Biochar: What is it and what can it do for soil?

?

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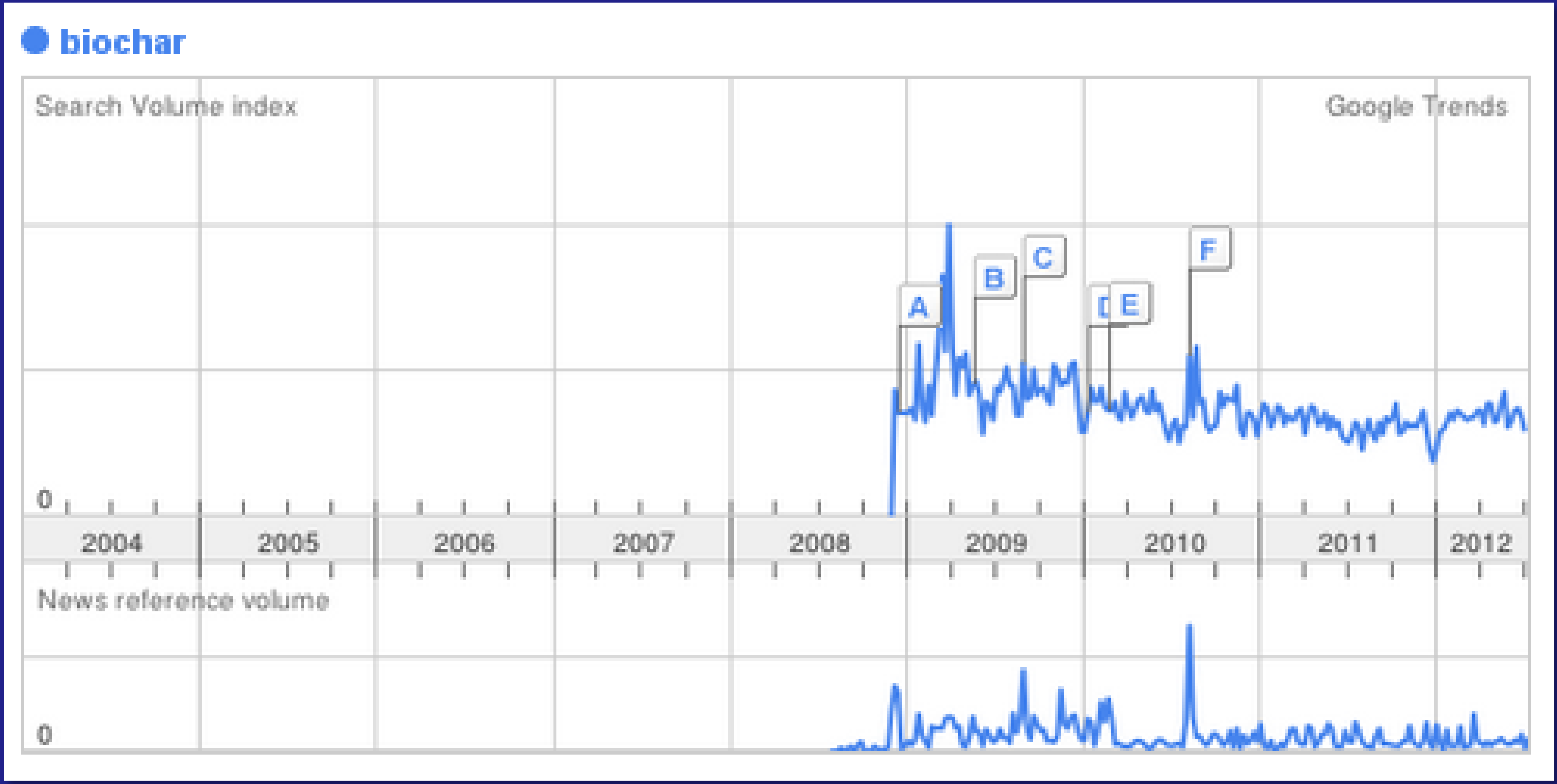
USDA

October 1 - Stearns County Master Gardner’s Monthly Meeting

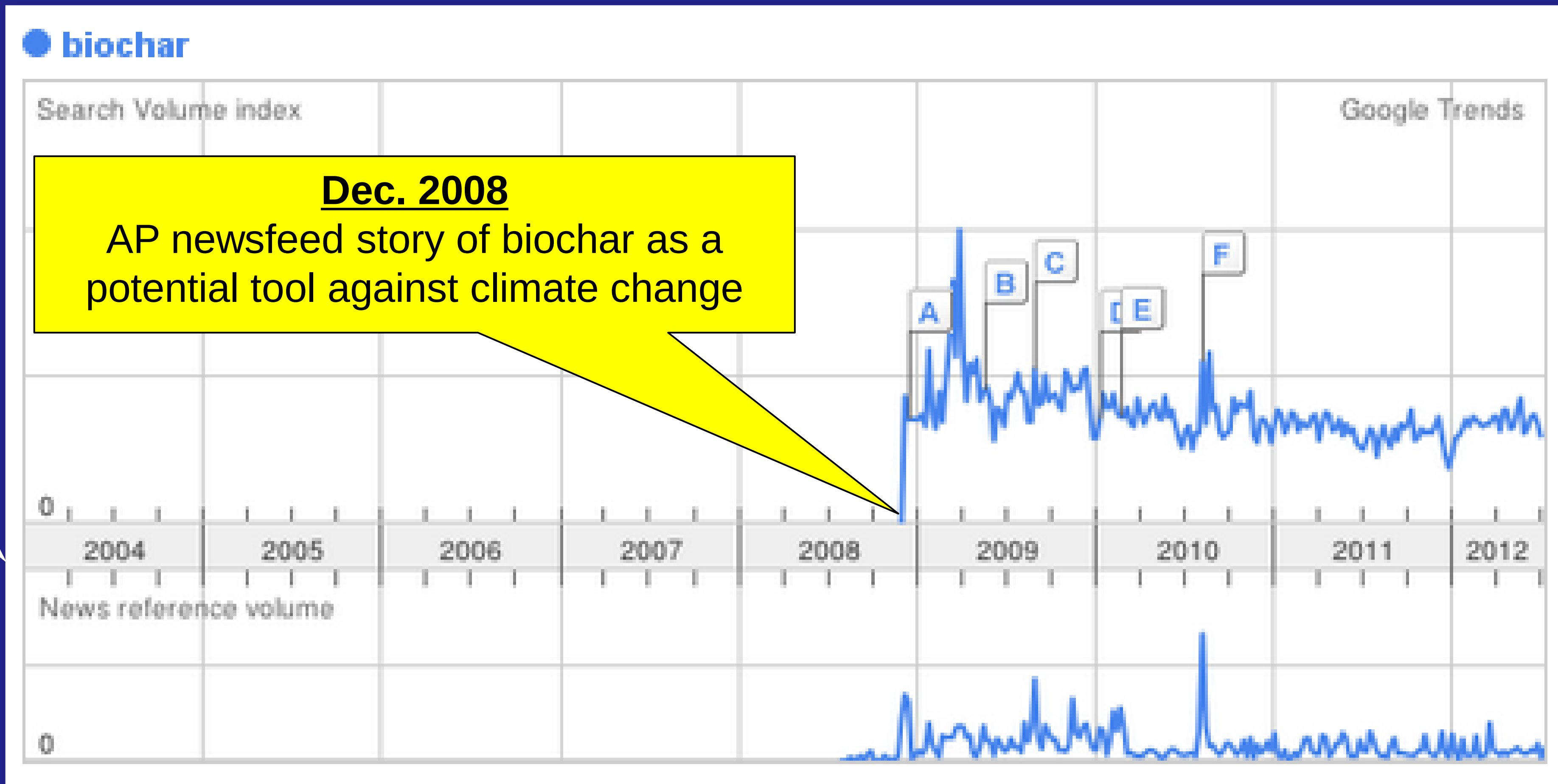
Agricultural Research Service

Step 1. Biochar: What is it ?

Biochar – Google Trends™ Reports



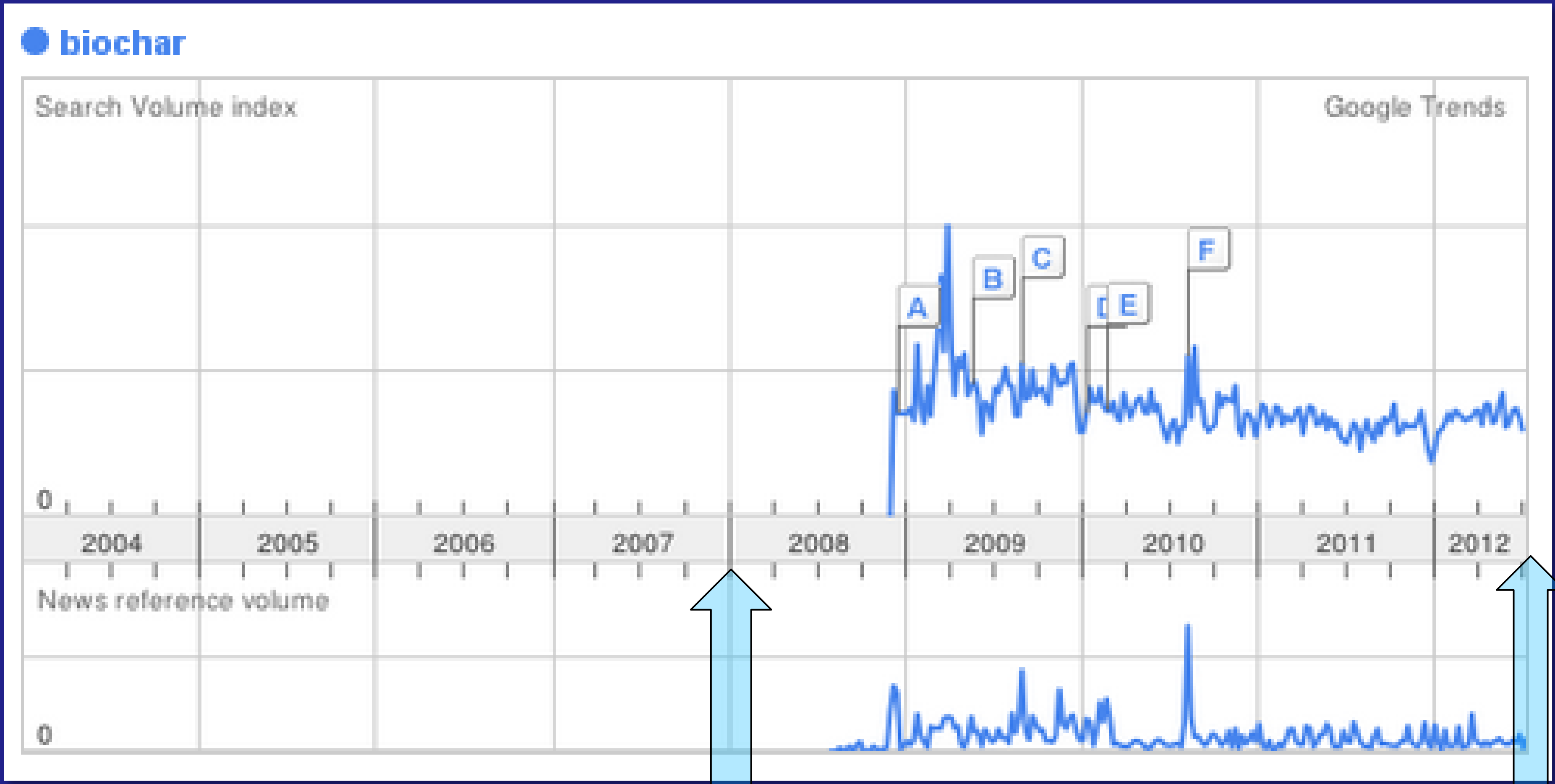
Biochar – Google Trends



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

1. Australia
2. New Zealand
3. South Africa
4. Malaysia
5. Ireland
6. Canada
7. United States
8. United Kingdom
9. Switzerland
10. India

