Biochar:
What is it and what can it do?

?

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Presentation to the Washington County UM Extension Master Gardeners
Jan. 26, 2012
Bayport, MN

Agricultural Research Service (*ARS*)

• In-house scientific research agency for the United States Department of Agriculture (USDA).

Goal: Finding solutions to agricultural problems that affect Americans every day, from field to table

- 2,500 scientists
- 6,000 other employees
- 1,000 research projects within 20 National Programs
- 100 research locations including a few in other countries
- $1.1 billion (USD) fiscal year 2012 budget

USDA

Agricultural Research Service

USDA-ARS
Soil and Water Management Unit
St. Paul, MN

- 6 USDA-ARS scientists
  - Nutrient cycling
  - Greenhouse gas
  - Agrochemicals
  - Drainage

•Located on the UM -St. Paul Campus

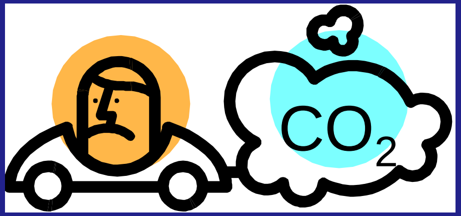
MISSION: Develop and evaluate agricultural management practices that optimize production while reducing impacts on air, soil and water quality

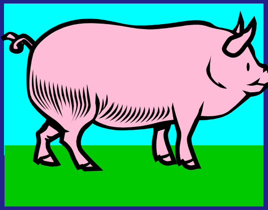
Step 1. Biochar: What is it ?

Carbon (many forms)







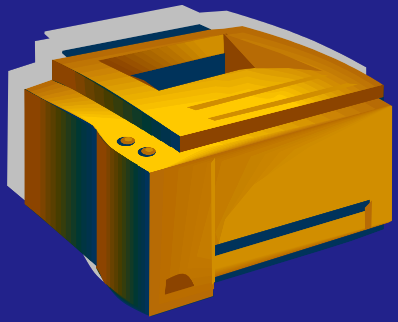
Biomass Carbon

Black Carbon

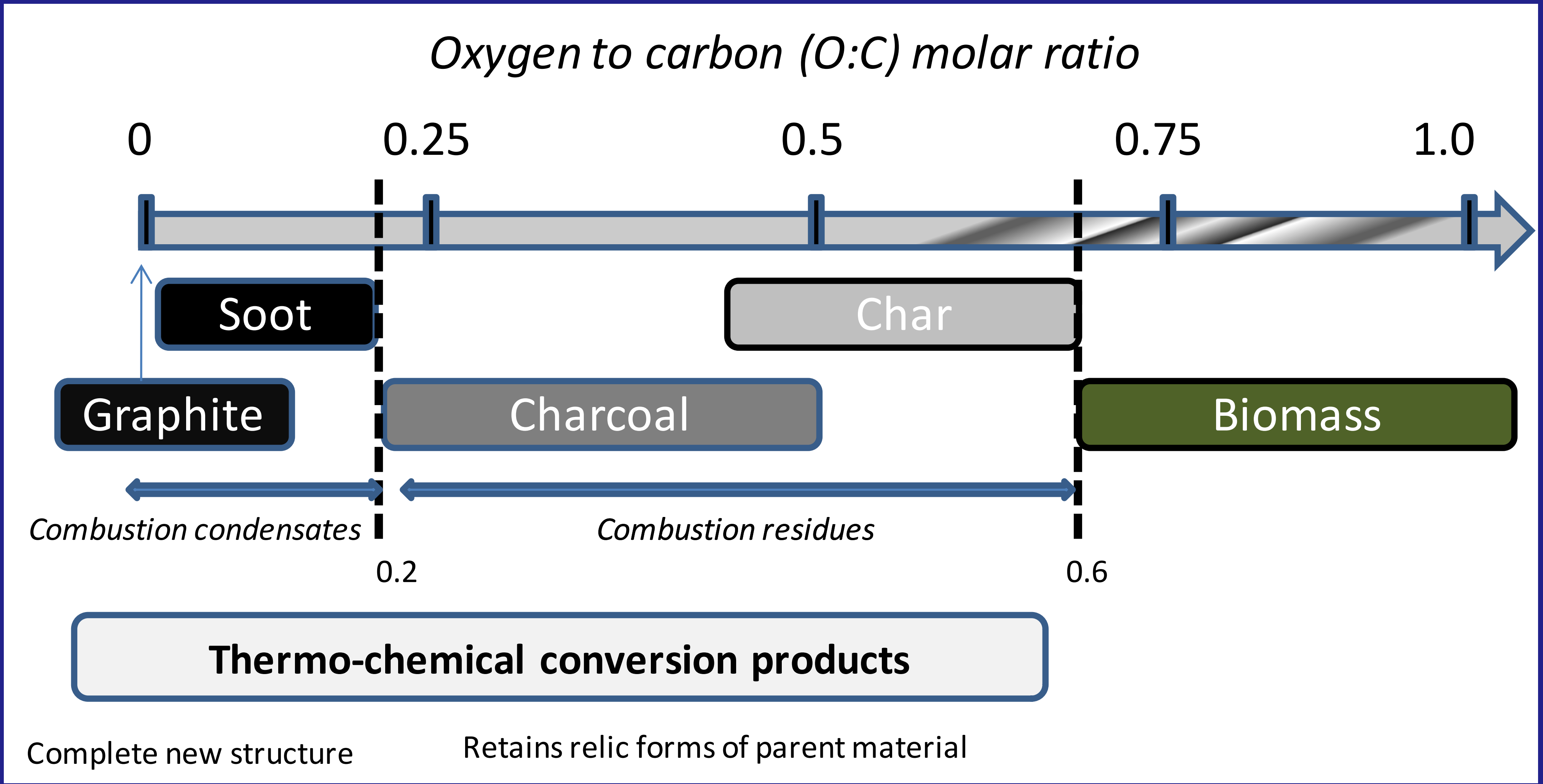
•*Black carbon* is the range of solid residual products resulting from the chemical and/or thermal conversion of any carbon containing material (e.g., fossil fuels and biomass) (Jones et al., 1997)








Black Carbon "Spectrum"



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

Problem → Lack of nomenclature uniformity

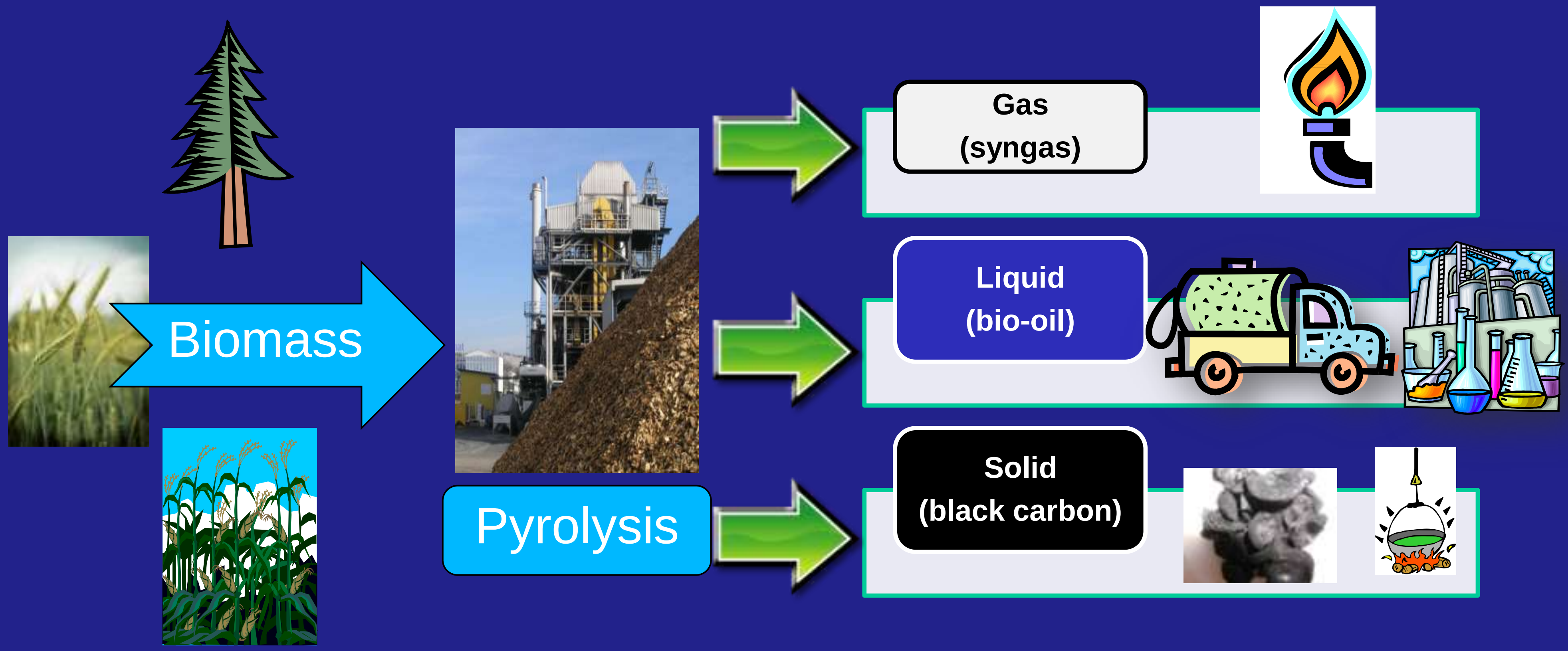
(Jones et al., 1997)

Formation of Black Carbon: “Pyrolysis”

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

    Cooking → roasting, baking, frying, grilling
- Also occurs in lava flows and forest/prairie fires


Overview of Pyrolysis



Building Blocks→ Tear apart and reorganize → Form new compounds and chemicals

Wide Spectrum of Pyrolysis

Both temperature and time factors:

