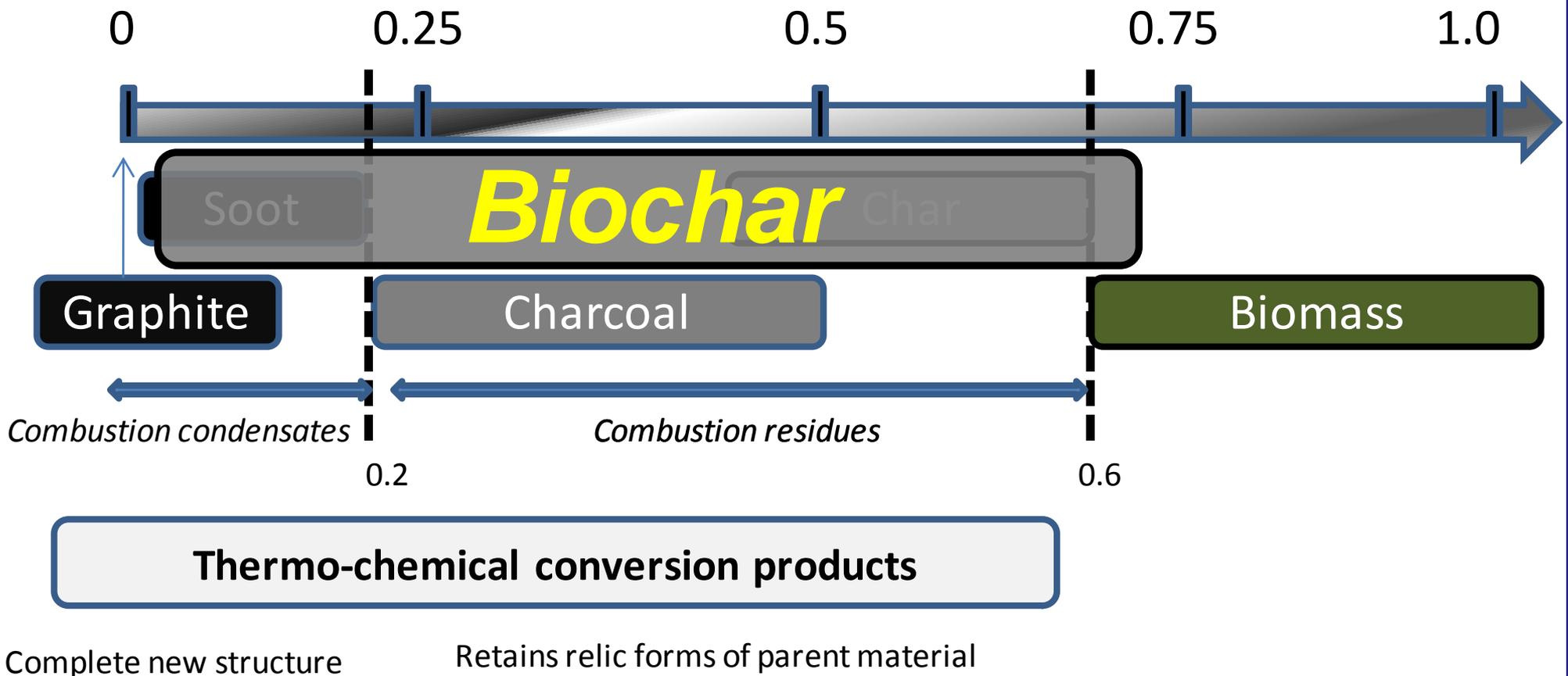
Carbon Sequestration



Biochar: Black Carbon Continuum

Biochar – Spans across multiple divisions in the Black C Continuum
However, biochar is NOT a new division or material...

Oxygen to carbon (O:C) molar ratio



Biochar: Structure



Pyrolysis (biochar)



Biochar: Structure



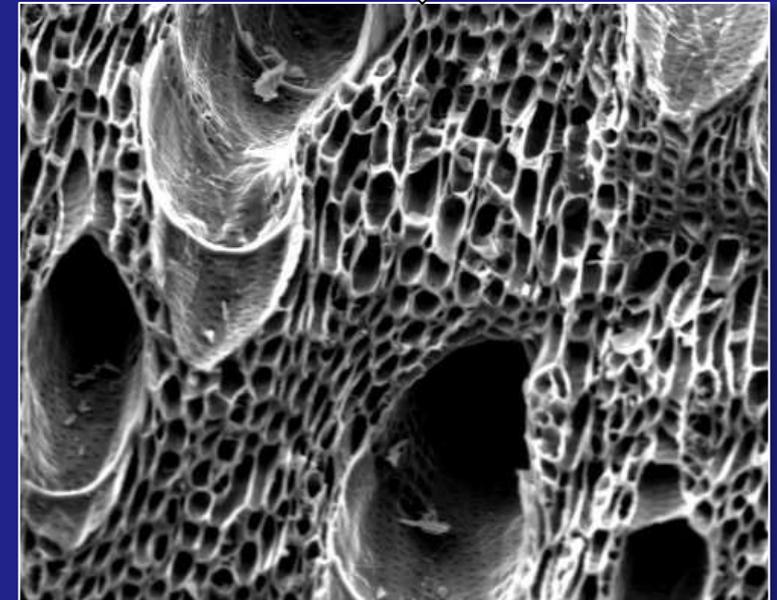
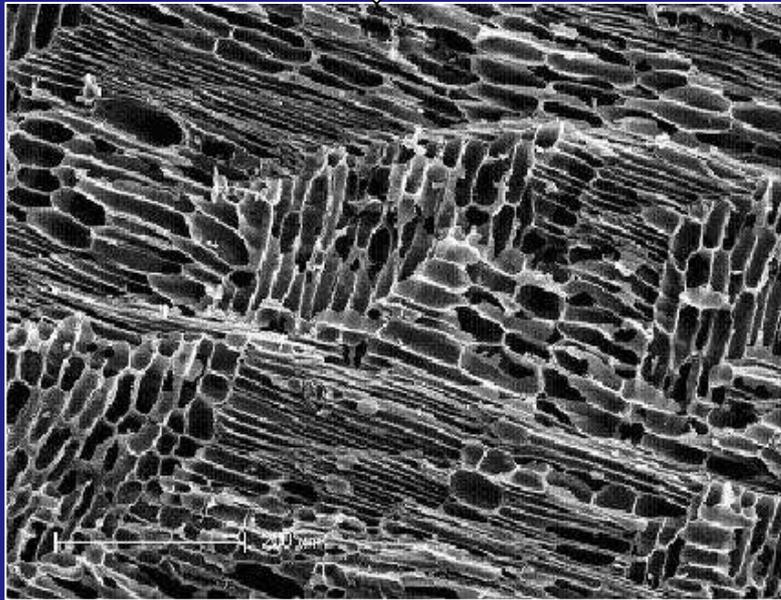
Pyrolysis (biochar)