Biochar – Google Trends (US)

Subregions

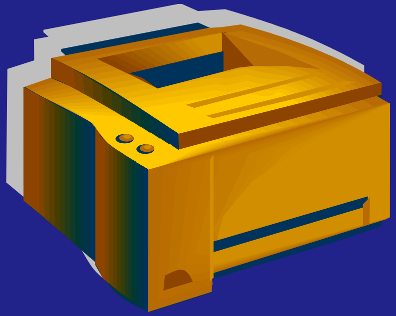
1. Vermont, United States
2. Hawaii, United States
3. Colorado, United States
4. Maine, United States
5. Oregon, United States
6. Washington, United States
7. Iowa, United States
8. Massachusetts, United States
9. District of Columbia, United States
10. North Carolina, United States

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
  - 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



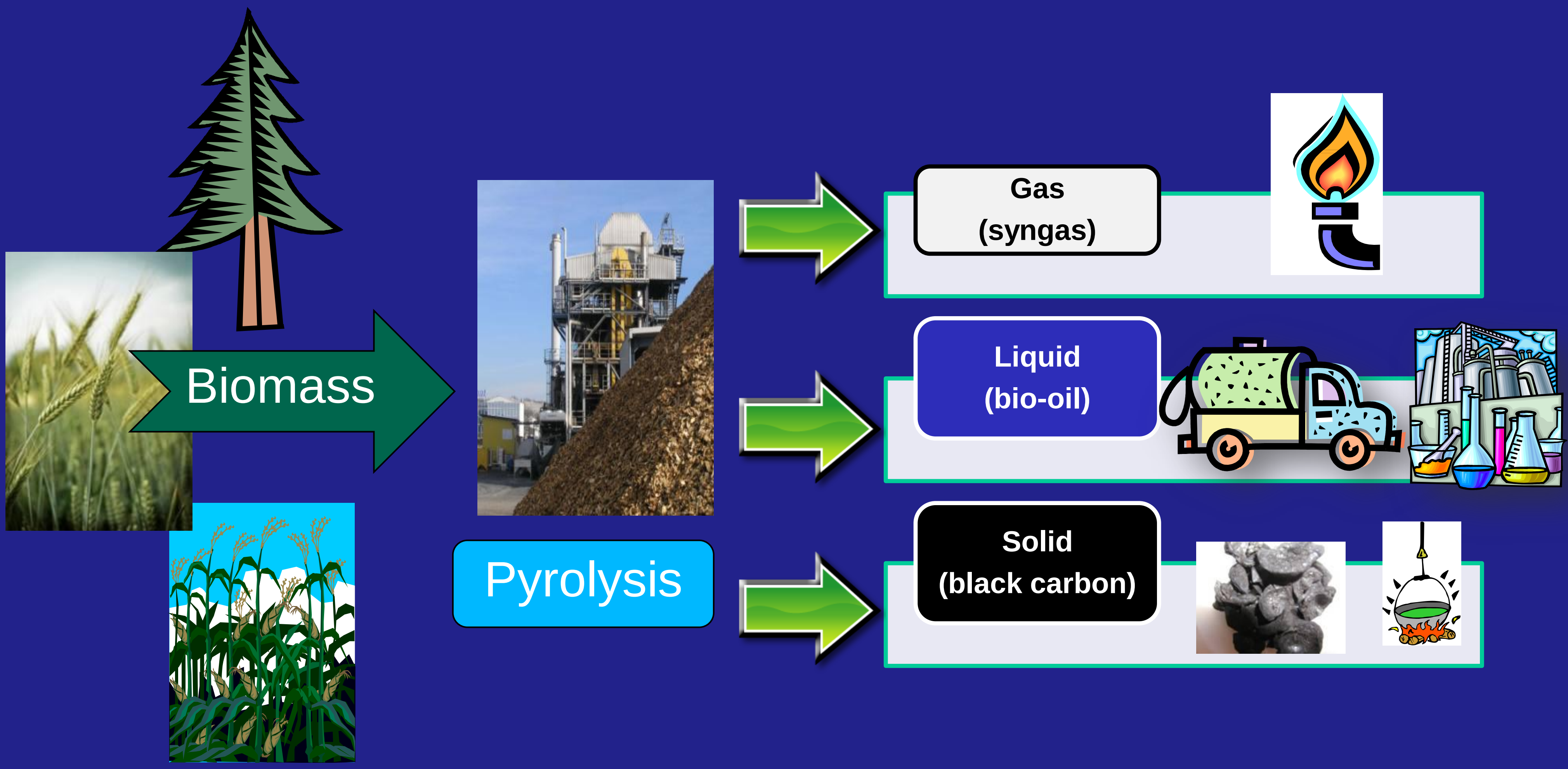
Formation of Black Carbon: “Pyrolysis”

- 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

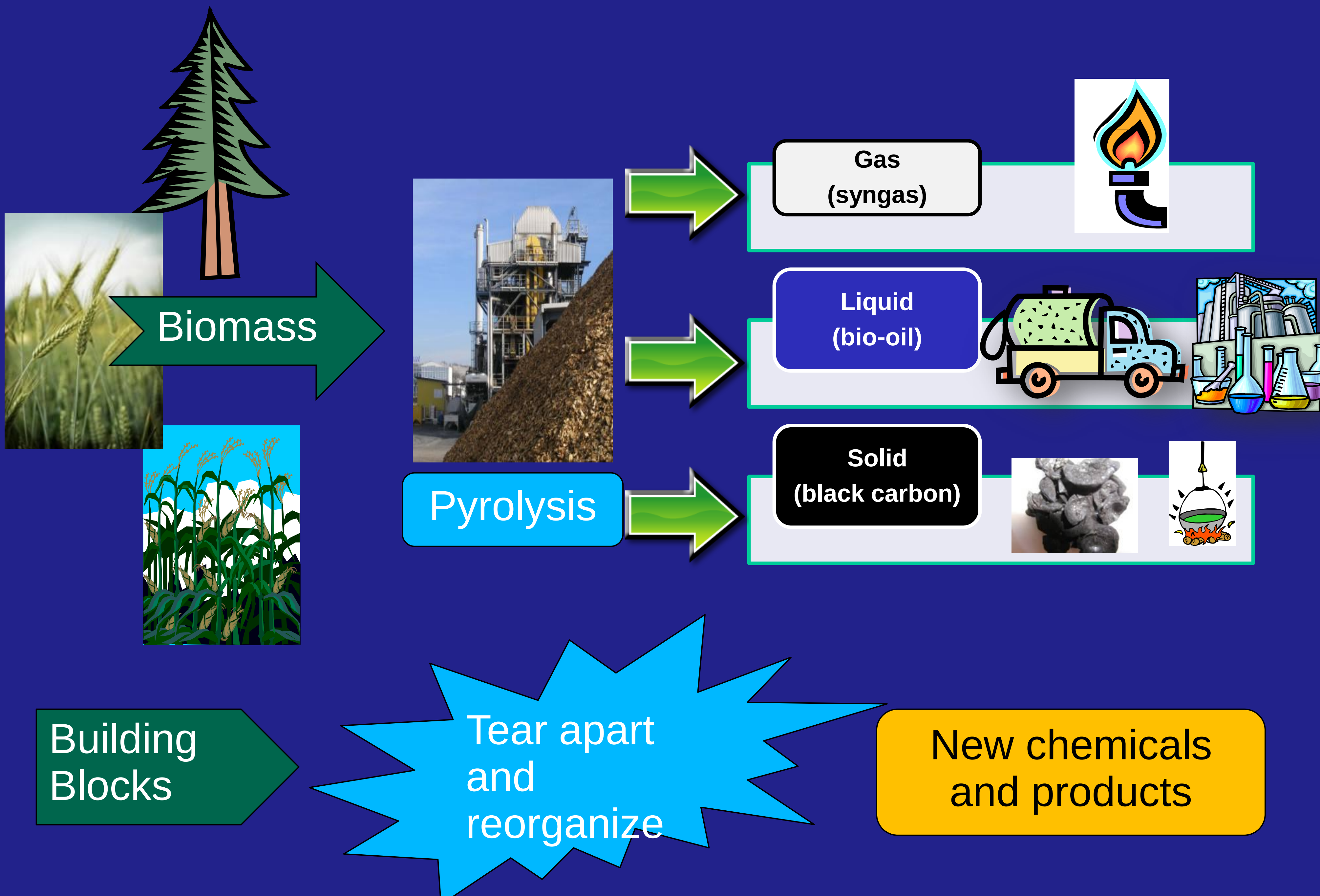




Overview of Pyrolysis



Overview of Pyrolysis



Wide Spectrum of Pyrolysis

Both temperature and time factors:

- High temperature pyrolysis
  - →gasification (>800 ^{o}C) {+ O_2 }

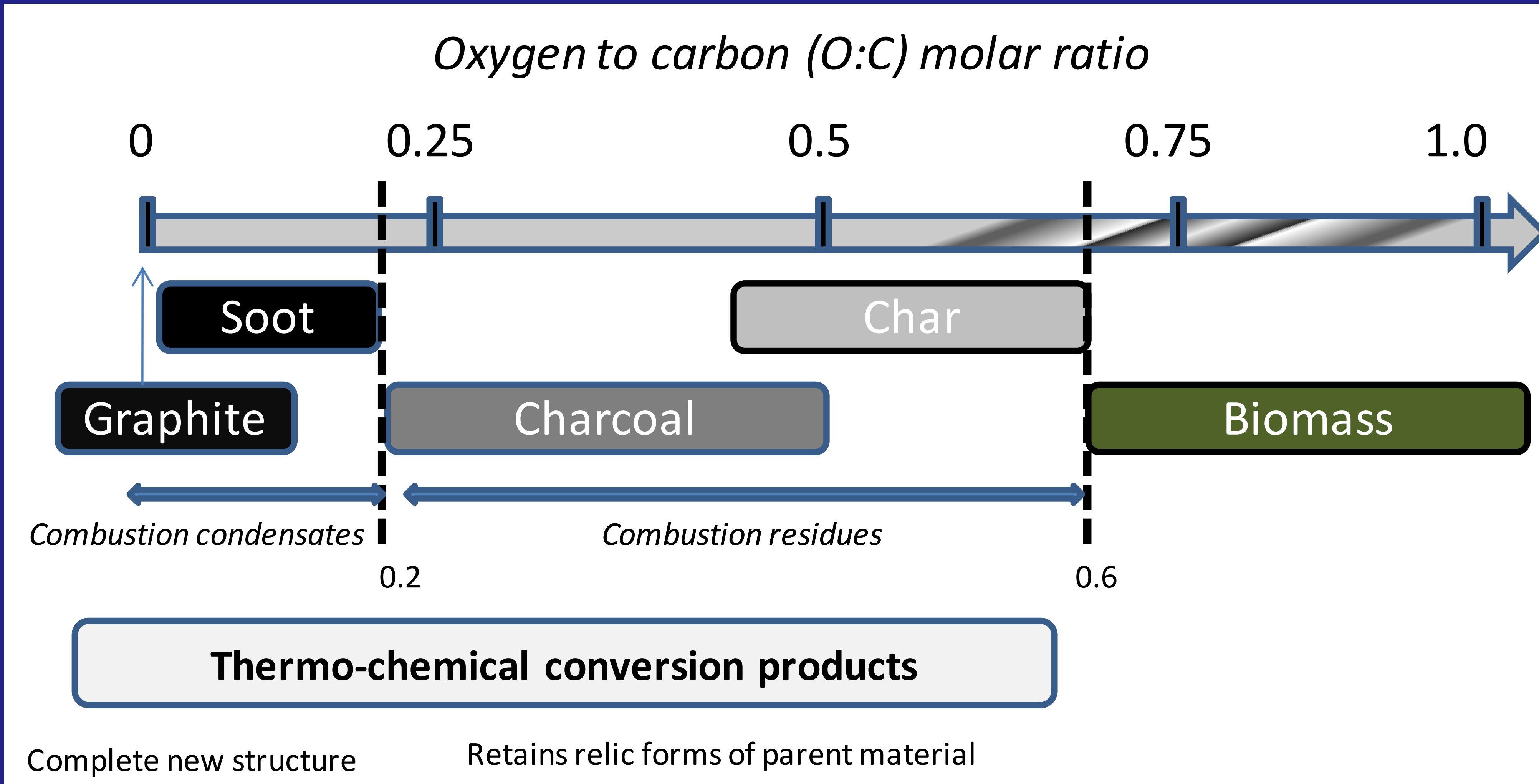
- "Fast" or "Slow" pyrolysis (300-600 ^{o}C)

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

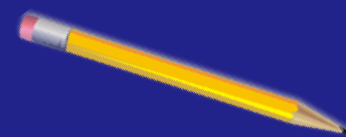
Problem → Lack of nomenclature uniformity

(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)

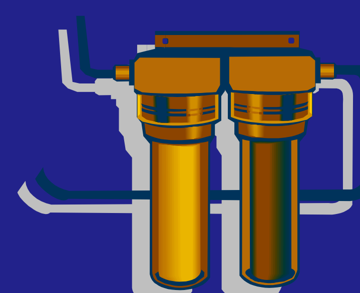


Pencils

Used as fuel
(3000-4000 BC)

Charcoal production
(15^{th} century)

Water filtration
(2000 BC)



Activated Charcoal
Filtration Today

Biochar: New purpose not a new material

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

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

<u>Atmospheric C sequestration</u>

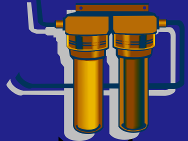
Dates to 1980’s and early 2000’s

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

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

Used as fuel
(3000-4000 BC)

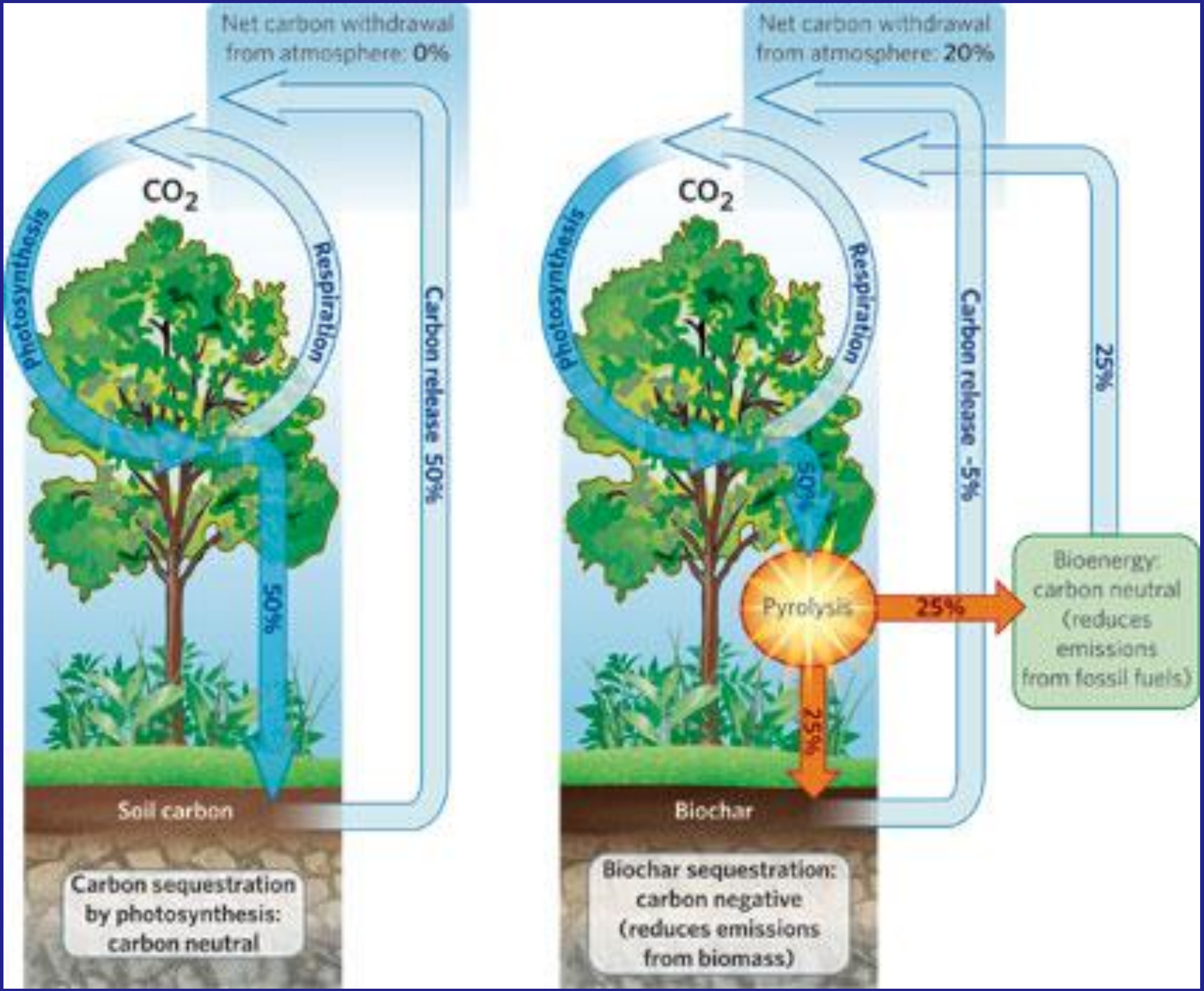
Water filtration
(2000 BC)



Charcoal production
(15^{th} century)

Climate Change Mitigation
(1980’s)

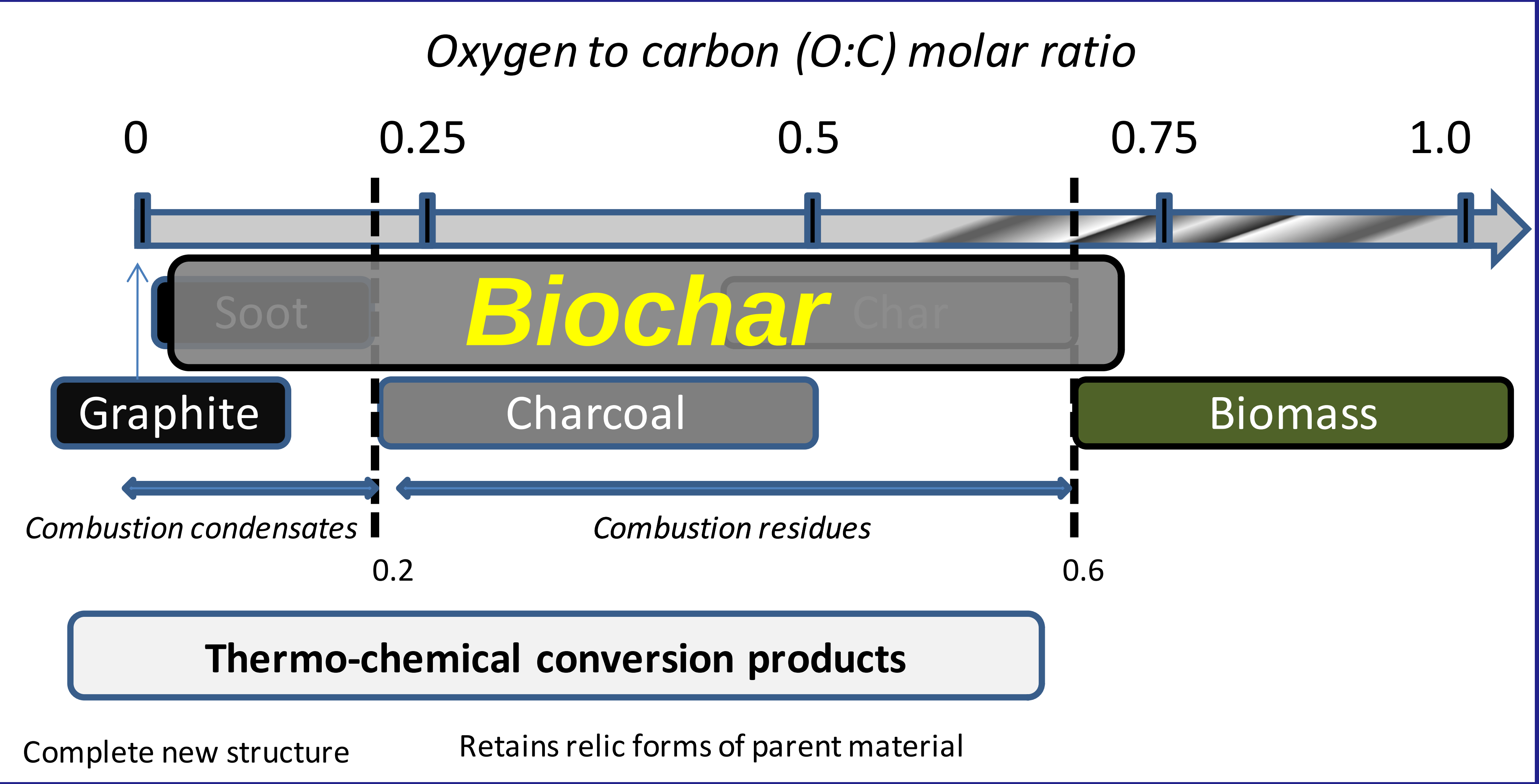
Biochar Carbon Sequestration



Lehmann 2006

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 (Summary)