- High temperature pyrolysis
  →gasification (>800 ºC) {+ O_2 }

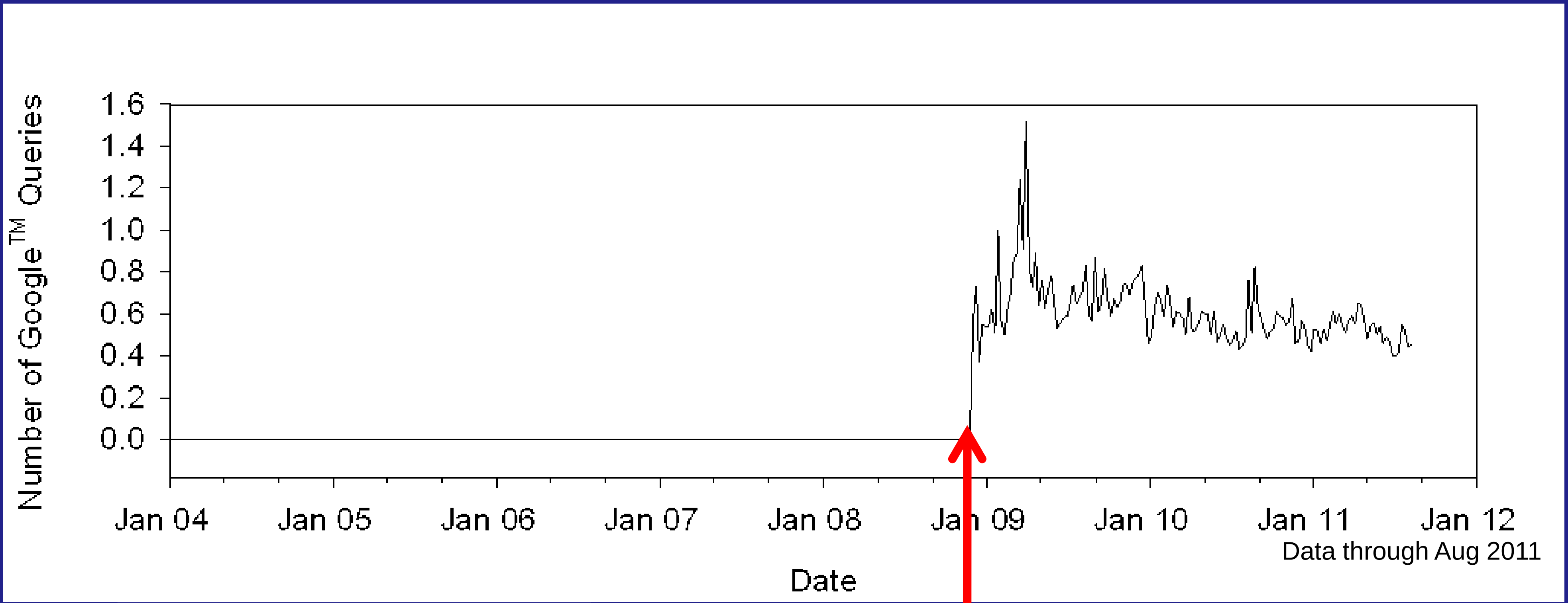
- "Fast" or "Slow" pyrolysis (300-600 ºC)
  - Fast pyrolysis
    - 60% bio-oil, 20% biochar, and 20% syngas
    - Time = seconds
  - Slow pyrolysis
    - Can be optimized for char production (>40% biochar yields)
    - Time = hours

Pyrolysis unit in Florence, SC (USDA-ARS)

Others Ways to Make Black Carbon

Back to Biochar

Google™ Timeline



1998 - First use of *biochar* to describe the solid residue in scientific literature from biomass pyrolysis (Bapat and Manahan, 1998)

10 years later

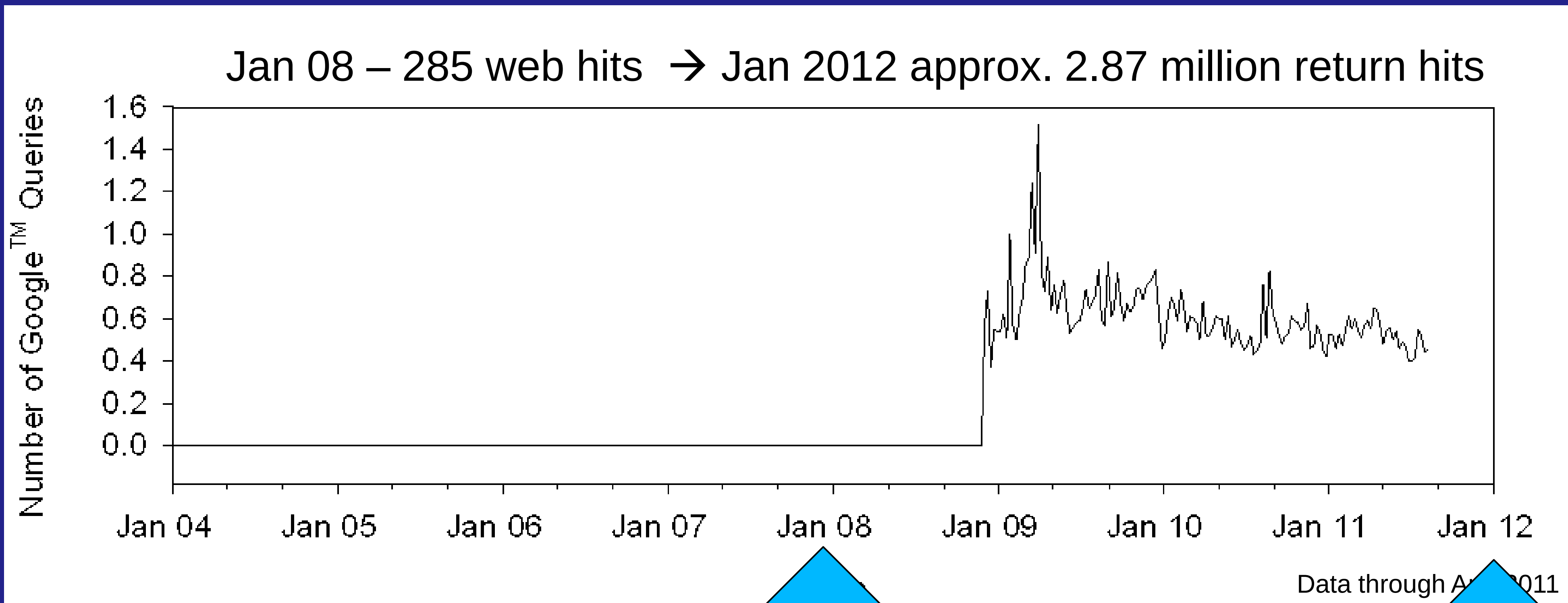
Dec. 2008 – Biochar linked in newsfeed story as a potential abatement to climate change; even though scientifically was mentioned over 20 years prior (~1985)