Biochar: Structure

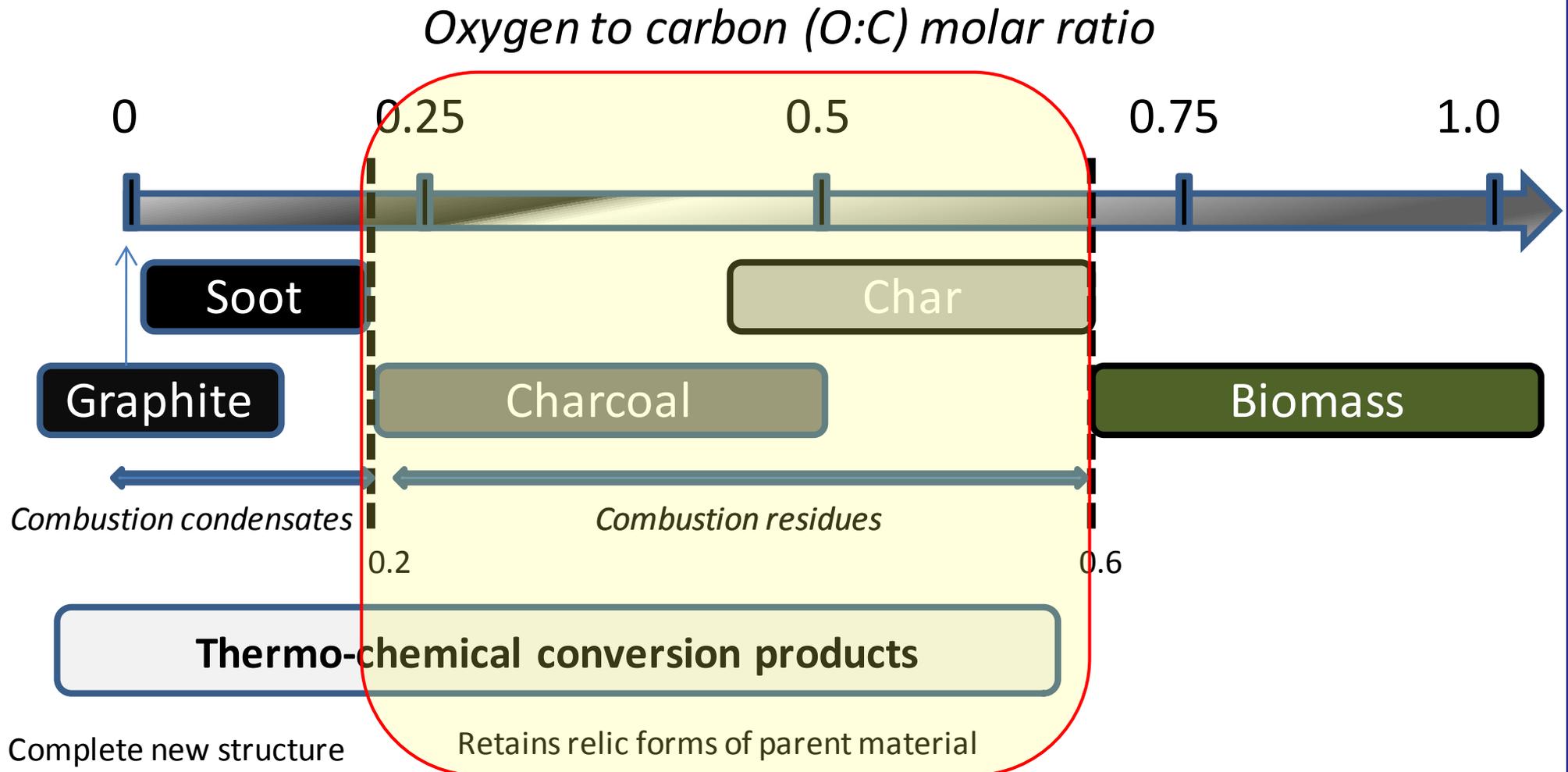


Pyrolysis (biochar)



Biochar : Majority still show relic structures in the biochar

Black Carbon "Spectrum"



Adapted from Hedges et al., 2000; Elmquist et al., 2006; Spokas, 2010

Biochar

Gaining significant attention:

– 1. Carbon Storage

- Biochar can store atmospheric carbon, potentially providing a mechanism for reduction in atmospheric CO₂ levels

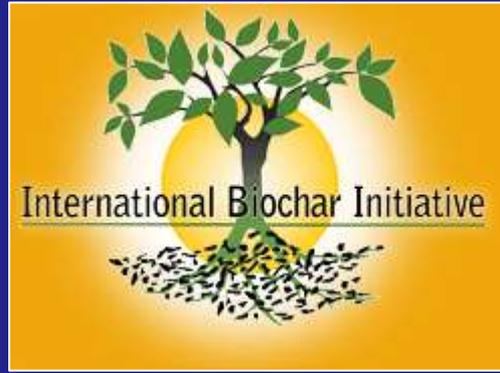
– 2. Soil Improvements

- Improve water quality
- Improve soil fertility
- Reduce GHG emissions

– 3. Bioenergy



Defining Biochar



International Biochar Initiative (IBI) Definition:

“Biochar is a solid material obtained from the carbonization of biomass. Biochar may be added to soils with the intention to improve soil functions and to reduce emissions from biomass that would otherwise naturally degrade to greenhouse gases. Biochar also has appreciable carbon sequestration value. These properties are measurable and verifiable in a characterization scheme, or in a carbon emission offset protocol.”

Biochar Summary

Biochar is black carbon that is made for the purpose of carbon sequestration.

Biomass Materials



Easily degradable
(0-5 yrs)



Pyrolysis



Recalcitrant carbon form
(black carbon)
(>50 to 1,000,000 yrs?)

Biochar (Summary)



However, just like cooking...