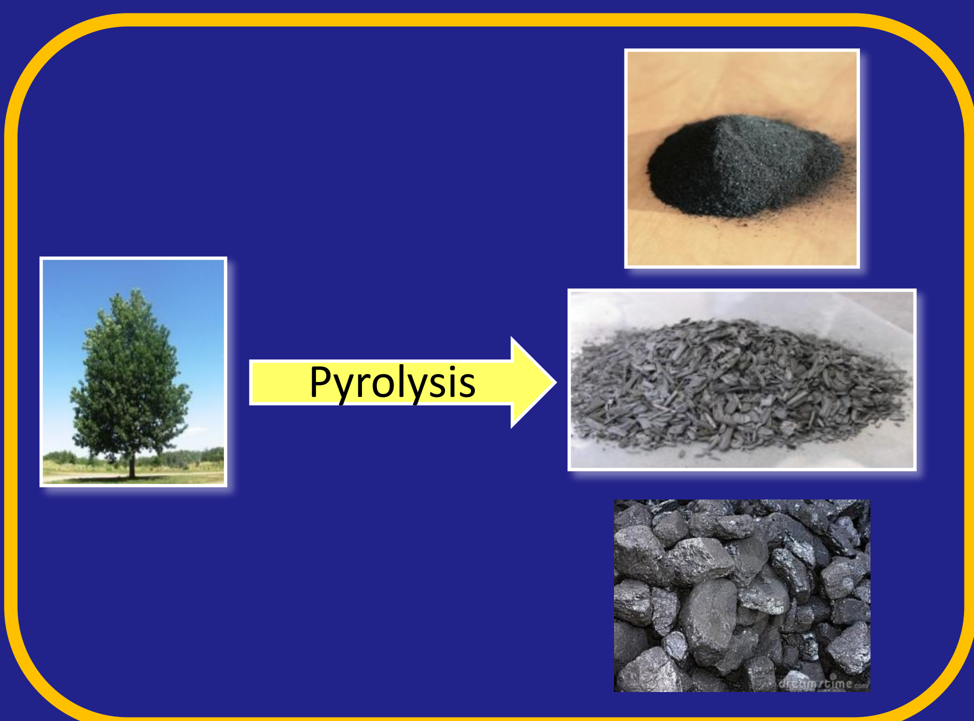
However, just like cooking…

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***"



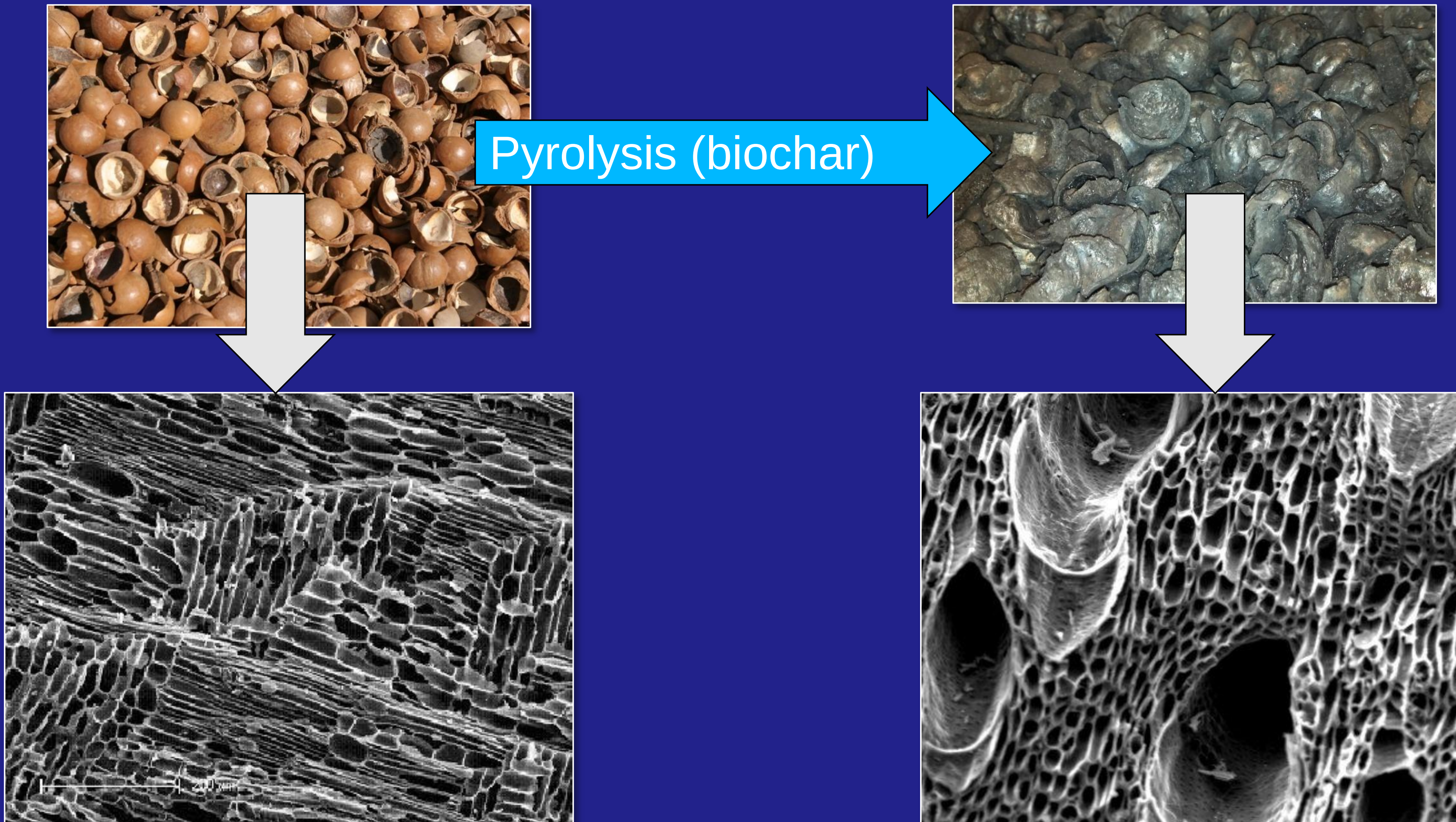
Biochar: Structure

Pyrolysis (biochar)

Biochar: Structure

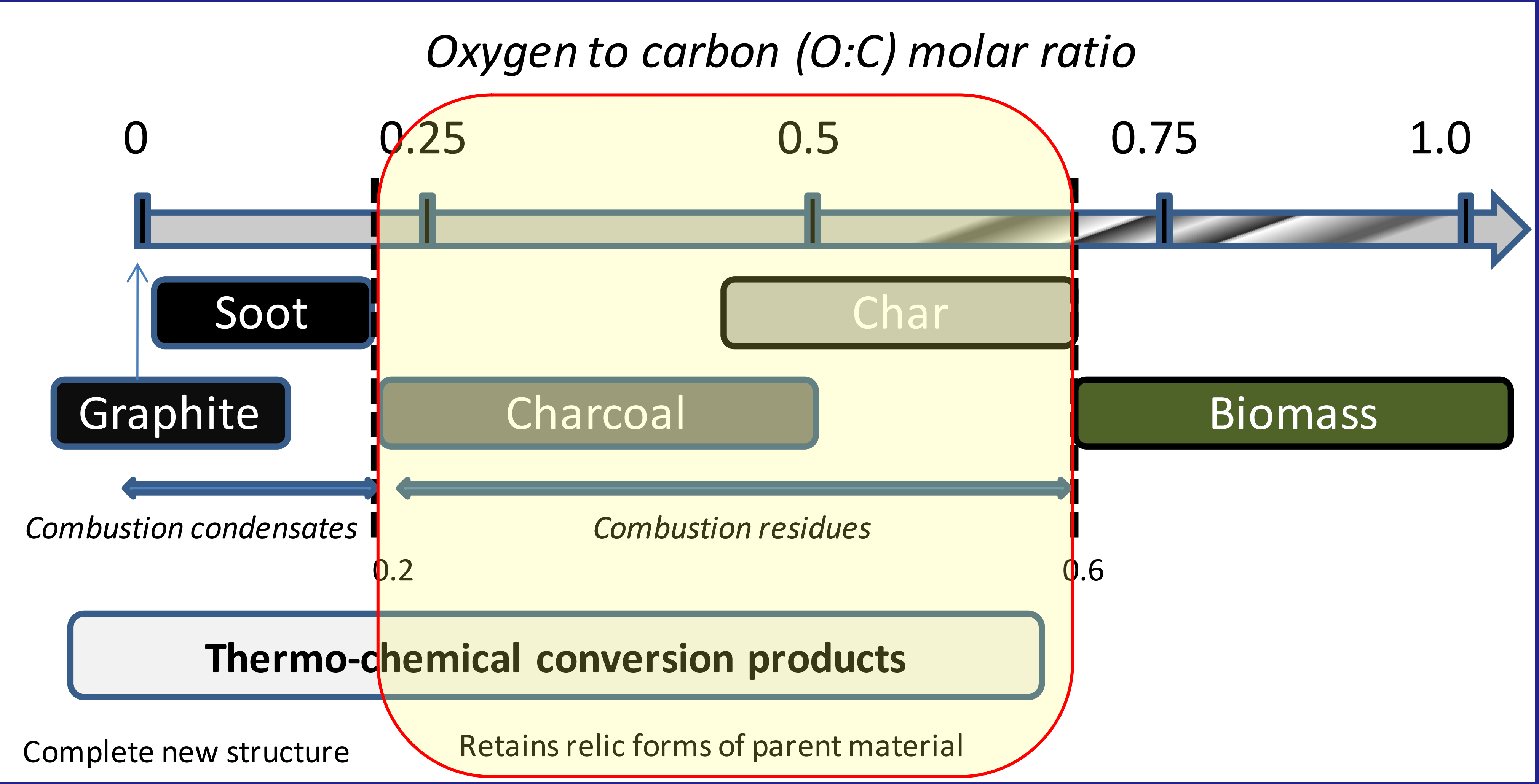
Pyrolysis (biochar)