Biochar – Returned Web Results

Jan 2008 – 285 results

4 years later

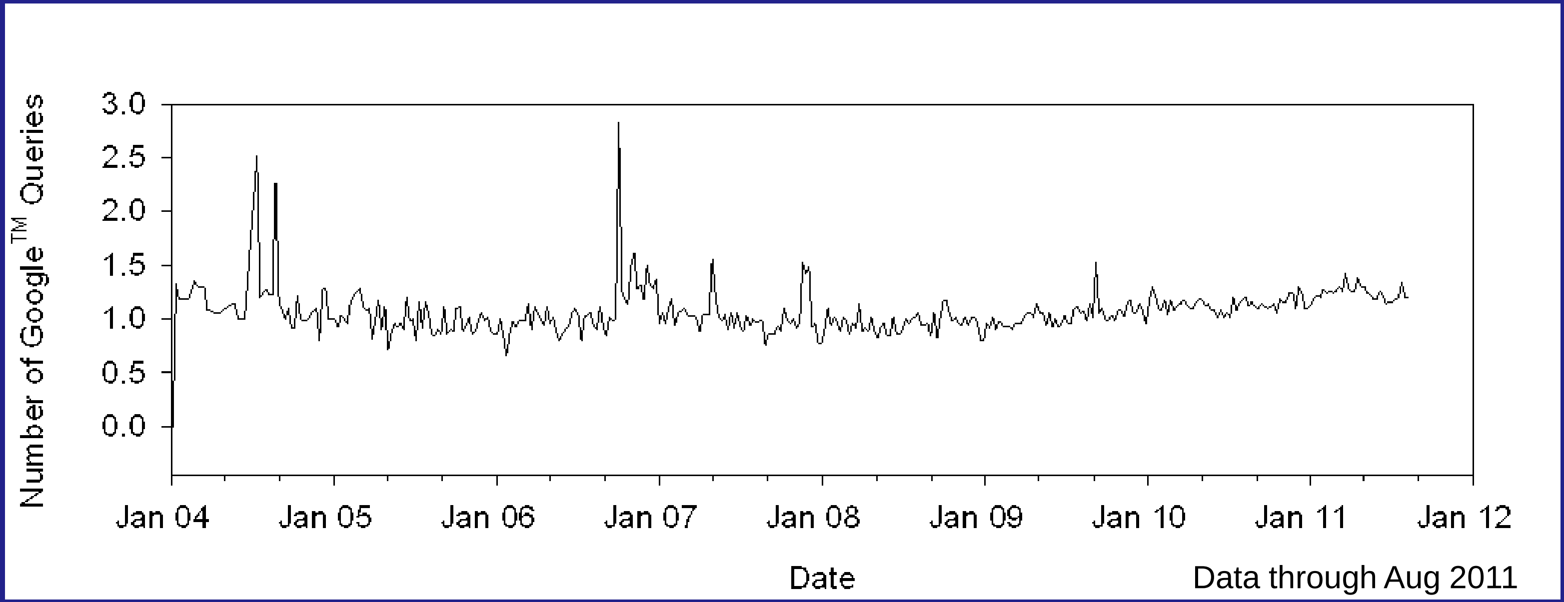
Biochar – Returned Web Results



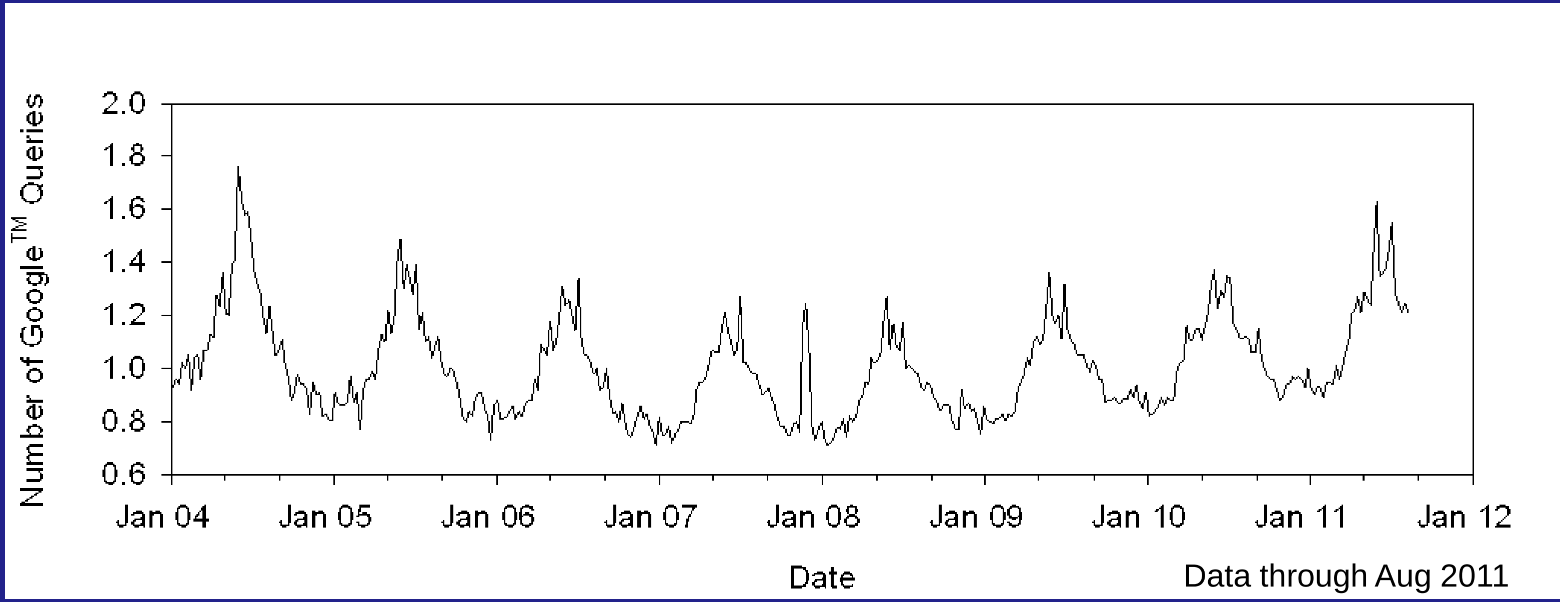
Jan 2008 – 285 results

Jan 2012 – 2.87 million results

Back to Google Search Trends



Black Carbon



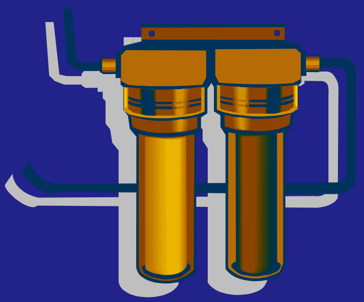
Charcoal

Biochar: New purpose not a new material

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

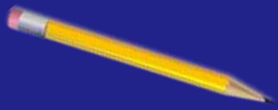
Cave Drawings
(>10,000 to 30,000 BC)

Used as fuel
(3000-4000 BC)



Water filtration
(2000 BC)

Charcoal production
(15th century)



Pencils – 2012

Biochar: New purpose not a new material

- **<u>What is new?</u>**

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

<u>Atmospheric C sequestration</u>

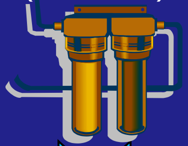
Dates to 1980’s and early 2000’s

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

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

Used as fuel (3000-4000 BC)

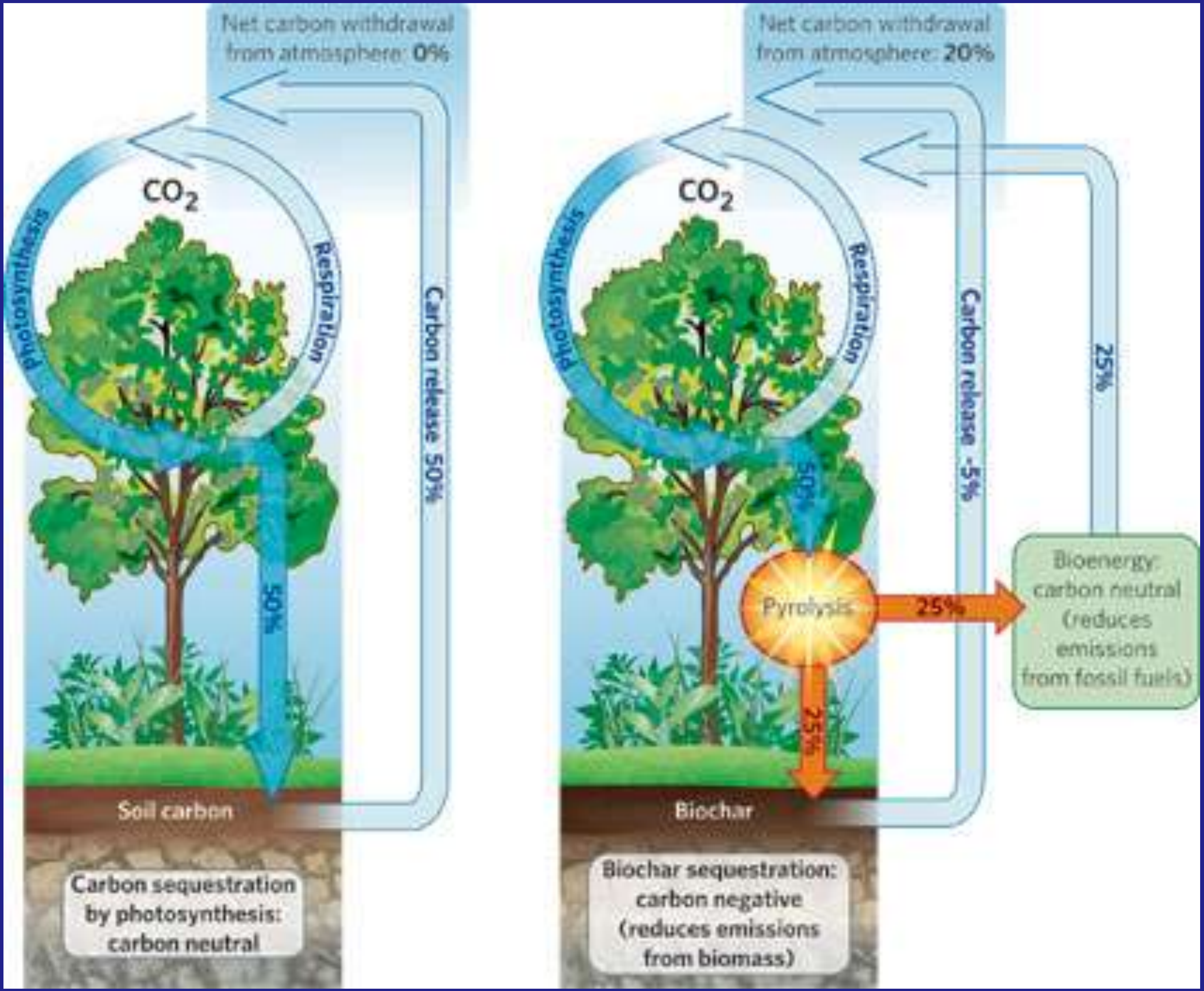
Water filtration (2000 BC)



Charcoal production (15th century)

Climate Change Mitigation (1980’s)

Carbon Cycle (+ Biochar)