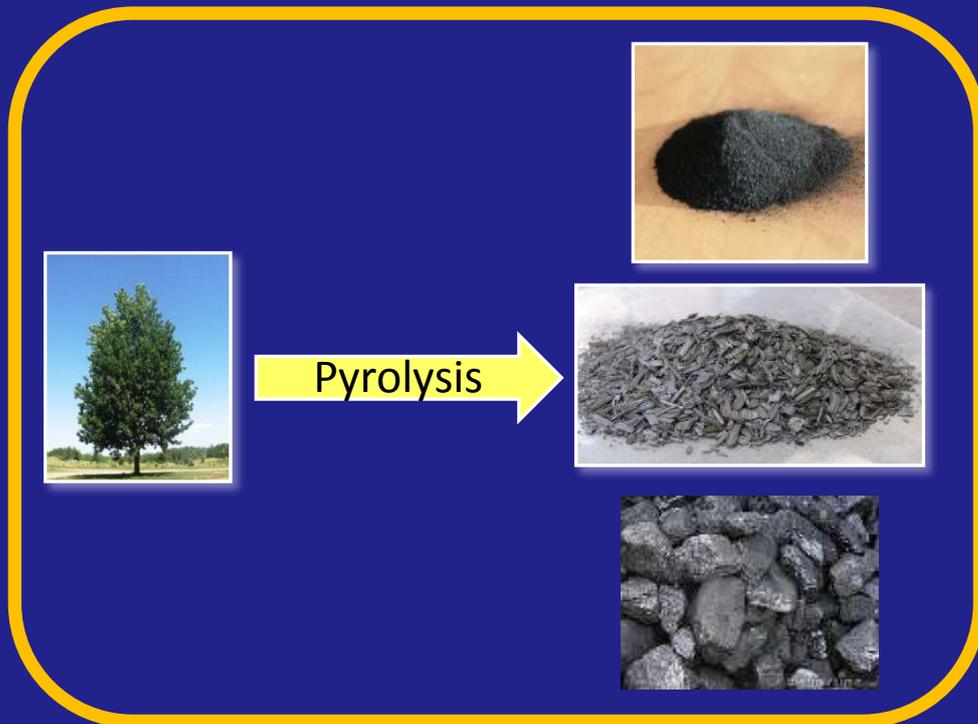
The same recipe –
might not taste the same cook to cook...



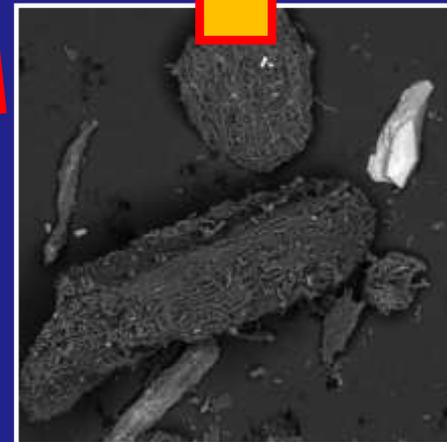
Even though same
conditions –

Can result in different
biochar chemistries

“Not all biochars are equal”



Biochar Soil Application



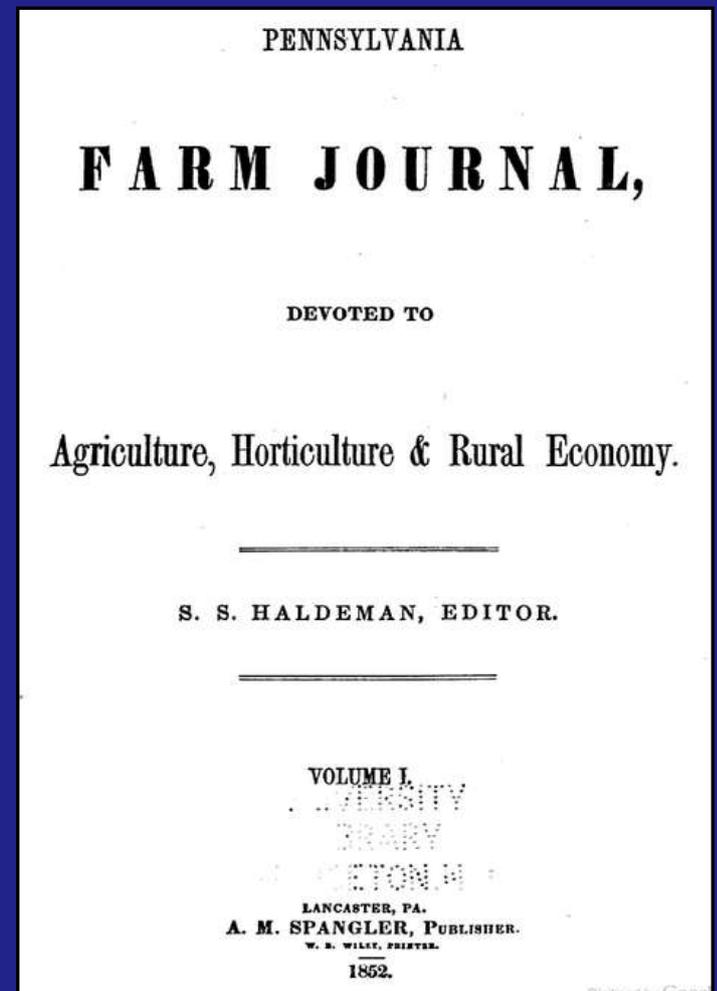
“The use of charcoal (*biochar*) as a fertilizer is not a new thing, though it is only within the few last years that agriculturists have taken much notice of it.”



Biochar: Not new for soil additions....

“The use of charcoal (*biochar*) as a fertilizer is not a new thing, though it is only within the few last years that agriculturists have taken much notice of it.”

-- Pennsylvania Farm Journal (1852)
Editorial (Haldeman) Page 57



Biochar: Soil Application

- The assumed target for biochar has been soil
Why?
- Focus has been on “creating” *Terra Preta* soils



Observations of increased soil fertility and productivity.
Postulated from ‘slash and burn’ historic charcoal additions

The Big Question

Soil Amendment
Carbon Sequestration
?

OR

Fuel/Energy Source
Waste Disposal
?



Biochar: Soil Application History

However, on the other side:

- Wood distillation plants 1800-1950's
 - Wood pyrolysis – source of chemicals and energy prior to petroleum (fossil fuels)
 - Some historic plants on US-EPA Superfund site list
- Other charcoal sites
 - Not always productive
 - Reduced seed germination
 - Reduced plant growth



(BEGLINGER AND LOCKE, 1957)

Comparison between “natural” and synthetic biochar

“Natural” biochar



- Variable mixed materials (grass, trees, and soil)
- Variable production temperatures
- Exposure to the natural environment – air, wind, & solar

Synthetic (man-made) biochar



- Homogeneous feedstock (same materials)
- Constant production temperature
- Limited to no exposure to natural climate conditions

Soil Application... Long History

Applications date back to the beginning of modern science [1800's]:

And even earlier...



Fire pits built on soil...