Biochar: Structure



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

Biochar is black carbon

that is made for the purpose of carbon sequestration

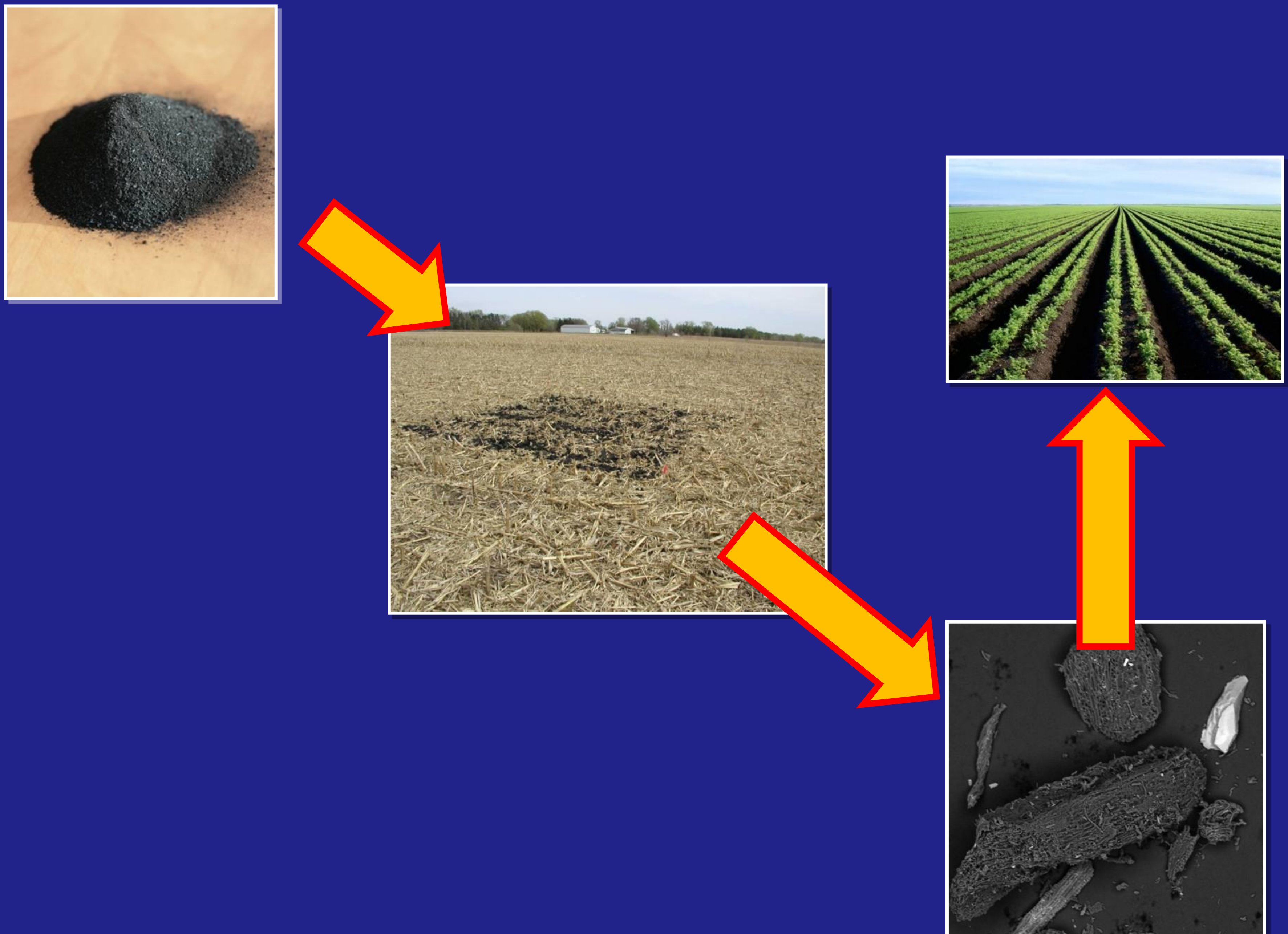
Biomass Materials

Easily degradable
(0-5 yrs)

Pyrolysis

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

Biochar Soil Application

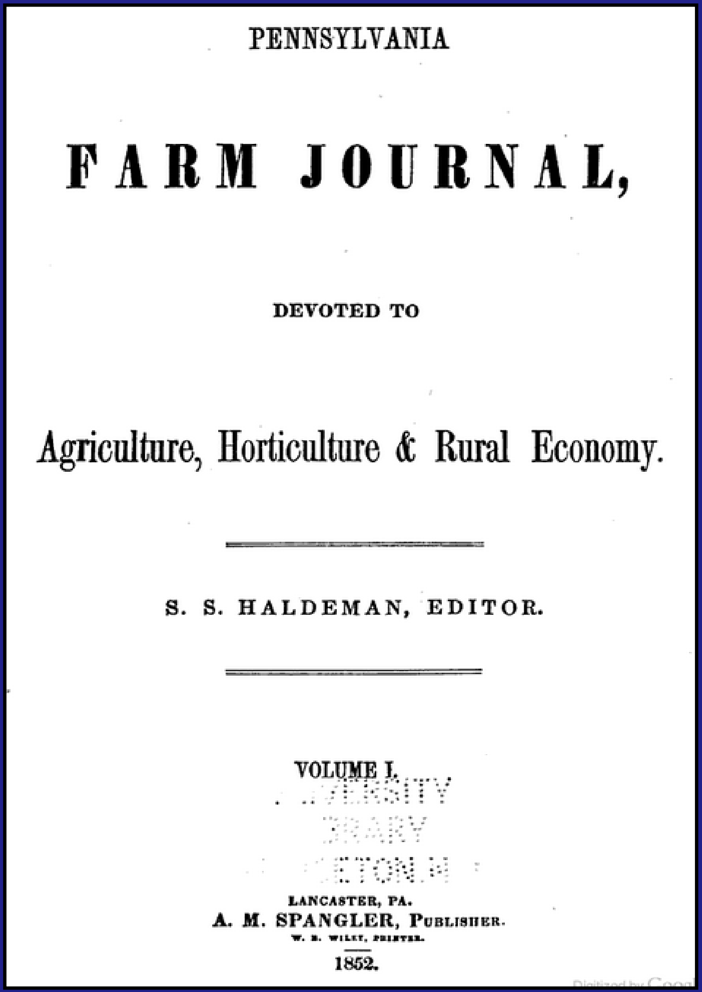


"The use of charcoal (*biochar*) as a fertilizer is not a new thing, though it is only within the few last years that agriculturists have taken much notice of it."

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


PENNSYLVANIA

FARM JOURNAL,

DEVOTED TO

Agriculture, Horticulture & Rural Economy.

S. S. HALDEMAN, EDITOR.

VOLUME I.

LANCASTER, PA.
A. M. SPANGLER, PUBLISHER.
W. B. WILEY, PRINTER.
1852.

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…

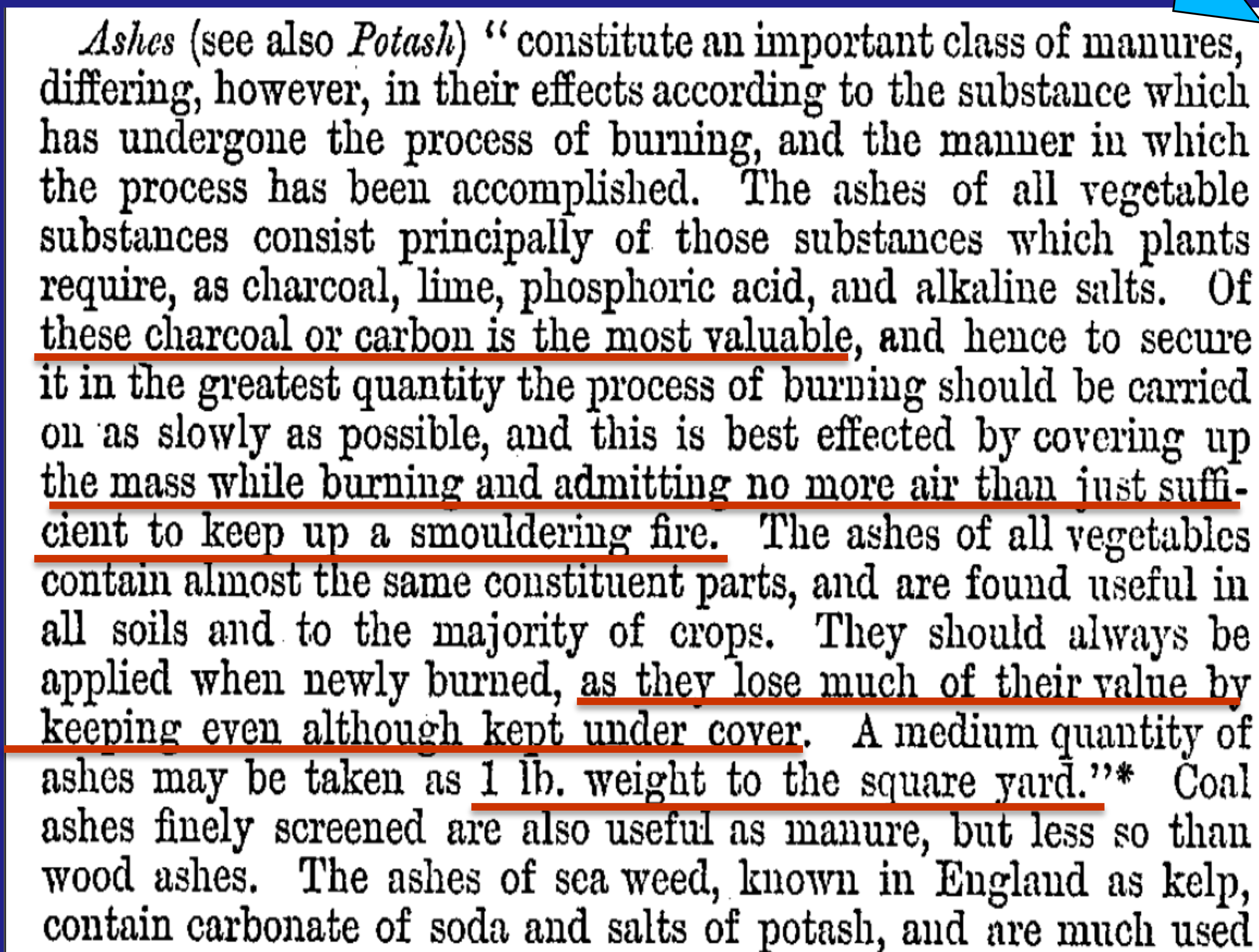
Fire pits built on soil…

Ancient Egyptians - pyroligneous acid (bio-oil)