Lehmann 2006

Carbon Sequestration: Storage of C

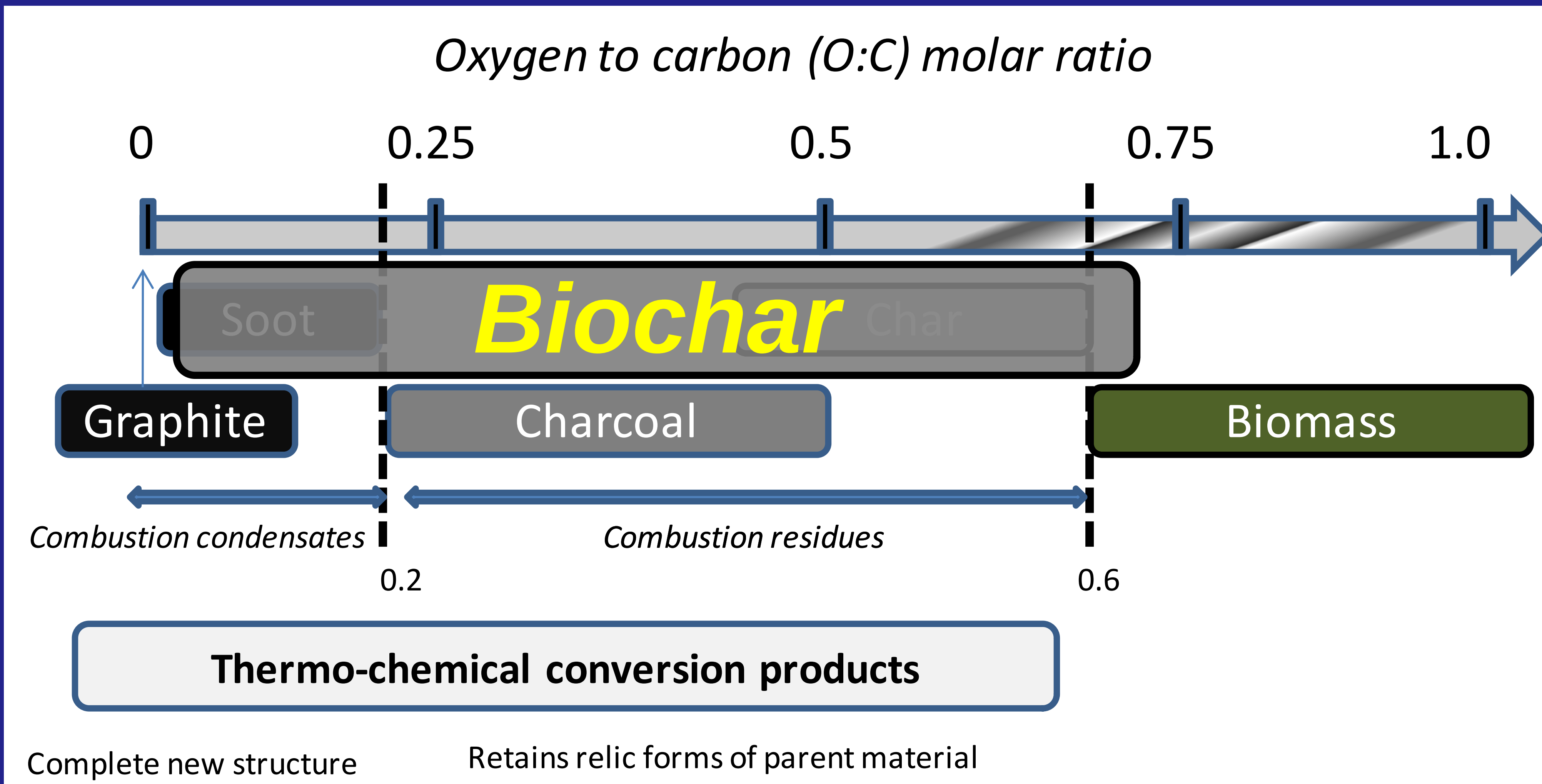
Carbon Sequestration Rates

Ecosystem	Range of CO_2 Sequestration Rates (metric tons C/acre/yr)
Cropland	0.2 to 0.6 [0.5]
Grassland / Prairie	0.1 to 1.0 [0.8]
Forest	0.05 to 4.0 [1.2]
Swamp / Floodplain / Wetland	2.2 to 3.7 [3.0]




Biochar: Black Carbon Continuum

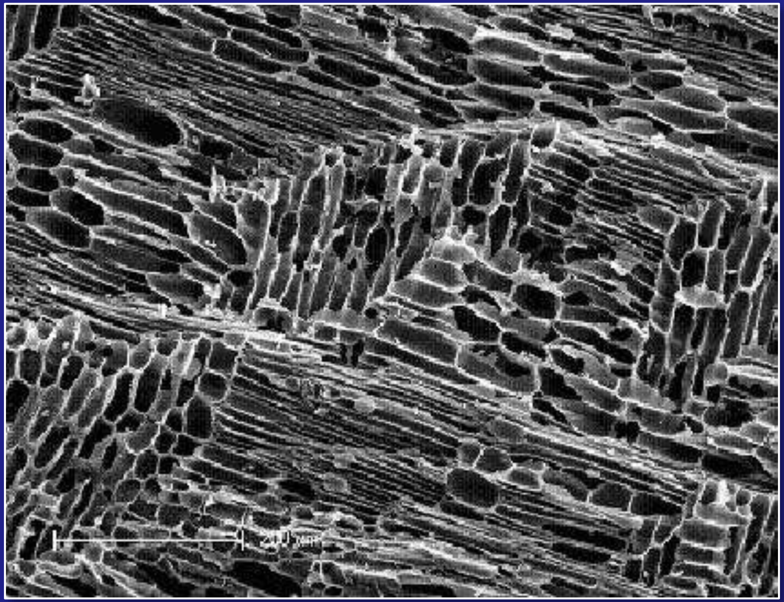
Biochar – Spans across multiple divisions in the Black C Continuum
However, *biochar is NOT a new division or material…*

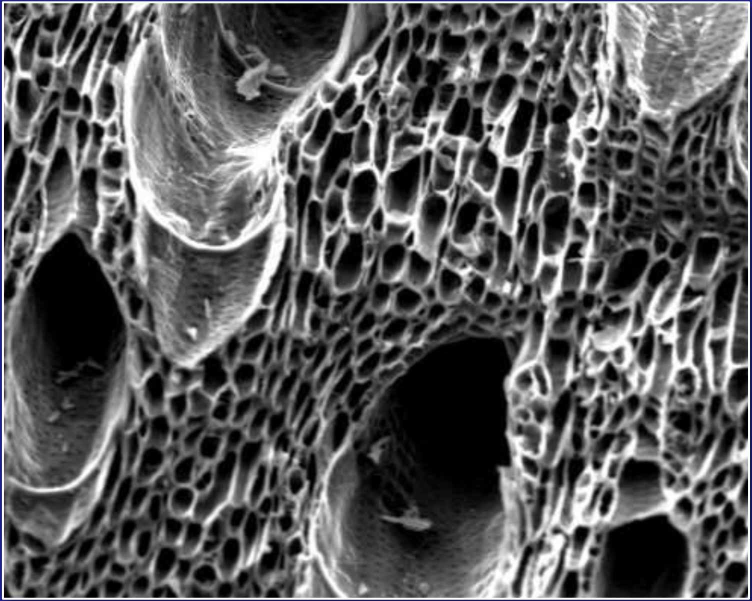


Adapted from Hedges et al., 2000; Elmquist et al., 2006

Biochar: Structure

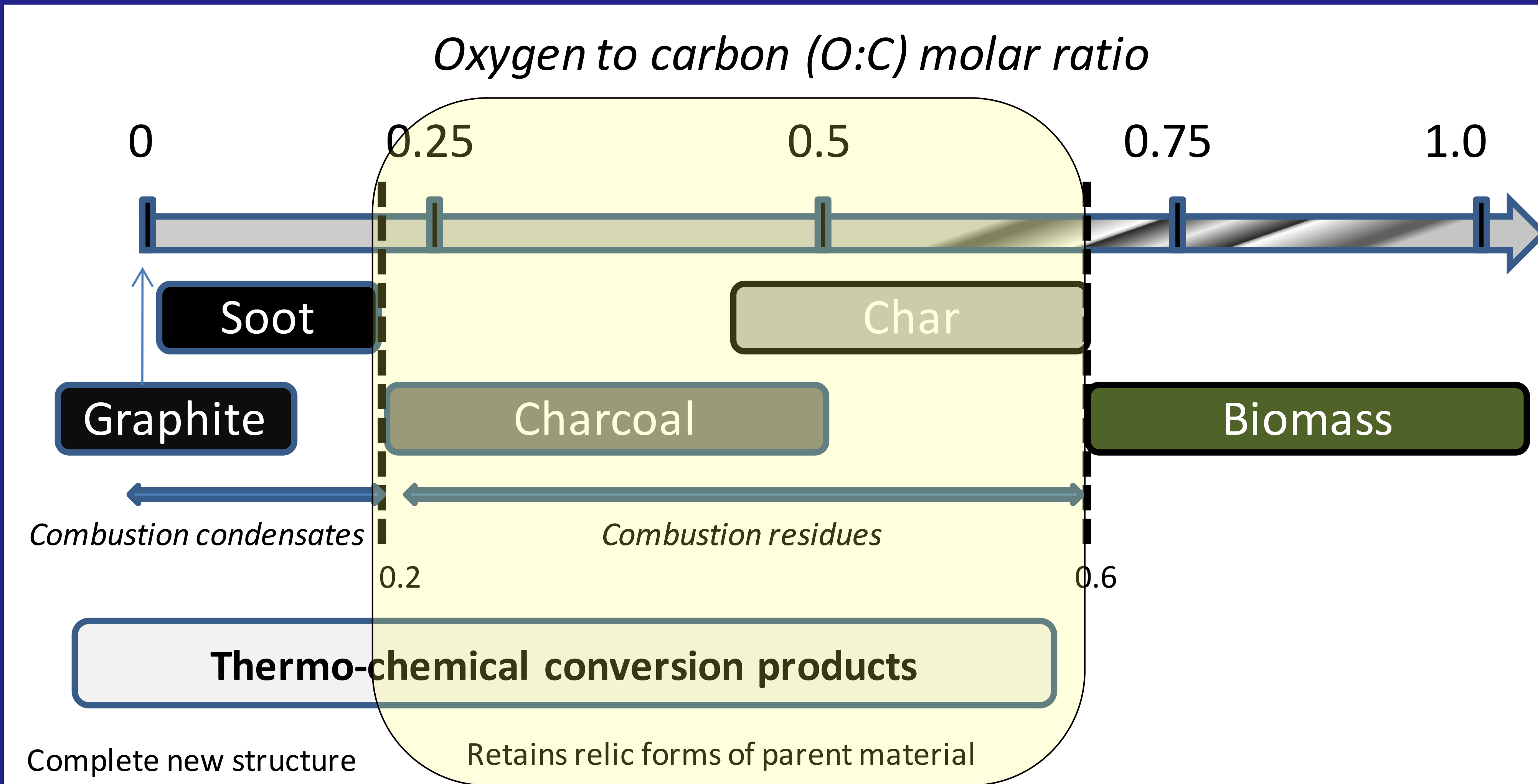
Pyrolysis (biochar)





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 CO_2 levels
- 2. Soil Improvements
  - Improve water quality
  - Improve soil fertility
  - Reduce GHG emissions
- 3. Bioenergy

Biochar (Summary)

- Solid residue remaining after the heating of biomass materials (renewable) without oxygen (incomplete combustion) 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 Interactions

Biochar: Soil Application

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

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

Comparisons of “Natural” vs. Synthetic

Natural Black Carbon (*Biochar?*)	Synthetic (Pyrolysis) Biochar

-Heterogeneous feedstock

- <u>Impurities</u>
  - Soil and oxygen
    Minerals (metals) alter yields
    (e.g. Robertson, 1969; Bonijolya et al., 1982; Baker, 1989)
- <u>Multiple feedstock sources</u>
  - Species and types

-Pure homogeneous feedstock

-Variable temperature

- 80 to 1000 ^{o}C

-“Constant” temperature

- Industrial Process

-Air cooled/Precipitation/Solar (UV)

- Exposed to environmental conditions

-Typically cooled under anaerobic conditions (no water)

Biochar: Soil Application History

However, on the other side:

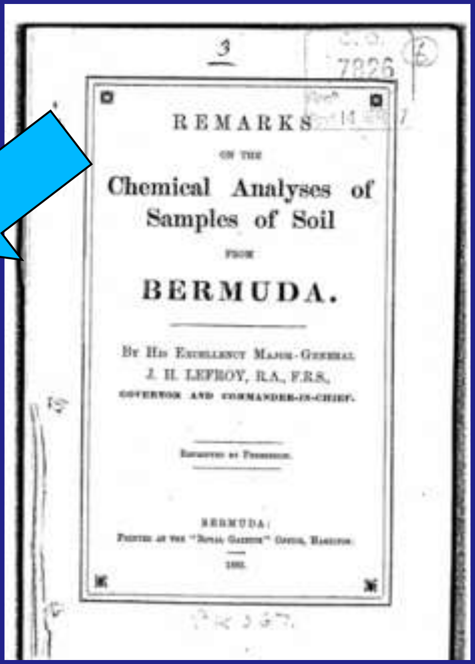
- Wood distillation plants [1800-1950's]
  - Wood pyrolysis – source of chemicals and energy prior to petroleum (fossil fuels)
  - Some historic plants on US-EPA Superfund site list
- Other charcoal sites
  - Not always productive
    - Reduced seed germination
    - Reduced plant growth

(BEGLINGER AND LOCKE, 1957)

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



(LeFroy, 1883)

Quote is from a 1833 report

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

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

- Recent review of historical and recent biochar applications:

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

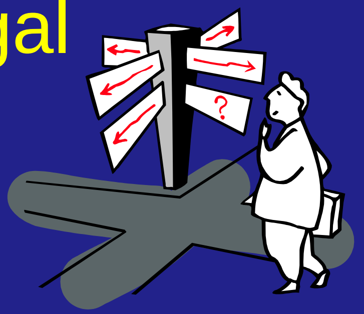
(Spokas et al., 2011)

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

(Møller and Jennions, 2001)

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



Warnock et al. (2007)

Biochar: Soil Stability

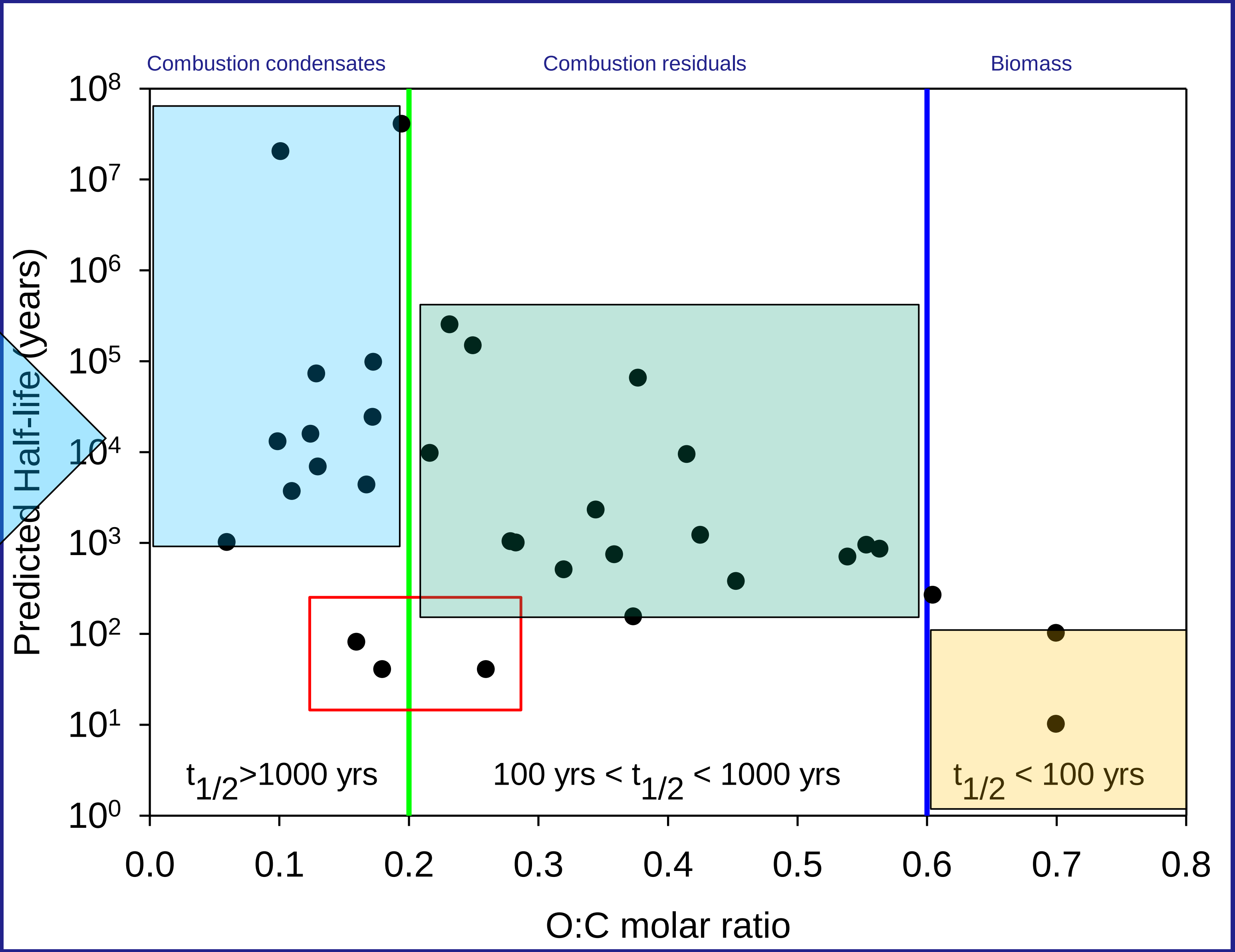
- Over a 100 year history of research

  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

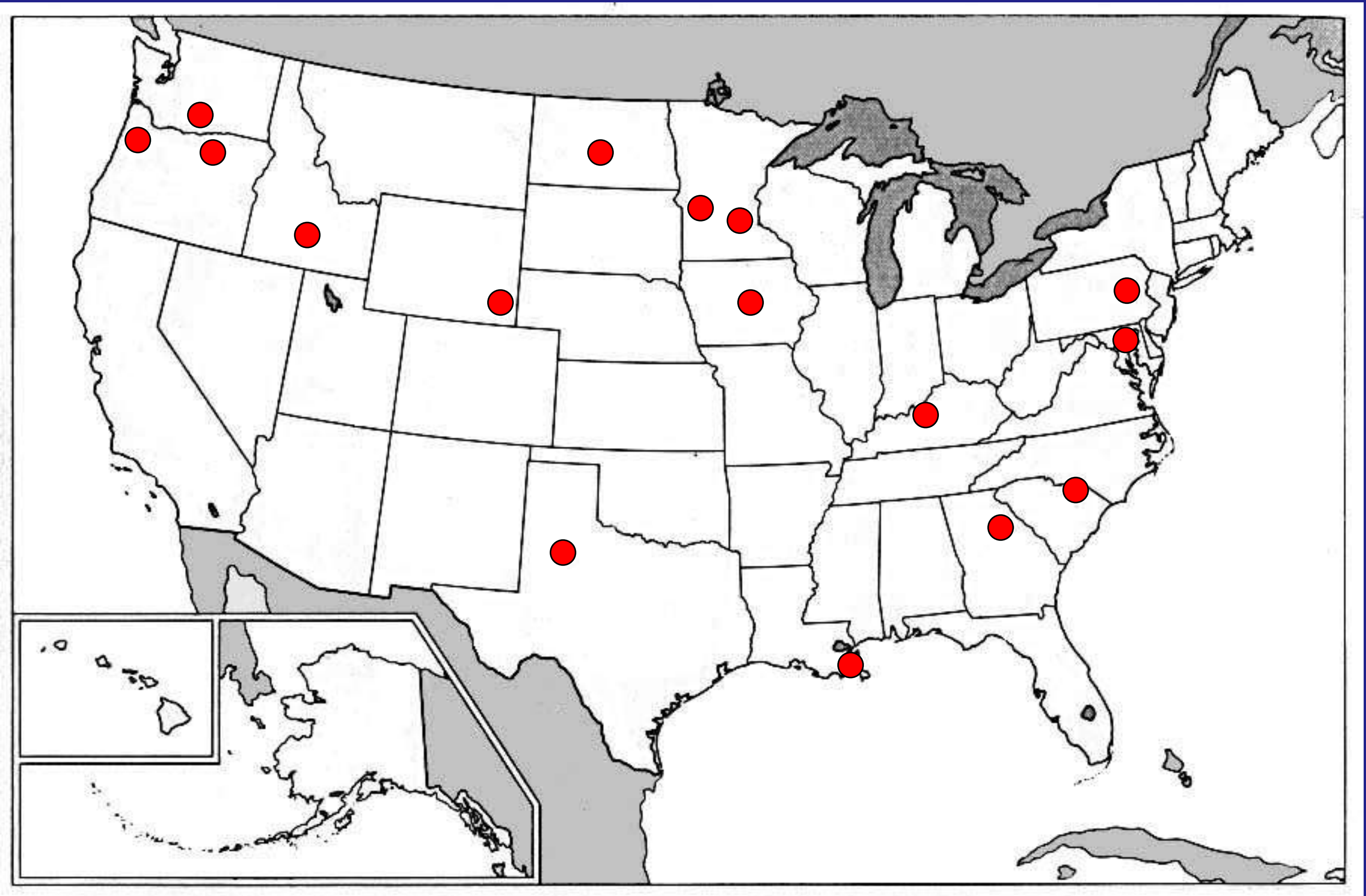
Possible Stability Explanation → O:C Ratio

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
Steinbeiss et al. (2009)	<30
Swift (2001)	1,000-10,000
Zimmerman (2010)	100-10,000