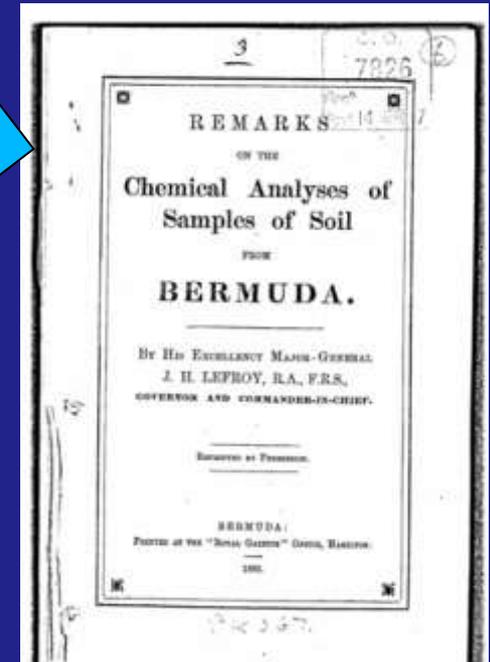
Ancient Egyptians - pyroligneous acid
(bio-oil)

-used for embalming

Soil Application... Long History

Applications date back to the beginning of modern science [1800's]:

Ashes (see also *Potash*) “constitute an important class of manures, differing, however, in their effects according to the substance which has undergone the process of burning, and the manner in which the process has been accomplished. The ashes of all vegetable substances consist principally of those substances which plants require, as charcoal, lime, phosphoric acid, and alkaline salts. Of these charcoal or carbon is the most valuable, and hence to secure it in the greatest quantity the process of burning should be carried on as slowly as possible, and this is best effected by covering up the mass while burning and admitting no more air than just sufficient to keep up a smouldering fire. The ashes of all vegetables contain almost the same constituent parts, and are found useful in all soils and to the majority of crops. They should always be applied when newly burned, as they lose much of their value by keeping even although kept under cover. A medium quantity of ashes may be taken as 1 lb. weight to the square yard.”* Coal ashes finely screened are also useful as manure, but less so than wood ashes. The ashes of sea weed, known in England as kelp, contain carbonate of soda and salts of potash, and are much used



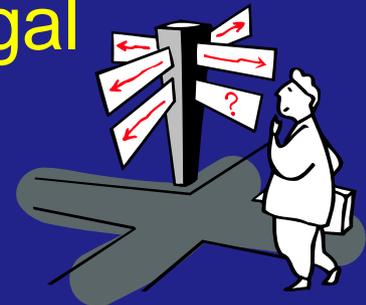
(John Henry LeFroy, 1883)

Quote is from a 1833 report

Application rate
≈5000 lb/ac
(5500 kg/ha)

Proposed Biochar Mechanisms

1. Alteration of soil physical-chemical properties
 - ✓ pH, CEC, decreased bulk density, increased water holding capacity
2. Biochar provides improved microbial habitat
3. Sorption/desorption of soil GHG and nutrients
4. Indirect effects on mycorrhizae fungi through effects on other soil microbes
 - ✓ Mycorrhization helper bacteria → produce *furan/flavoids* beneficial to germination of fungal spores



Soil Application

- Recent review of historical and recent biochar applications:



- 50% positive,
- 30% no effect, and
- 20% negative impacts on growth and/or yield

(Spokas et al., 2012)



Soil Application

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- 50% positive,
- 30% no effect, and
- 20% negative impacts on growth and/or yield

(Spokas et al., 2012)

- *However, should not be used as a basis for forecasting outcomes → Publication bias*

(Møller and Jennions, 2001)



Biochar: Soil Stability

➤ Over a 100 year history of research

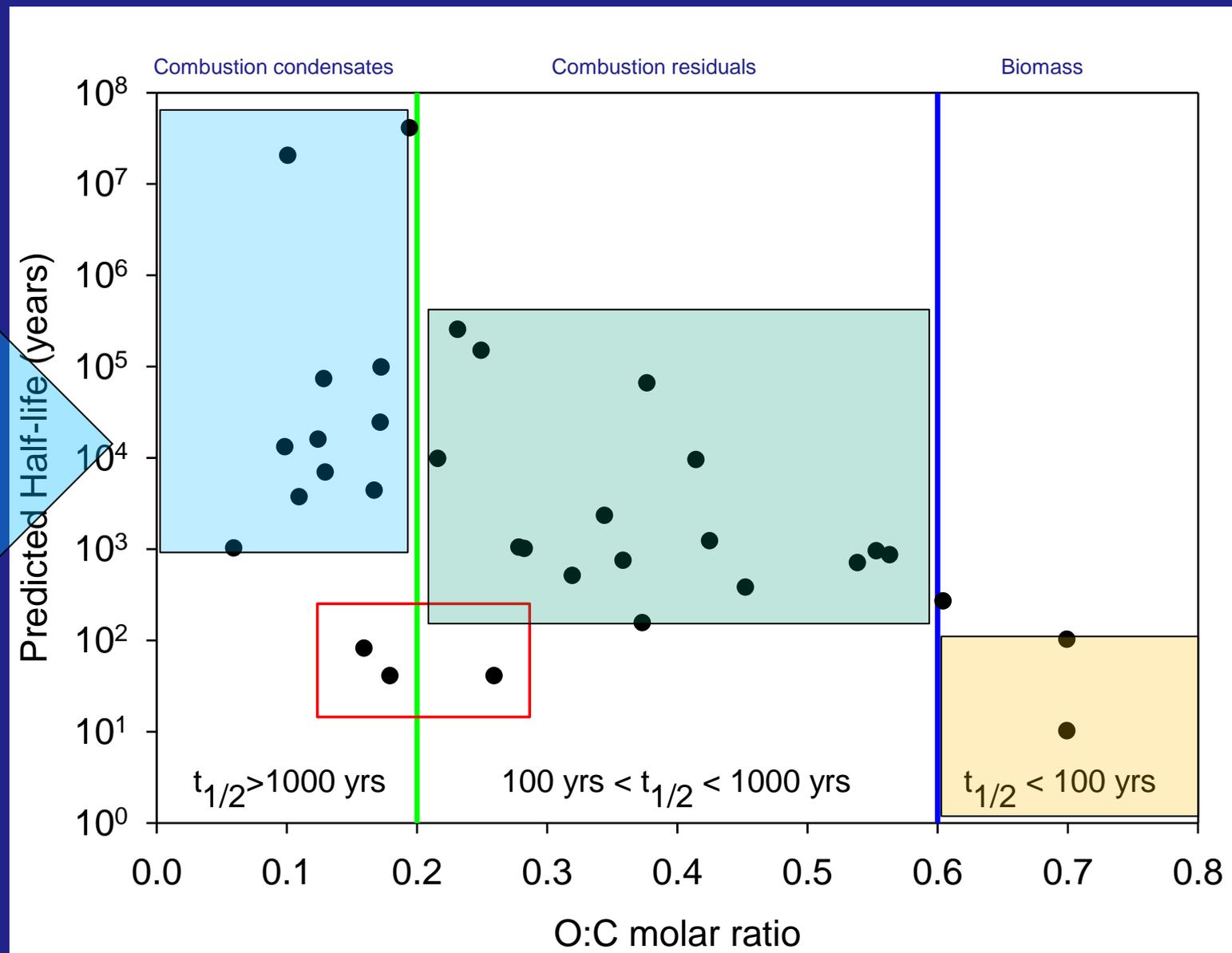
Potter (1908) – Initial observation of fungi/microbial degradation of lignite (low grade coal/black carbon)