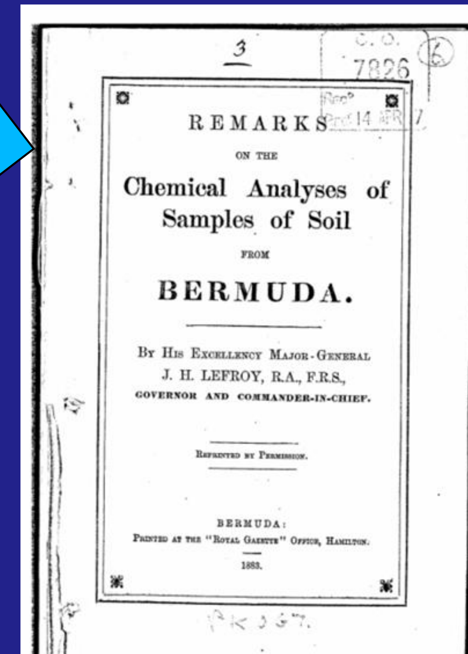
-used for embalming

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



REMARKS
ON THE
Chemical Analyses of Samples of Soil
FROM
BERMUDA.

By His Excellency Major-General J. H. LEFROY, R.A., F.R.S., Governor and Commander-in-Chief.

Reprinted by Permission.

BERMUDA:
Printed at the "Royal Gazette" Office, Hamilton.
1883.

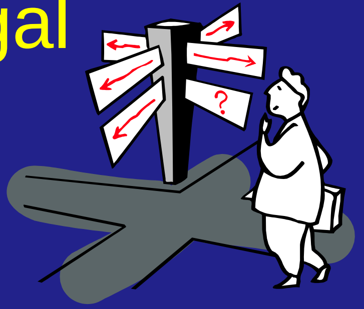
(John Henry LeFroy, 1883)

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



Warnock et al. (2007)

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, <u>should not</u> 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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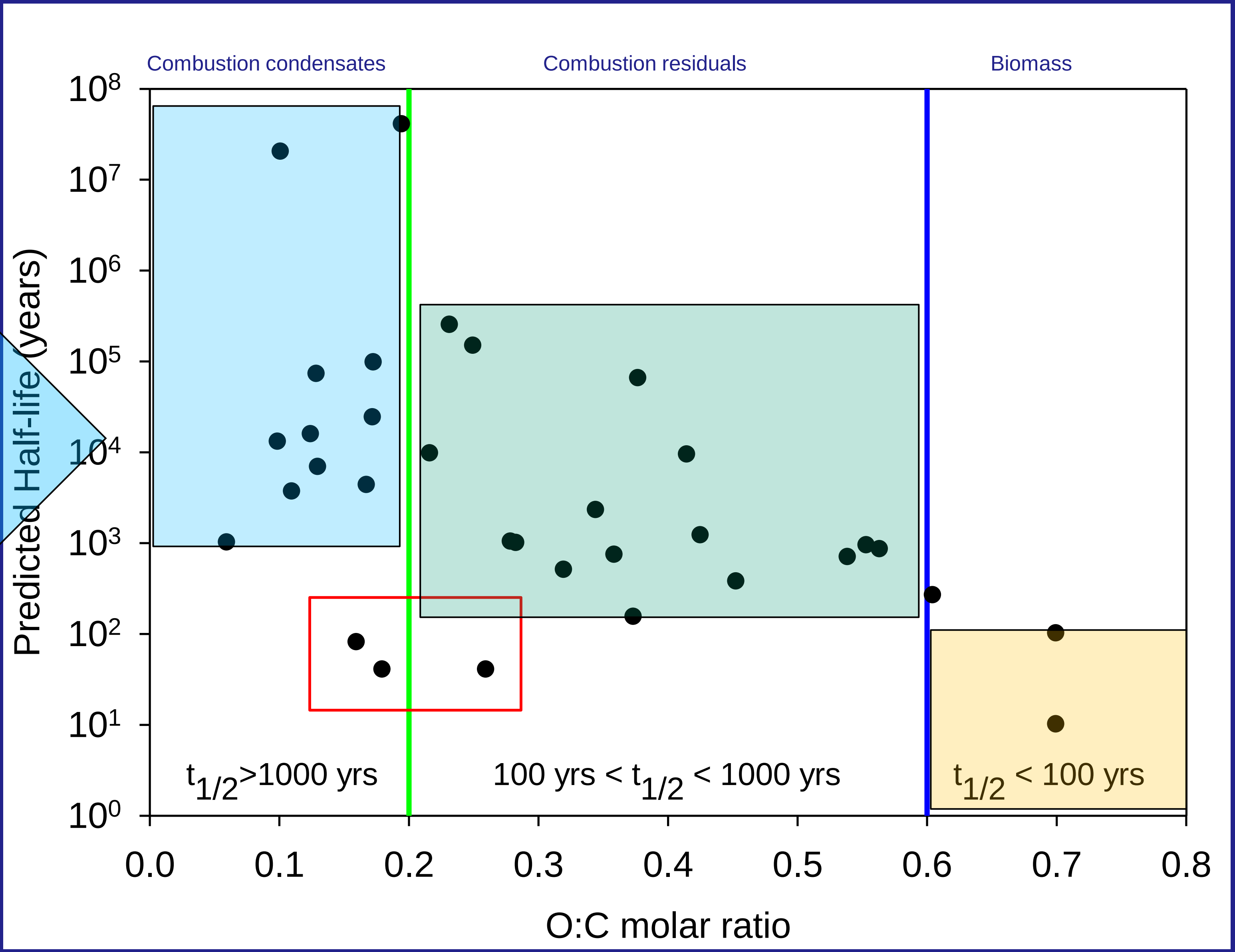
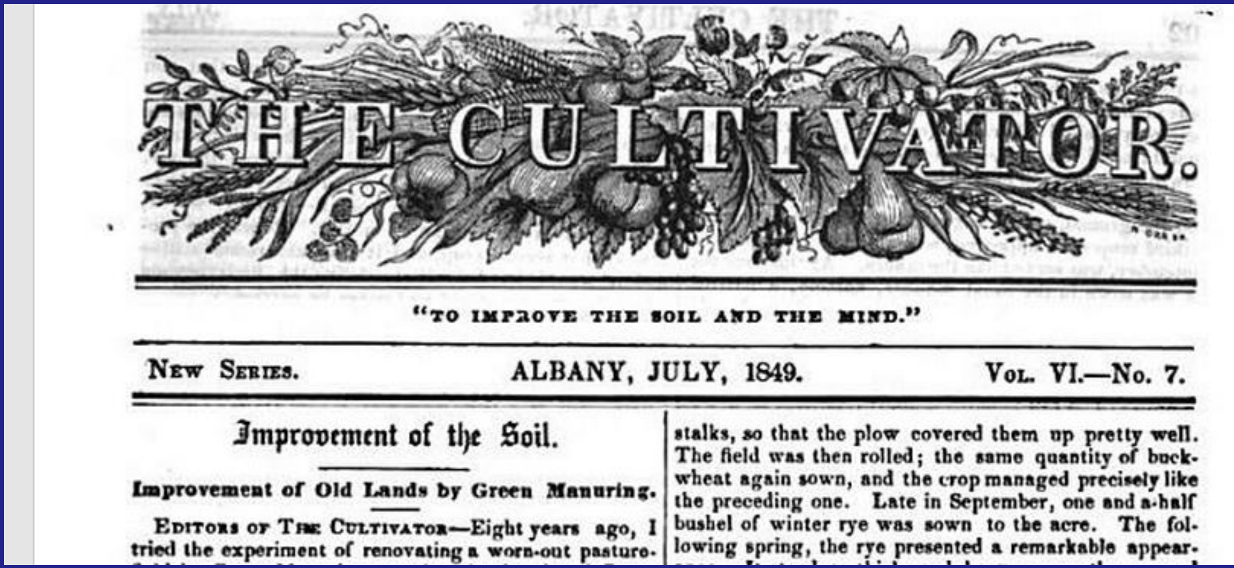


Summary of existing literature studies (n=35) on half-life estimation of biochar [Figure from Spokas (2010)]

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.

"TO IMPROVE THE SOIL AND THE MIND."

NEW SERIES. ALBANY, JULY, 1849. VOL. VI.—No. 7.

Improvement of the Soil.

Improvement of Old Lands by Green Manuring.

EDITORS OF THE CULTIVATOR—Eight years ago, I tried the experiment of renovating a worn-out pasture-

stalks, so that the plow covered them up pretty well. The field was then rolled; the same quantity of buck-wheat again sown, and the crop managed precisely like the preceding one. Late in September, one and a-half bushel of winter rye was sown to the acre. The fol-lowing spring, the rye presented a remarkable appear-

The Cultivator (1849): "Improvement of the Soil"

What has changed?