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

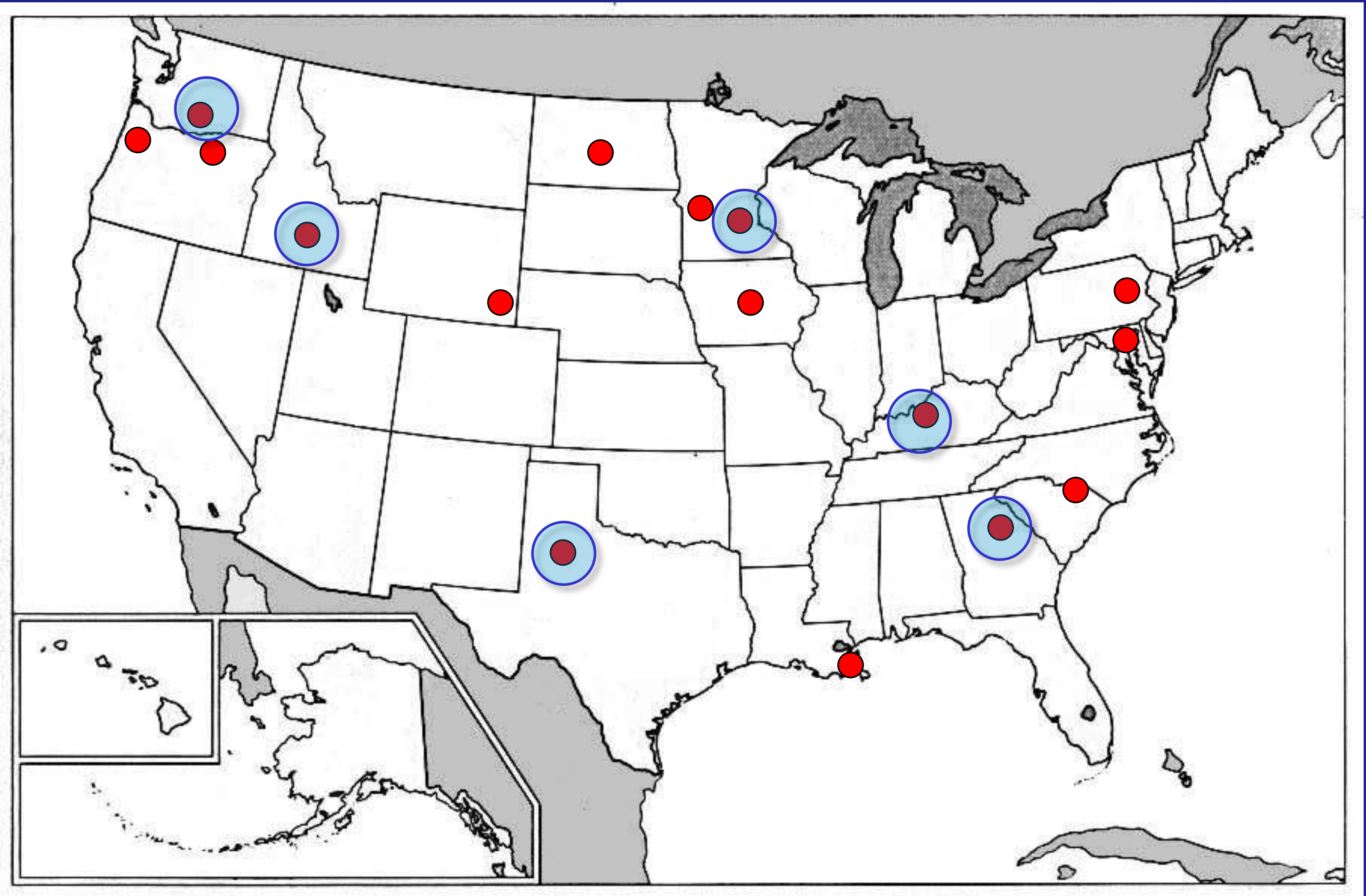
USDA-ARS Biochar and Pyrolysis Initiative (CHARNet)



16 Locations – Coordinated Multi-location Research Activities

Agricultural Research Service

USDA-ARS Biochar and Pyrolysis Initiative (CHARNet)



6 Locations – Coordinated field plot experiment using same hardwood biochar

USDA

Agricultural Research Service

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

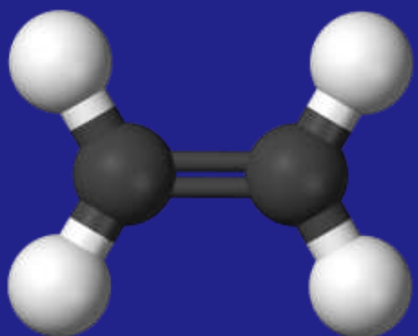
- •Biochar used in replicated field plots
- •Continuous corn (same crop for comparison)
- •In addition to following crop yield and soil carbon:
  - ✓ Soil gas concentrations and trace gas fluxes
  - ✓ Seedling Emergence/Initial seedling growth rates

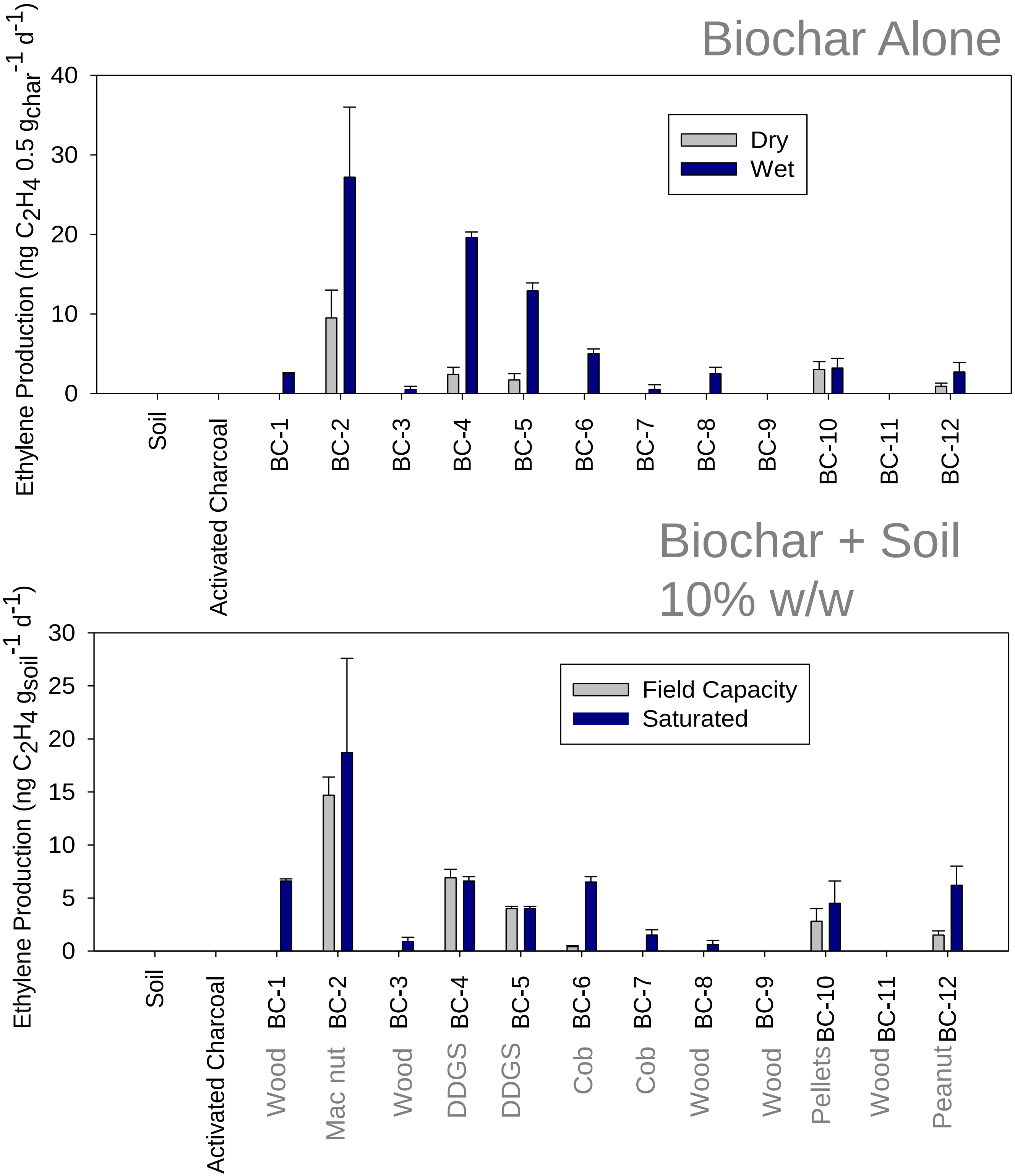
Biochar Impacts on Soil Microbes & N Cycling

- 90+ different biochars being 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 ^{o}C
  - Variety of pyrolysis processes
    - Fast, slow, hydrothermal, gasification, microwave assisted (MAP)