Biochar Degradation Study	Residence Time (yr)
Steinbeiss et al. (2009)	<30
Hamer et al. (2004)	40 to 100
Bird et al. (1999)	50-100
Lehmann et al. (2006)	100's
Baldock and Smernik (2002)	100-500
Hammes et al. (2008)	200-600
Cheng et al. (2008)	1000
Harden et al. (2000)	1000-2000
Middelburg et al. (1999)	10,000 to 20,000
Swift (2001)	1,000-10,000
Zimmerman (2010)	100's to >10,000
Forbes et al. (2006)	Millennia based on C-dating
Liang et al. (2008)	100's to millennia



Possible Stability Explanation → O:C Ratio

Biochar Degradation Study	Residence Time (yr)
Baldock and Smernik (2002)	100-500
Bird et al. (1999)	50-100
Cheng et al. (2008)	1000
Forbes et al. (2006)	Millennia based on C-dating
Hamer et al. (2004)	40 (charred straw residue) 80 (charred wood)
Hammes et al. (2008)	200-600
Harden et al. (2000)	1000-2000
Liang et al. (2008)	several centuries to millennia
Lehmann et al. (2006)	100's
Middelburg et al. (1999)	10,000 to 20,000
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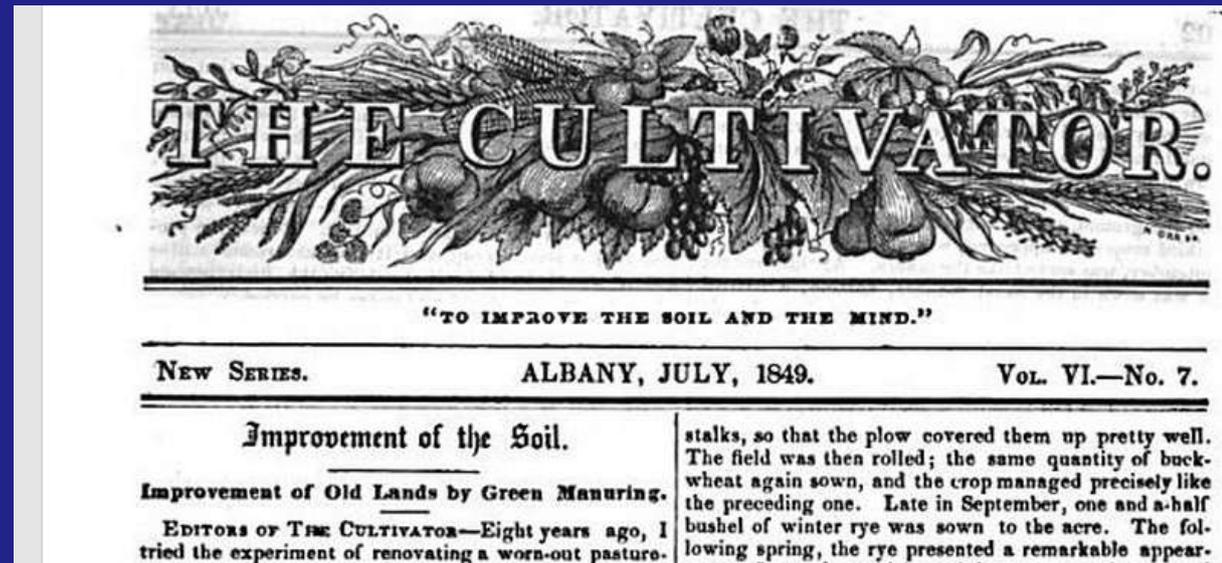


Summary of existing literature studies (n=35) on half-life estimation of biochar [Figure from Spokas (2010)]

Biochar Use ?

“...using charcoal as a fertilizer depends on circumstances.”

“...cost in many situations is probably too great to admit its profitable use as an ordinary manure (soil amendment).”



The Cultivator (1849): “Improvement of the Soil”

What has changed?

1849

Farmers \approx 69% of labor force

Avg farm size 200 acres

1 farmer supports 2 people

\$ 0.75 per bushel for corn



What has changed?