1849

Farmers ≈ 69% of labor force

Avg. farm size 160 acres

1 farmer supports 2 people

$ 0.75 per bushel for corn

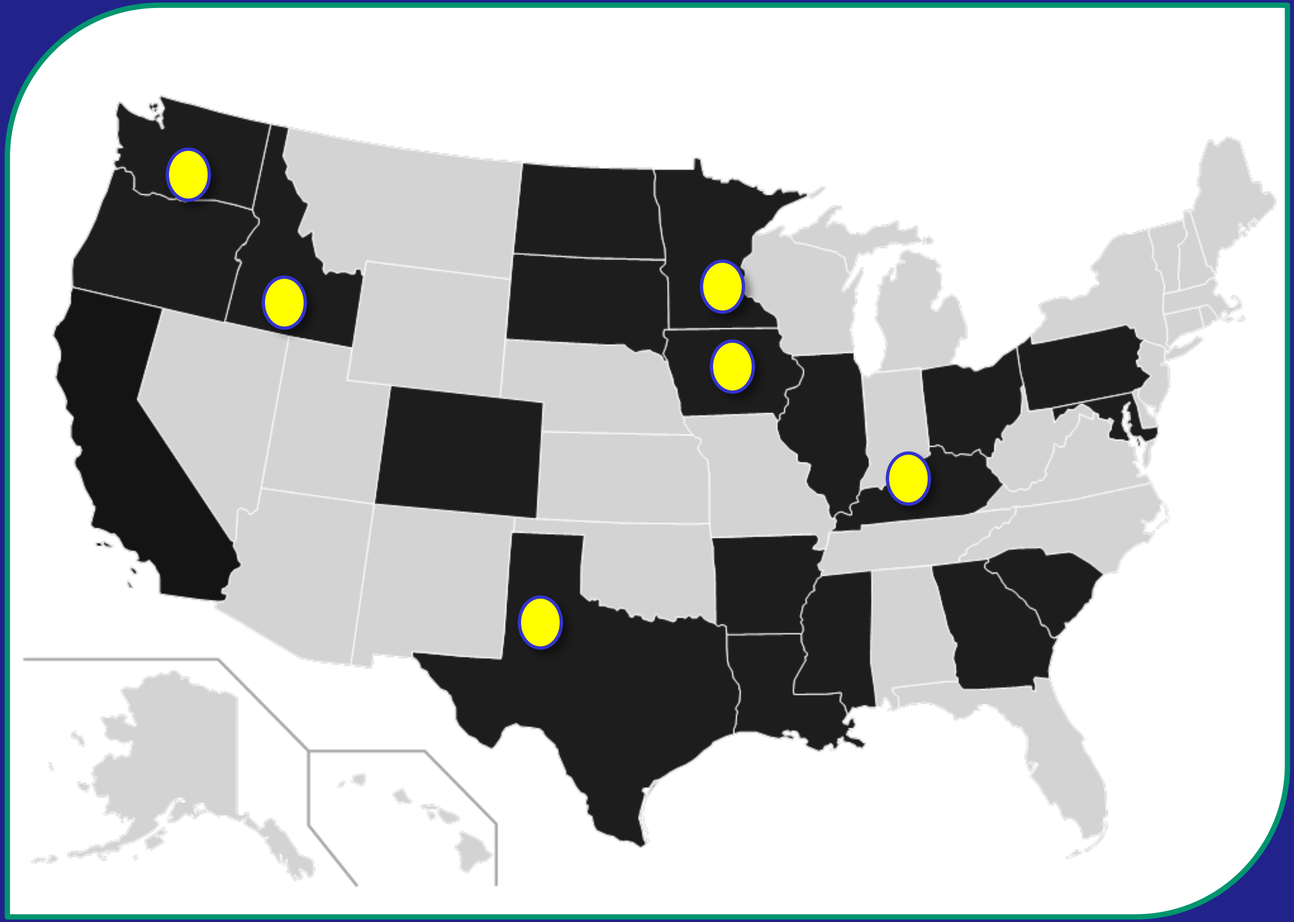
What has changed?

1849	Today
Farmers ≈69% of labor force	Farmers <2% of labor force
Avg farm size 160 acres	Avg farm size 461 acres
1 farmer supports 2 people	1 farmer supports >100 people
$ 0.75 per bushel for corn	$ 7.13 per bushel for corn

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

(Sept 27 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

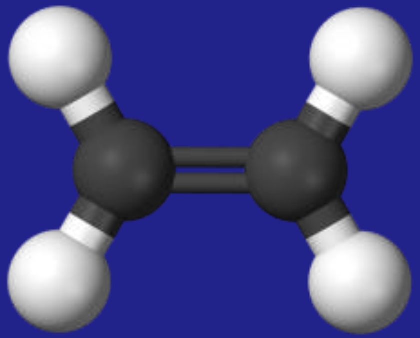
✓ Seedling Emergence/Initial seedling growth rates

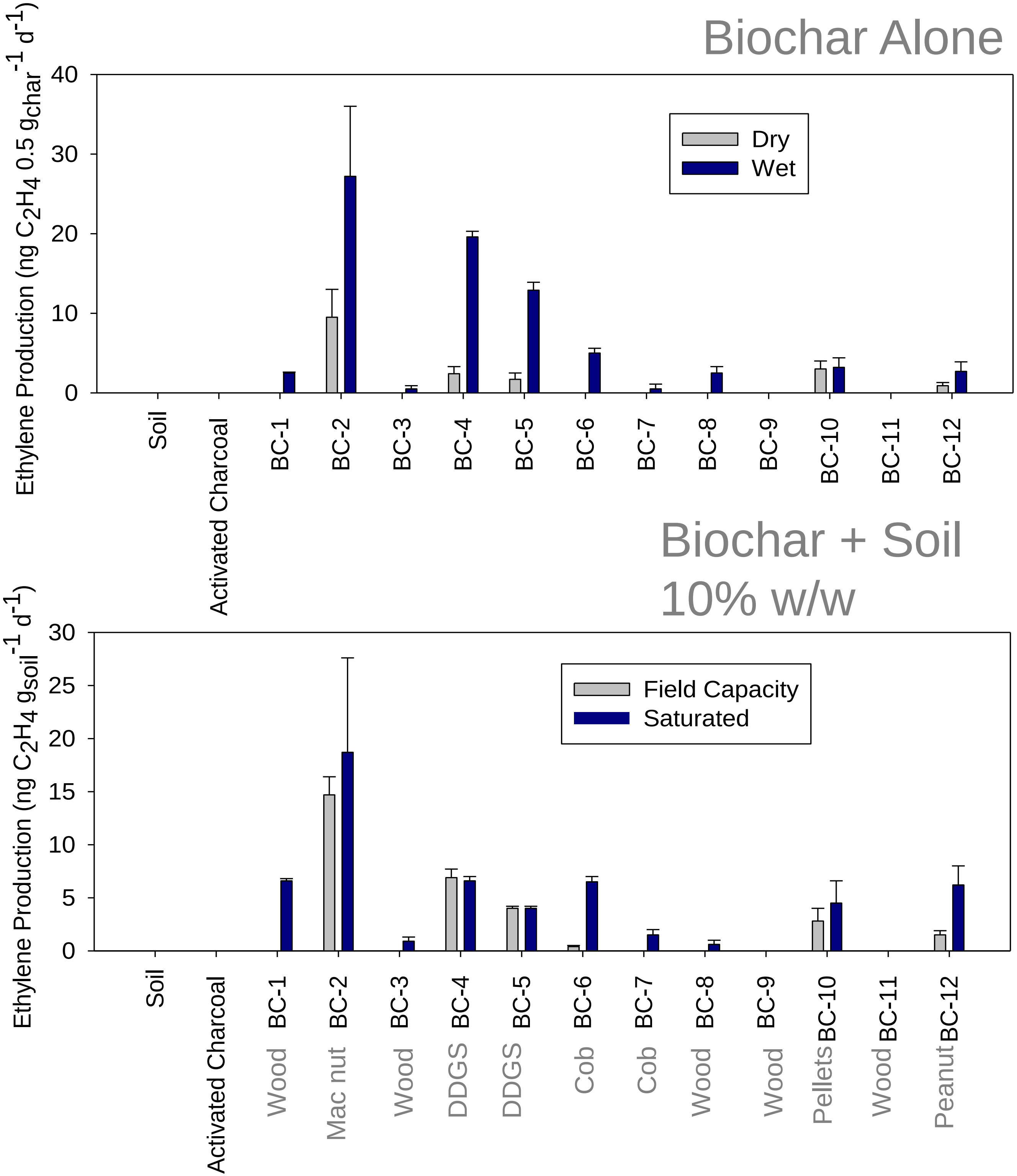
Biochar Impacts on Soil Microbes & N Cycling