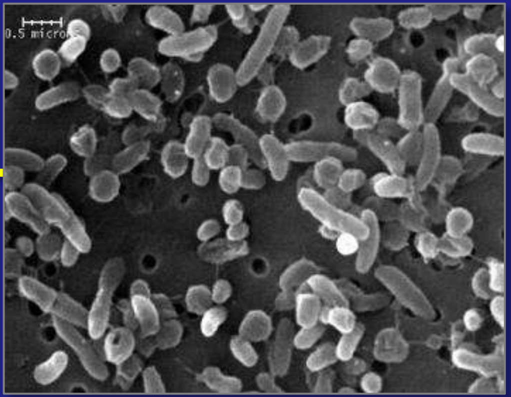



Ethylene (ethene) Production Rates



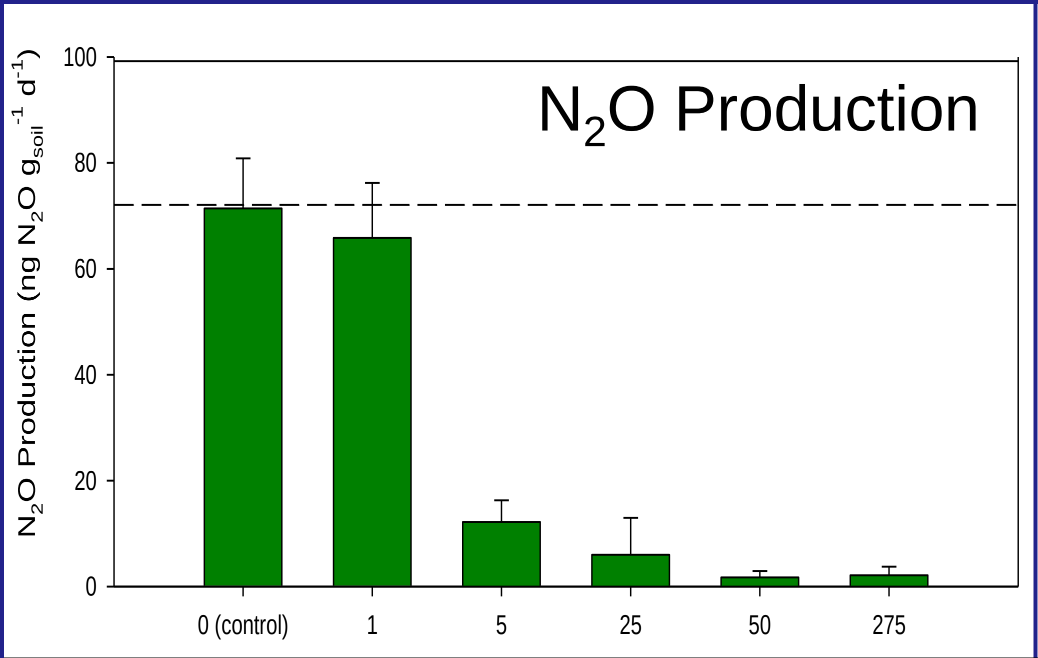


Ethylene Impacts

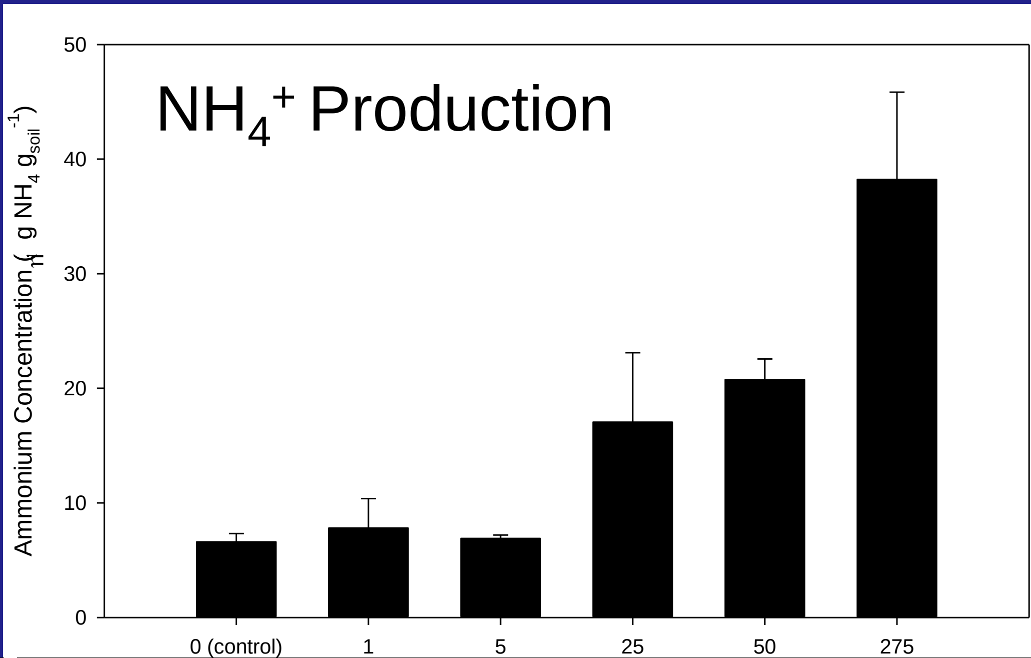


Soil Microbial Impacts

- ✓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)



Ethylene Headspace Concentration (0 to 275 ppmv)



Ethylene Headspace Concentration (0 to 275 ppmv)

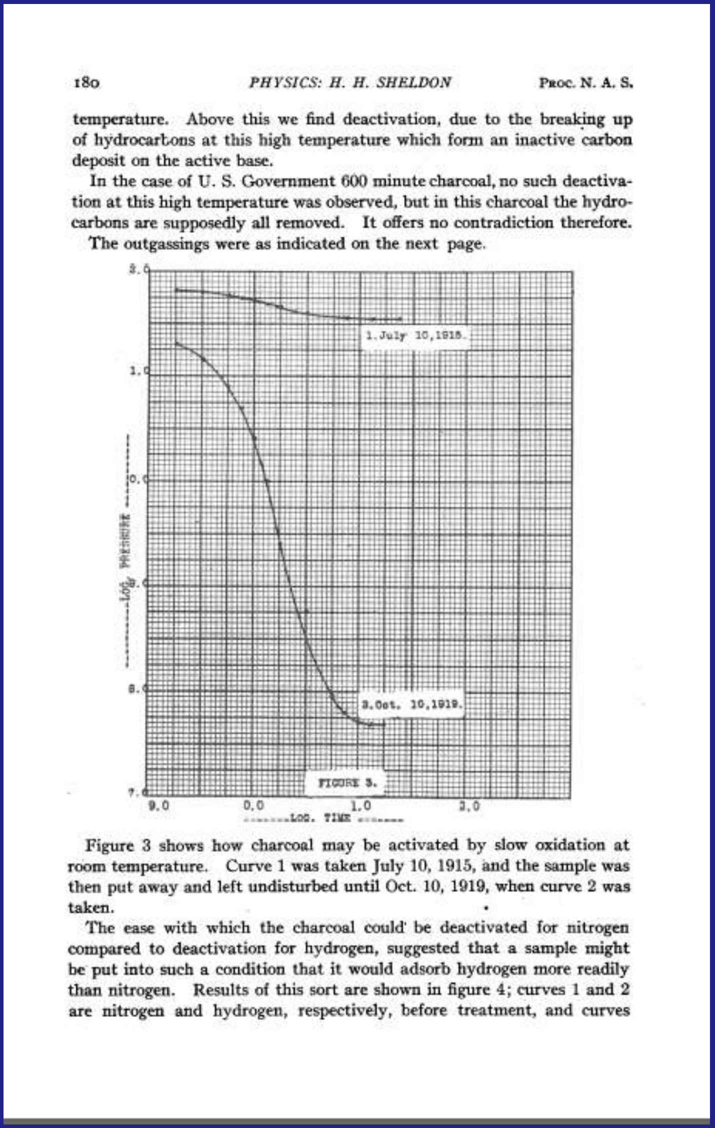
Post-processing of Biochar (Activation)

- Charcoal can be customized in terms of sorptive behavior by activation
  - "Designer Biochar" (J. Novak)
  - Processes:
    - <u>Thermal</u> and/or <u>chemical</u>
      - $ZnCl_2$, steam, acid, base, etc.

- However:

  Surface modification of charcoals <u>also occurs in air at ambient conditions</u>

  3 fold increase in N_2 sorption: 4 year storage (Sheldon, 1920)



180 *PHYSICS: H. H. SHELDON* PROC. N. A. S.

temperature. Above this we find deactivation, due to the breaking up of hydrocarbons at this high temperature which form an inactive carbon deposit on the active base.

In the case of U. S. Government 600 minute charcoal, no such deactivation at this high temperature was observed, but in this charcoal the hydrocarbons are supposedly all removed. It offers no contradiction therefore.

The outgassings were as indicated on the next page.

FIGURE 3.

LOG. TIME

Figure 3 shows how charcoal may be activated by slow oxidation at room temperature. Curve 1 was taken July 10, 1915, and the sample was then put away and left undisturbed until Oct. 10, 1919, when curve 2 was taken.

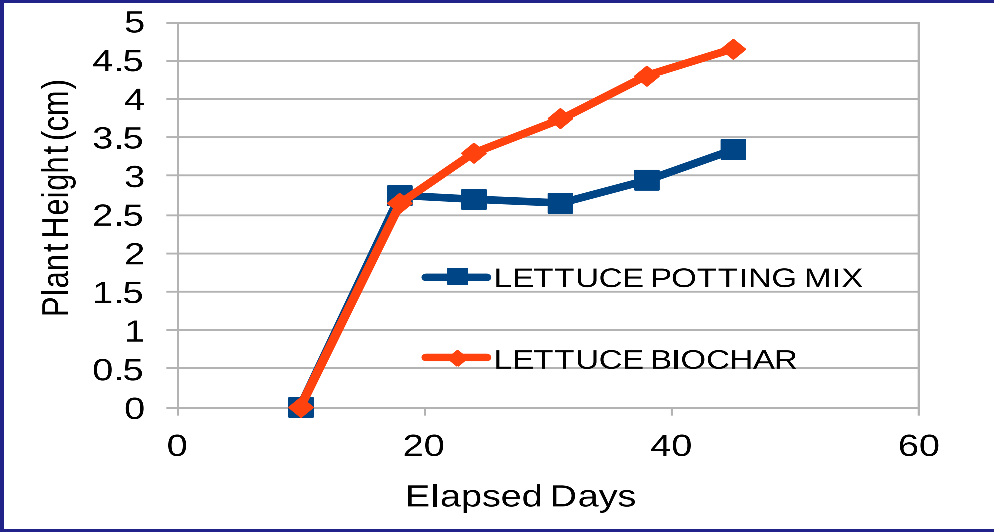
The ease with which the charcoal could be deactivated for nitrogen compared to deactivation for hydrogen, suggested that a sample might be put into such a condition that it would adsorb hydrogen more readily than nitrogen. Results of this sort are shown in figure 4; curves 1 and 2 are nitrogen and hydrogen, respectively, before treatment, and curves