1849

Farmers \approx 69% of labor force

Avg farm size 200 acres

1 farmer supports 2 people

\$ 0.75 per bushel for corn

*\$1.00 in 1914 had the same
buying power as \$22.57 in 2012*



Today

Farmers <2% of labor force

Avg farm size 461 acres

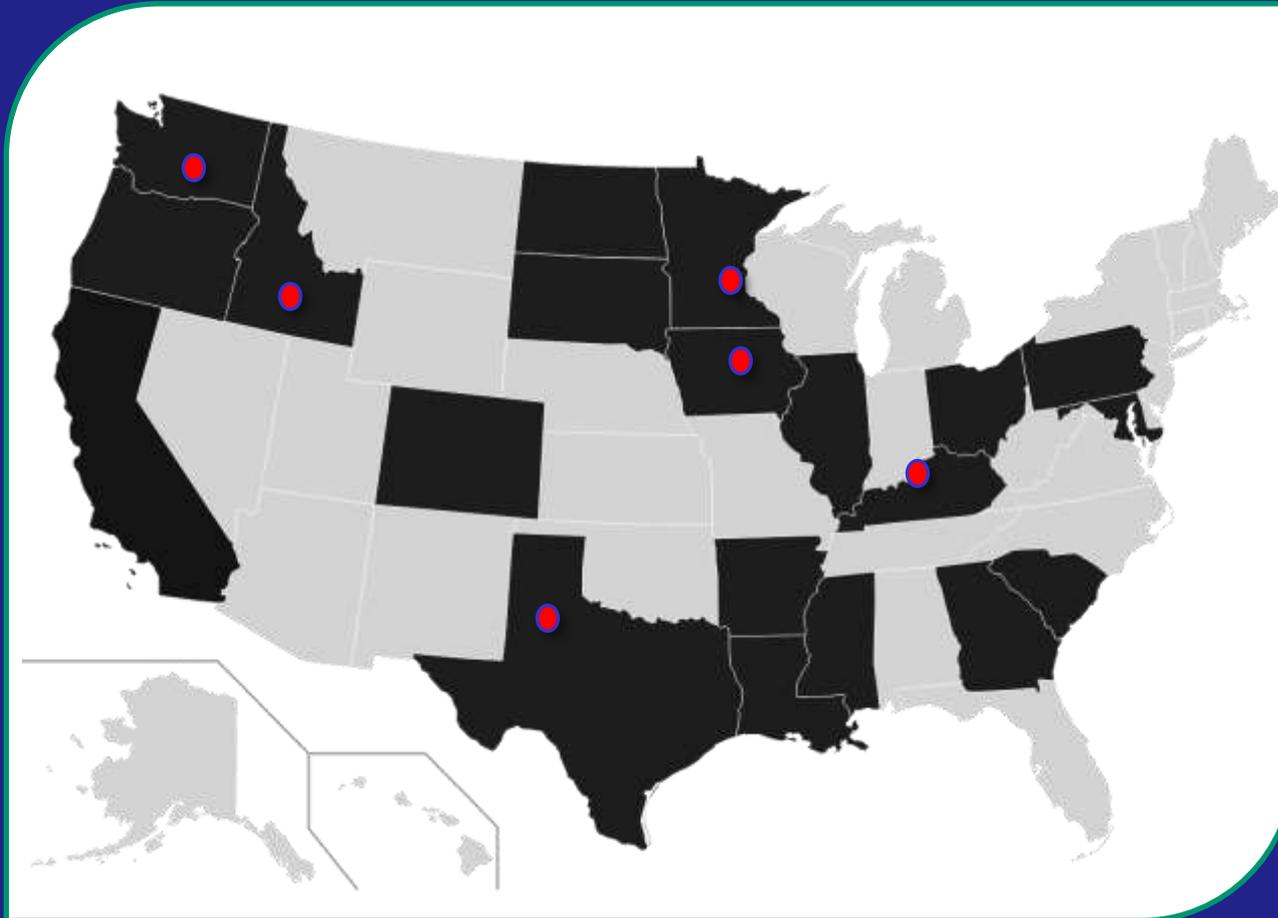
1 farmer supports >100 people

\$ 7.40 per bushel for corn

(July 13 2012)



USDA-ARS Biochar and Pyrolysis Initiative (CHARNet)



Over 20 Locations – 6 Coordinated field plot locations

ARS Biochar Research

Multi-location project

- 6 ARS locations:

 - Ames, IA; Kimberly, ID; St. Paul, MN;

 - Big Spring, TX; Bowling Green, KY; Prosser, WA.

 - +additional sites in the near future*

- Biochar used in replicated field plots

- Continuous corn (same crop for comparison)

- In addition to following crop yield and soil carbon:

 - ✓ Soil gas concentrations and trace gas fluxes

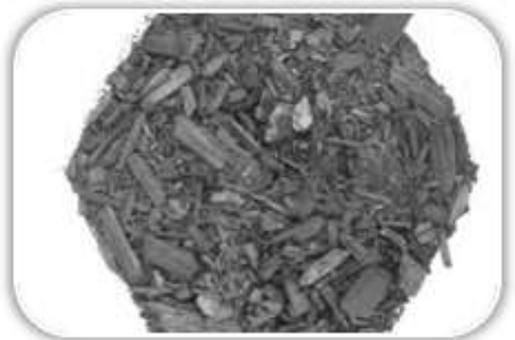
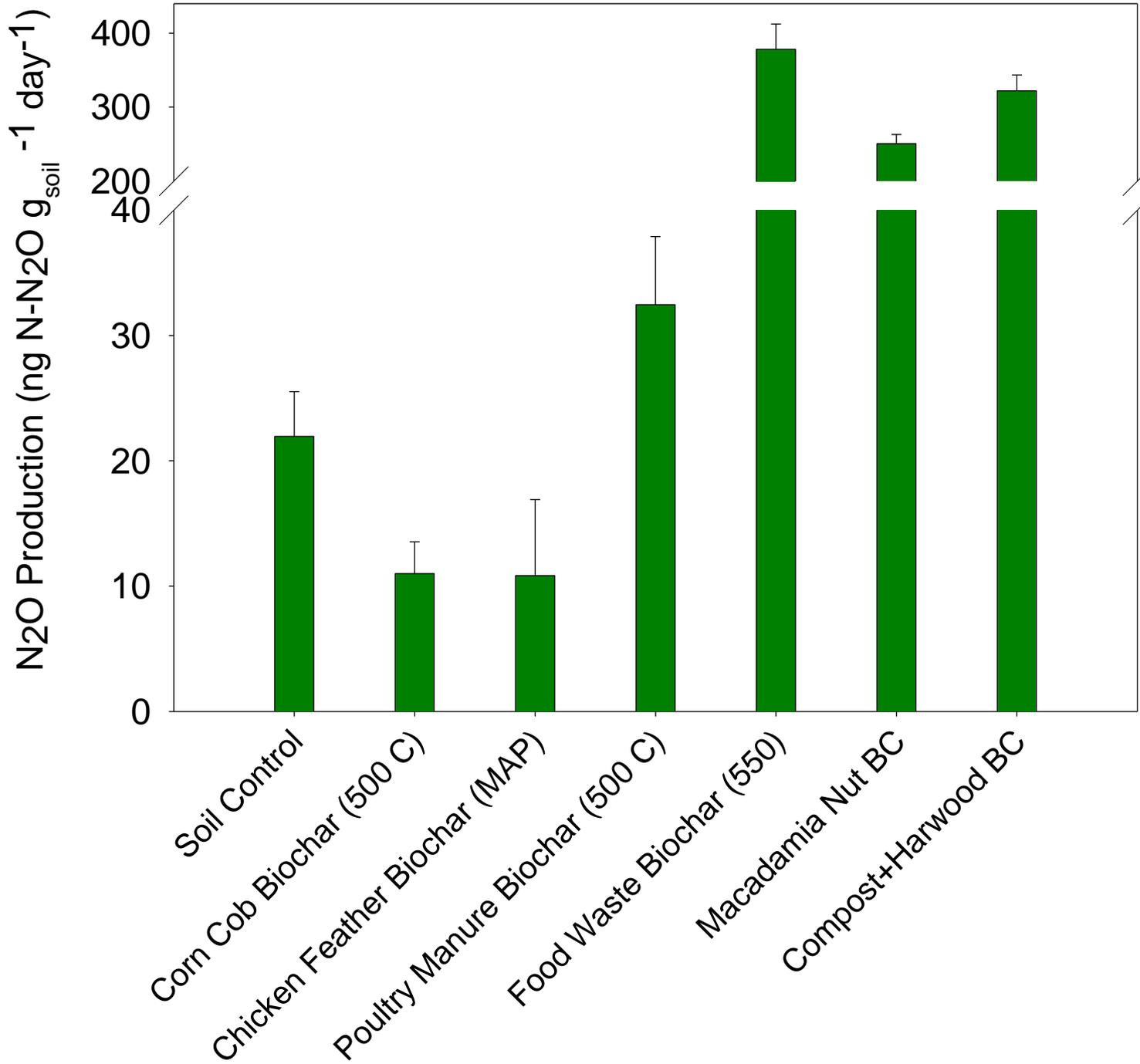
 - ✓ Seedling Emergence/Initial seedling growth rates



Biochar Impacts on Soil Microbes & N Cycling

- 100+ different biochars evaluated
- Over 19 different biomass parent materials
 - Hardwood, softwood, corn stover, corn cob, macadamia nut, peanut shell, sawdust, algae, coconut shell, sugar cane bagasse, switchgrass, turkey manure, chicken feathers, distillers grain
- Represents a cross-sectional sampling of available “biochars”
 - **C content** 1 to 84 %
 - **N content** 0.1 to 2.7 %
 - **Production Temperatures** 350 to 850 °C
 - Variety of pyrolysis processes
 - **Fast, slow, hydrothermal, gasification, microwave assisted (MAP)**