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

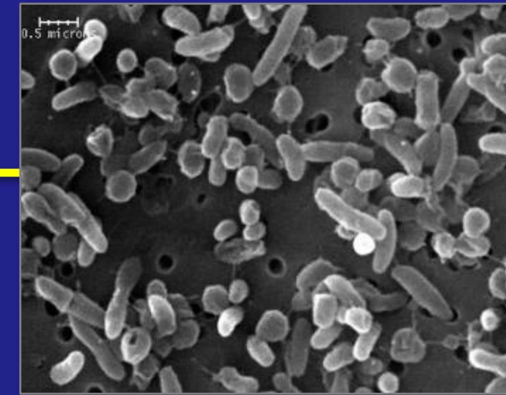



Ethylene (ethene) Production Rates



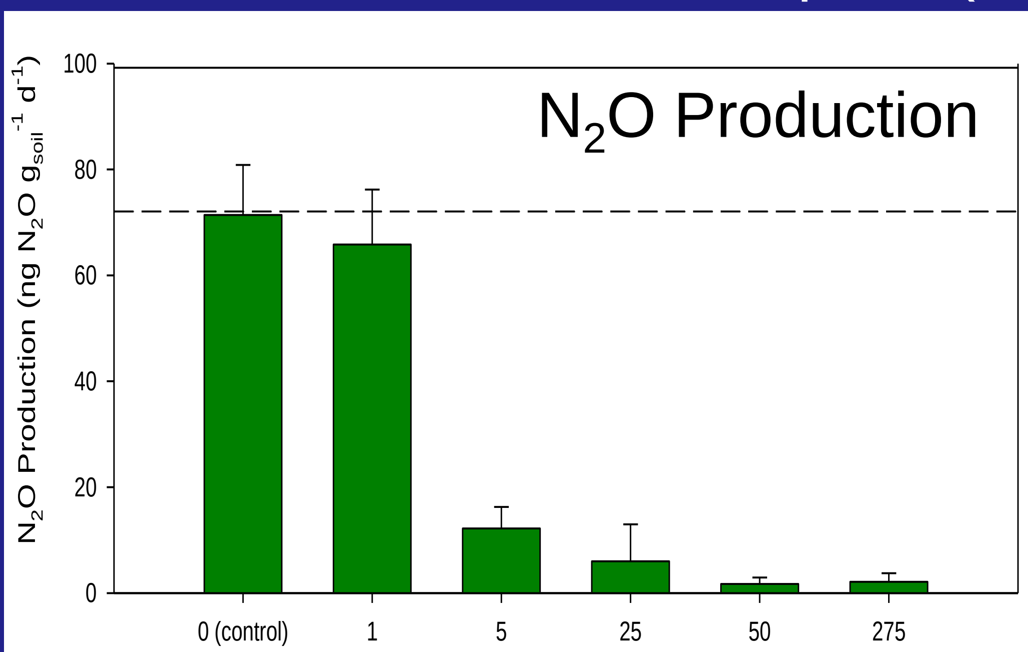


Ethylene Impacts

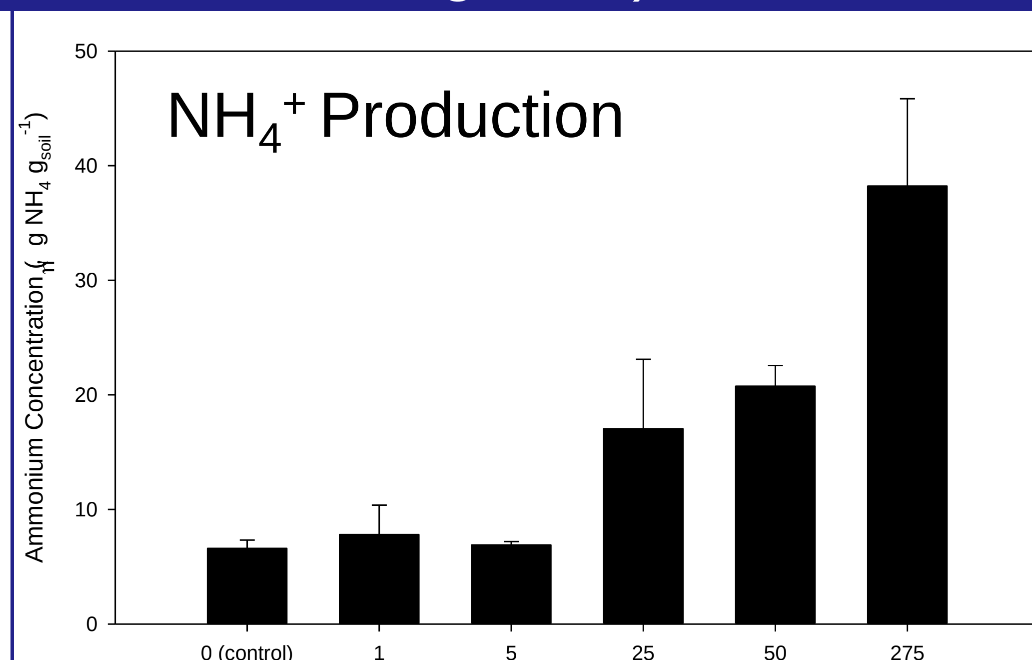


Soil Microbial Impacts

- ✓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)

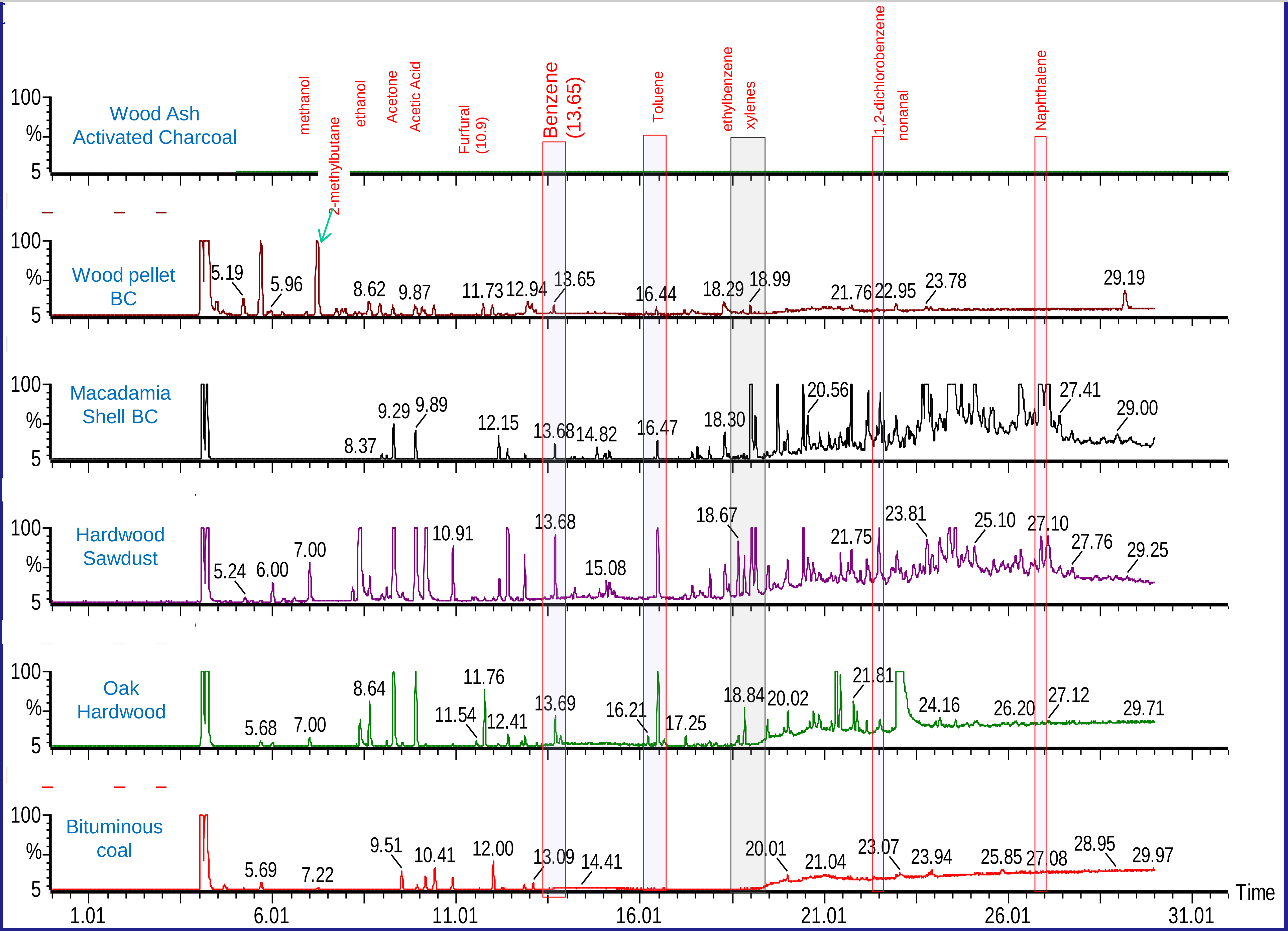


Ethylene Headspace Concentration (0 to 275 ppmv)



Ethylene Headspace Concentration (0 to 275 ppmv)

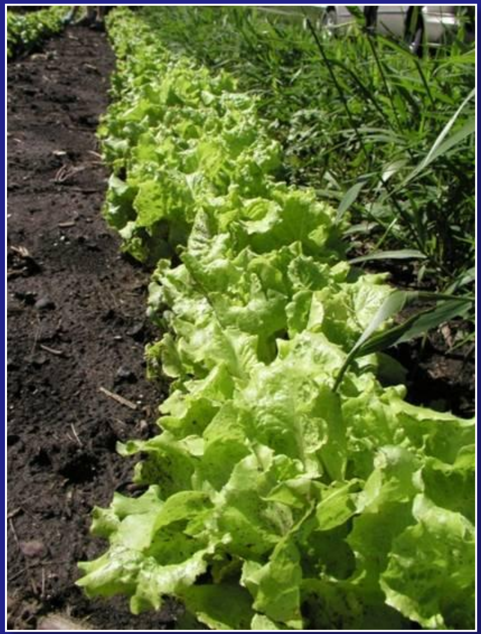
Headspace Thermal Desorption GC/MS scans of biochars



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

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

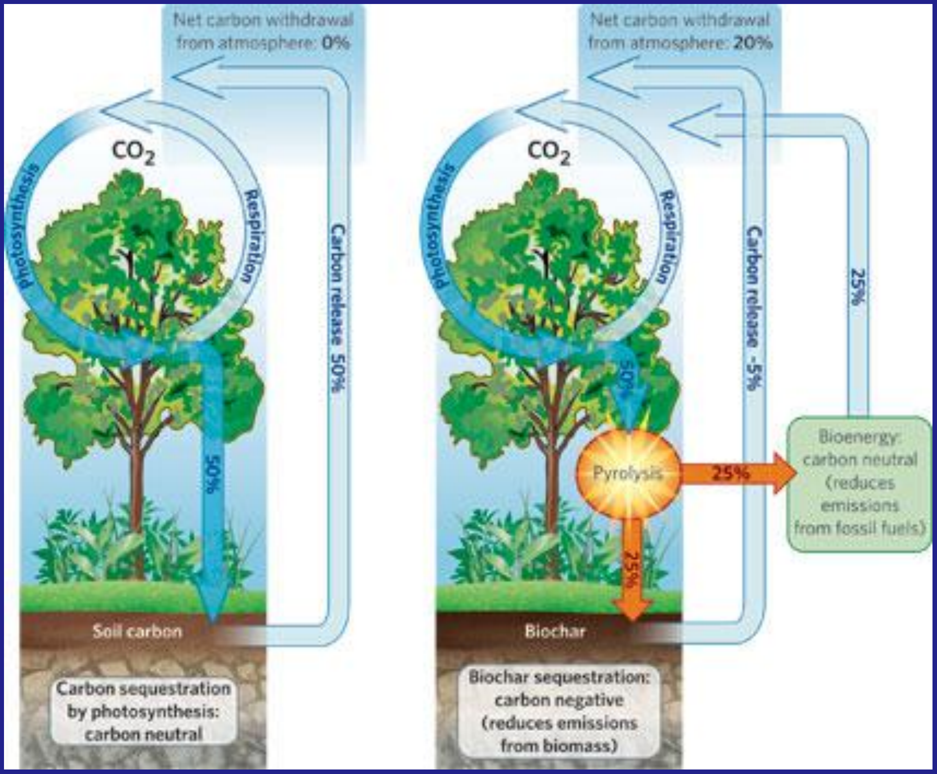


USDA Agricultural Research Service

MINNESOTA DEPARTMENT OF AGRICULTURE

Conclusions

- Biochar is not a new material → new purpose
  - **Carbon Sequestration**
    - Plant biomass fixes atmospheric CO_2
    - Biomass is transformed into a more resistant form of carbon
    - Disrupts atmospheric cycling of CO_2

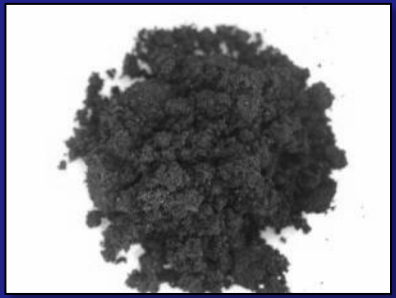


Conclusions

- 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:

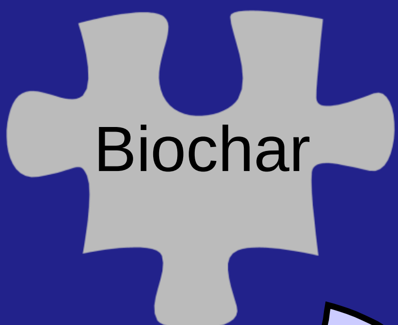





Conclusions

- 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 <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