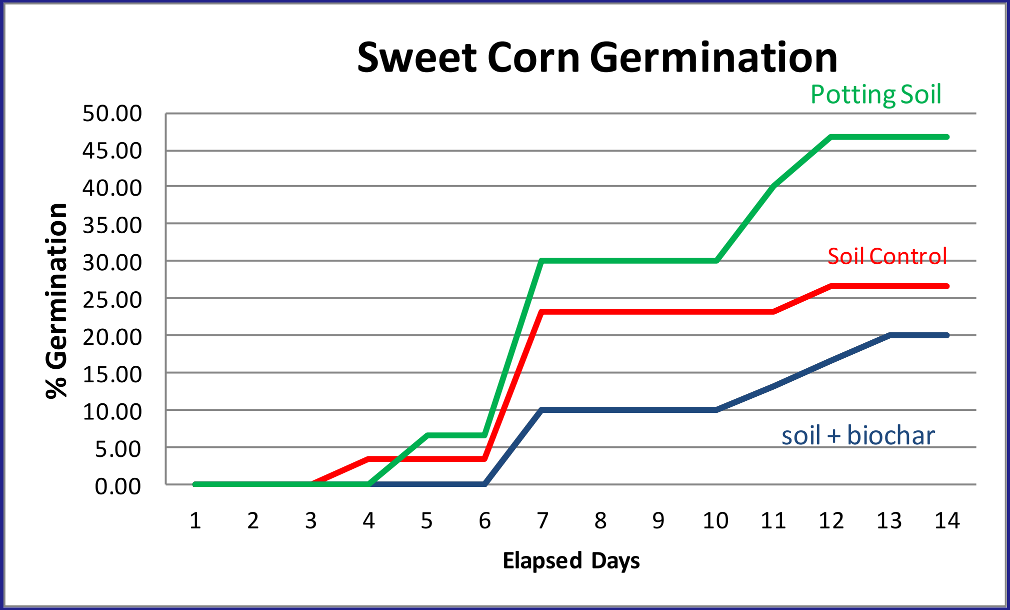
MN Department of Agriculture Project

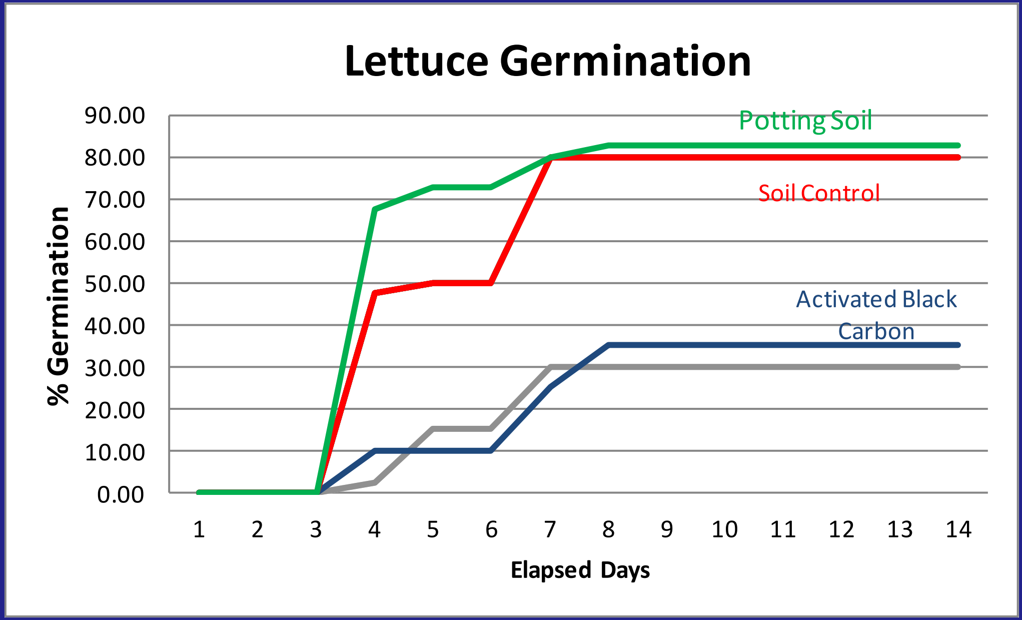
- Examining the bioaccumulation of sorbed chemical species in specialty crops
- Impacts on yield and growth on a variety of crops
- Field and laboratory components

MINNESOTA DEPARTMENT OF AGRICULTURE

MN Department of Agriculture Project







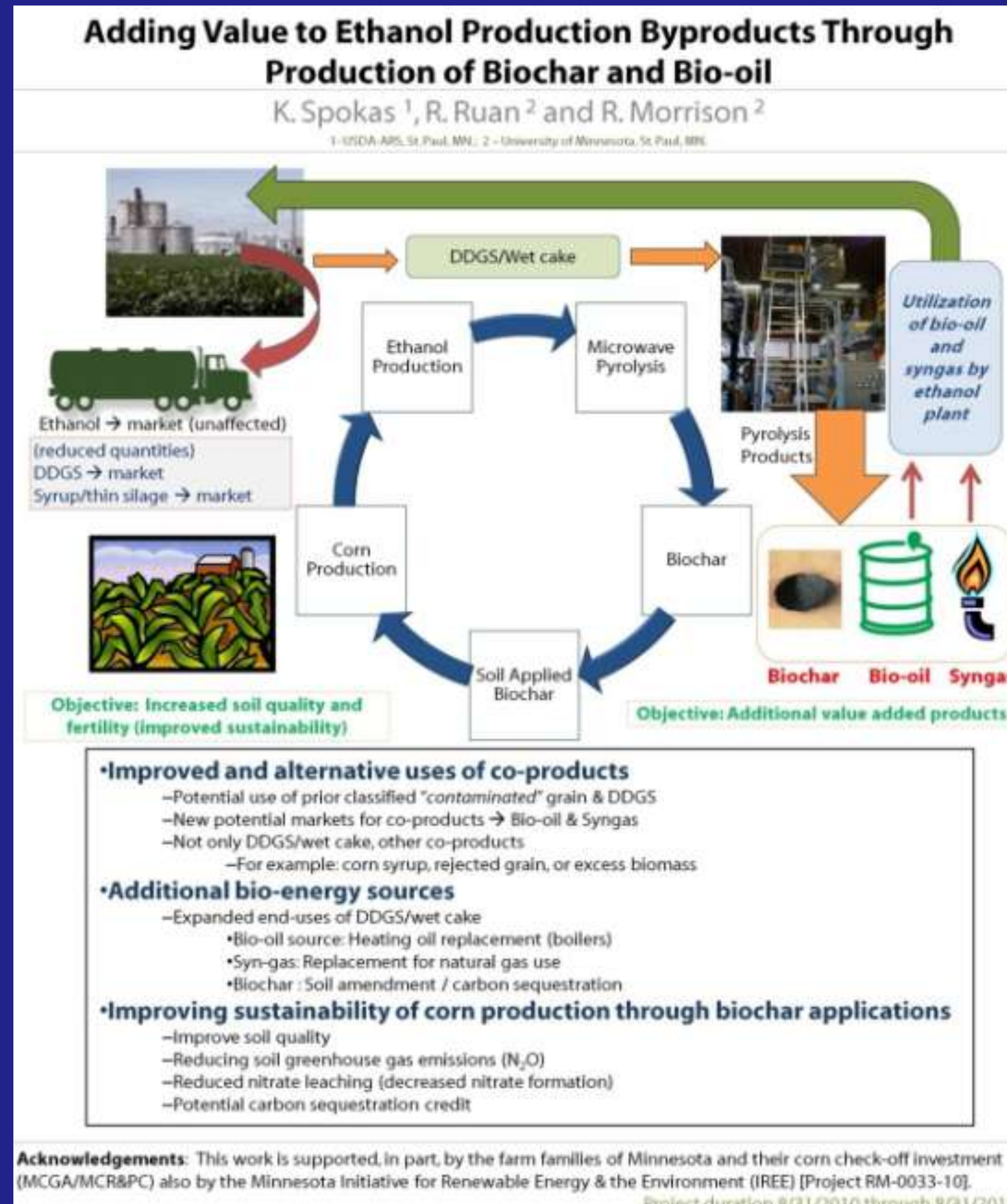
MINNESOTA DEPARTMENT OF AGRICULTURE

MN Corn Growers Association Project

MinnesotaCorn

- Improved & alternative use of distillers grain through microwave assisted pyrolysis

- Examining the potential impacts of distillers grain biochar on soil system – Potential closing the nutrient loop of corn production



So what can I do ???

- Become Involved in Research Efforts
  - Possible participation in collaborative research efforts:

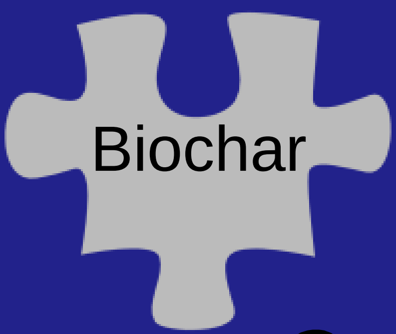
- USDA-ARS
  Kurt Spokas
  kurt.spokas@ars.usda.gov

- University of MN Extension Service
  Regional project: Biochar impacts/feedstock dependencies
  Lynne Hagen
  Lynne.Hagen@co.anoka.mn.us

- *"Start wherever you are and start small."*
  Rita Baily

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:

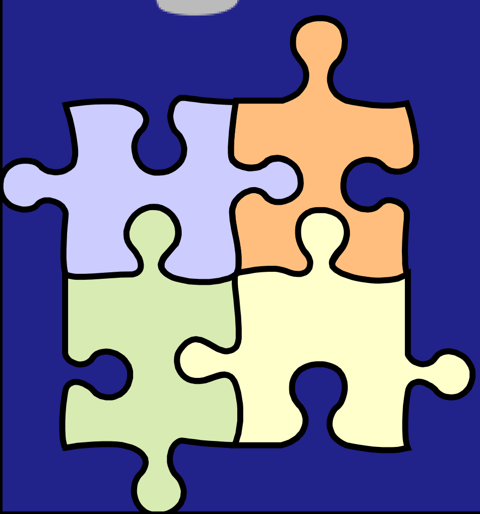


What is clear– Biochar could be a piece of the solution

Just as the climate issues did not arise from a single source;

the solution to the problem will not be a <u>single solution</u>

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 pyrloysis char (CQuest™) through non-funded CRADA agreement

Best Energies

Slow pyrolysis char through a non-funded CRADA agreement

Northern Tilth

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

University of Bonn (Germany)

Laboratorio di Scienze Ambientali R.Sartori - C.I.R.S.A. (University of Bologna, Italy)

IRNAS-CSIC (Spain)

USDA-ARS Biochar and Pyrolysis Initiative

Technical Support : Martin duSaire

Students: Tia Phan, Lindsey Watson, Lianne Endo, Amanda Bidwell, Eric Nooker
Kia Yang, Michael Ottman, Ed Colosky, and Vang Yang

"The nation that destroys its soil destroys itself." --Franklin D. Roosevelt