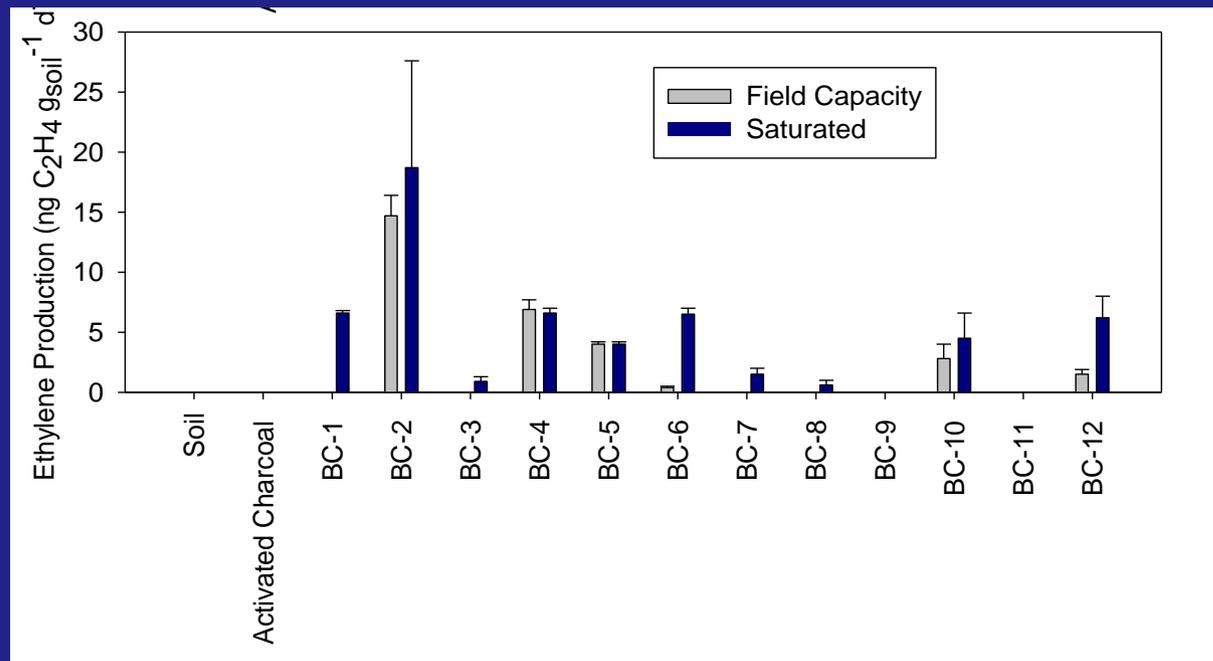
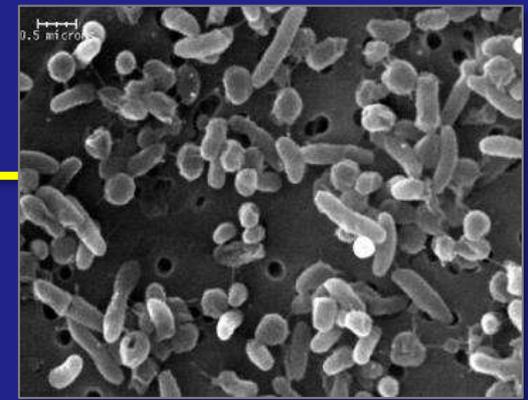


Ethylene Impacts

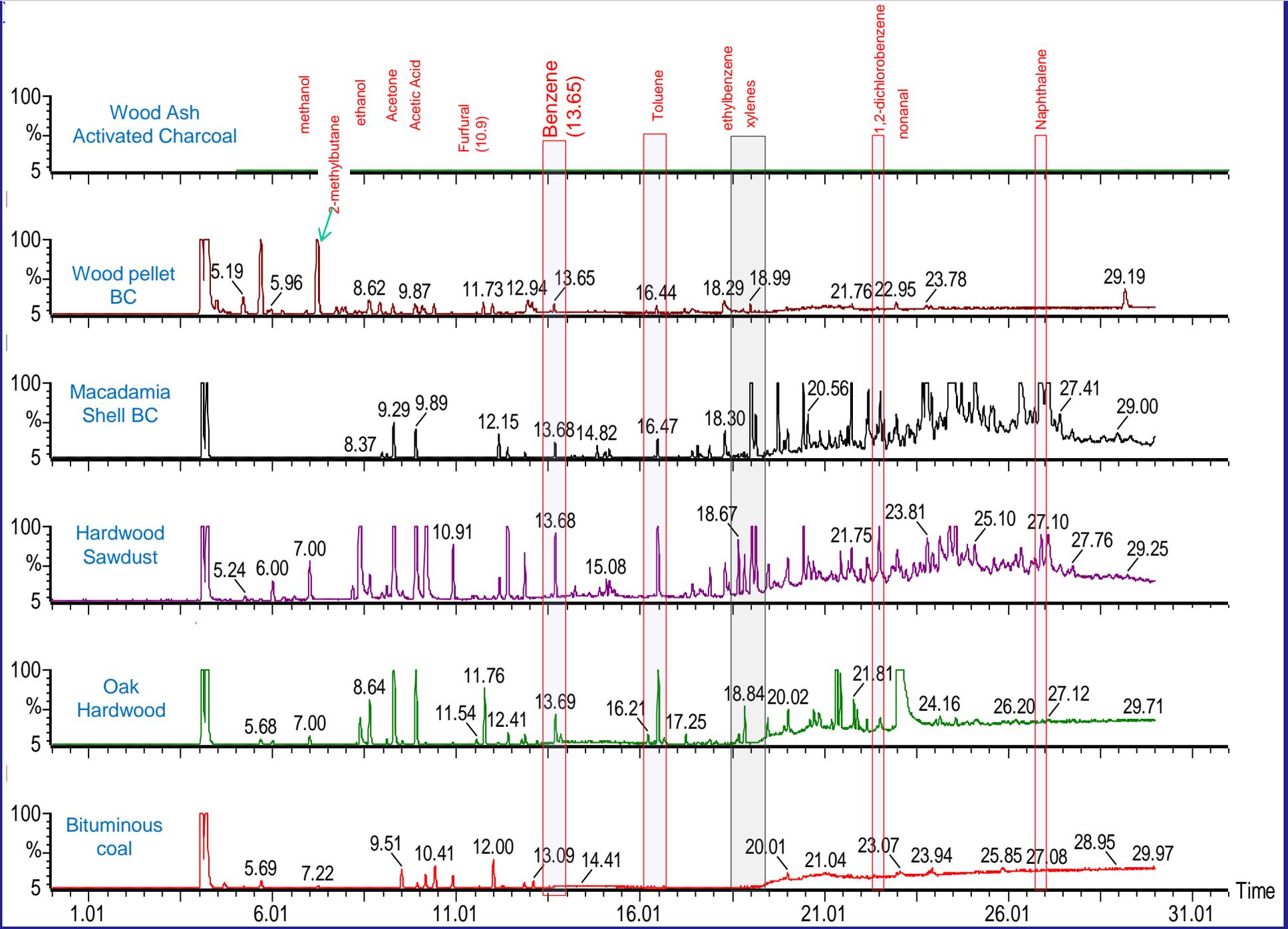
Soil Microbial Impacts

- ✓ Induces fungal spore germination
- ✓ Inhibits/reduces rates of nitrification/denitrification
- ✓ Inhibits CH_4 oxidation (methanotrophs)
- ✓ Involved in the flooded soil feedback

Both microbial and plant (adventitious root growth)



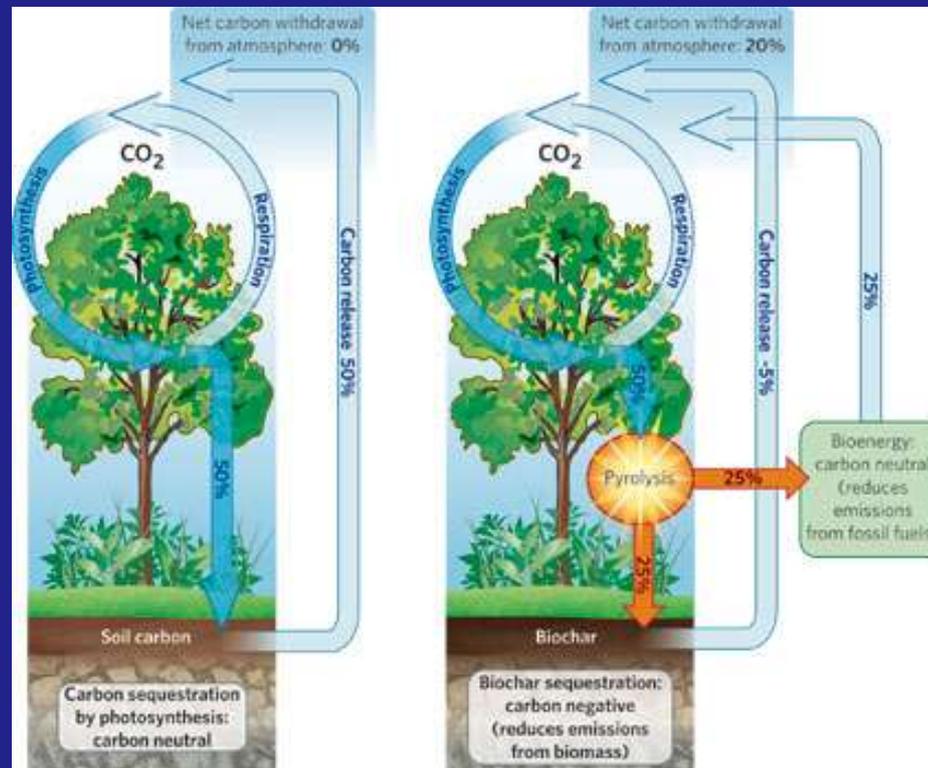
Headspace Thermal Desorption GC/MS scans of biochars



Biochar has a variety of sorbed volatiles = range of potential microbial inhibitors

Conclusions

- Biochar is not a new material → new purpose
 - Carbon Sequestration
 - Plant biomass fixes atmospheric CO₂
 - Biomass is transformed into a more resistant form of carbon
 - Disrupts atmospheric cycling of CO₂



Conclusions

- Biochar is not a new material – new purpose
- No absolute “biochar” consistent trends:
 - Highly variable and different responses to biochar as a function of soil ecosystem (microbial linkage), plant, & position on black carbon continuum:



Conclusions

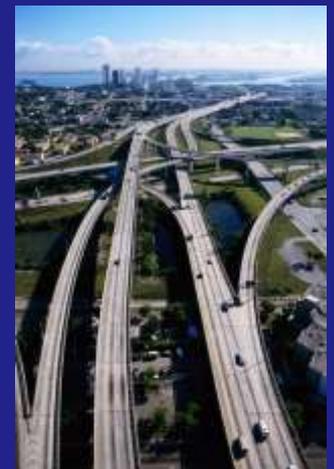
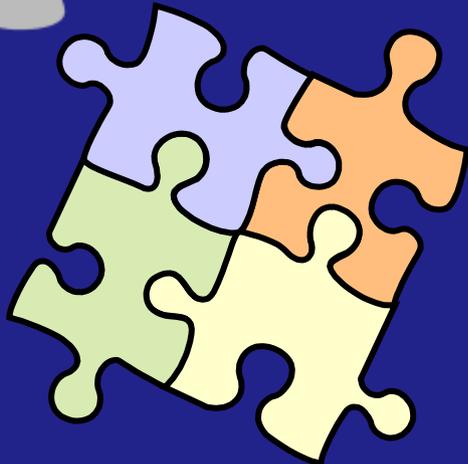
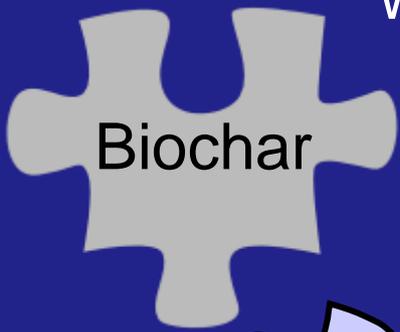
- Biochar is not a new material – new purpose
- No absolute “biochar” consistent trends:

What is clear – Biochar could be a piece of the solution

Just as the climate issues did not arise from a single source;
the solution to the problem will not be a single solution

Soil C sequestration can be one piece of the solution

Multiple avenues should be utilized



Acknowledgements

- Minnesota Department of Agriculture – Specialty Block Grant Program

- Minnesota Corn Growers Association

 - Dynamotive Energy Systems

 - Fast pyrolysis char (CQuest™) through non-funded CRADA agreement

 - Best Energies

 - Slow pyrolysis char through a non-funded CRADA agreement

 - Northern Tilt

 - Minnesota Biomass Exchange

 - NC Farm Center for Innovation and Sustainability

 - National Council for Air and Stream Improvement (NCASI)

 - Illinois Sustainable Technology Center (ISTC) [Univ. of Illinois]

 - Biochar Brokers

 - Chip Energy

 - AECOM

 - Penn State

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Kia Yang, Michael Ottman, Ed Colosky, and Vang Yang

MN Department of Agriculture Project



- Examining the bioaccumulation of sorbed chemical species in specialty crops
- Impacts on yield and growth on a variety of crops
- Field and laboratory components

