Iowa State University
Bioeconomy Institute

Biochar as Part of a Carbon Negative Economy

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Bioeconomy Institute

Goal: Securing sustainable supplies of energy and carbon from biomass

BEI Mission

- Research
  - Biomass production
  - Biomass conversion
  - Systems analysis
- Education
  - K-12
  - Undergraduate
  - Graduate
  - Continuing
- Outreach
  - Producers
  - Industry
  - General Public

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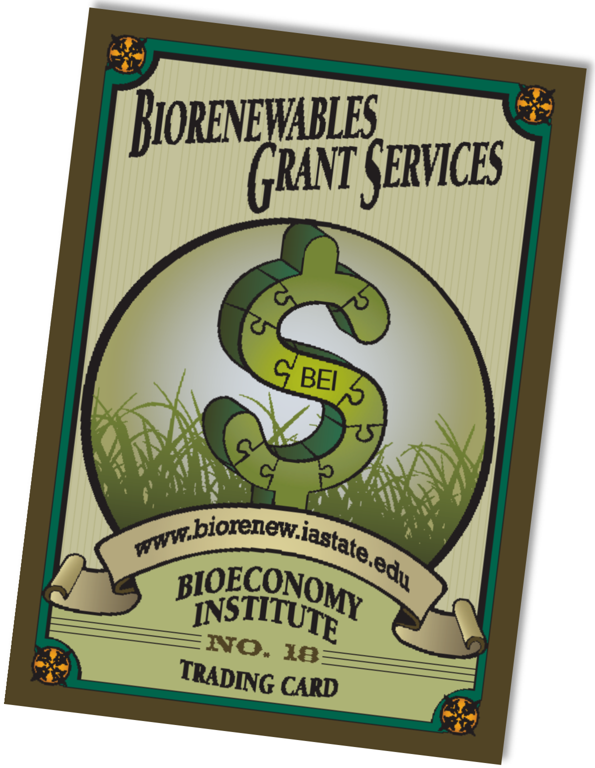
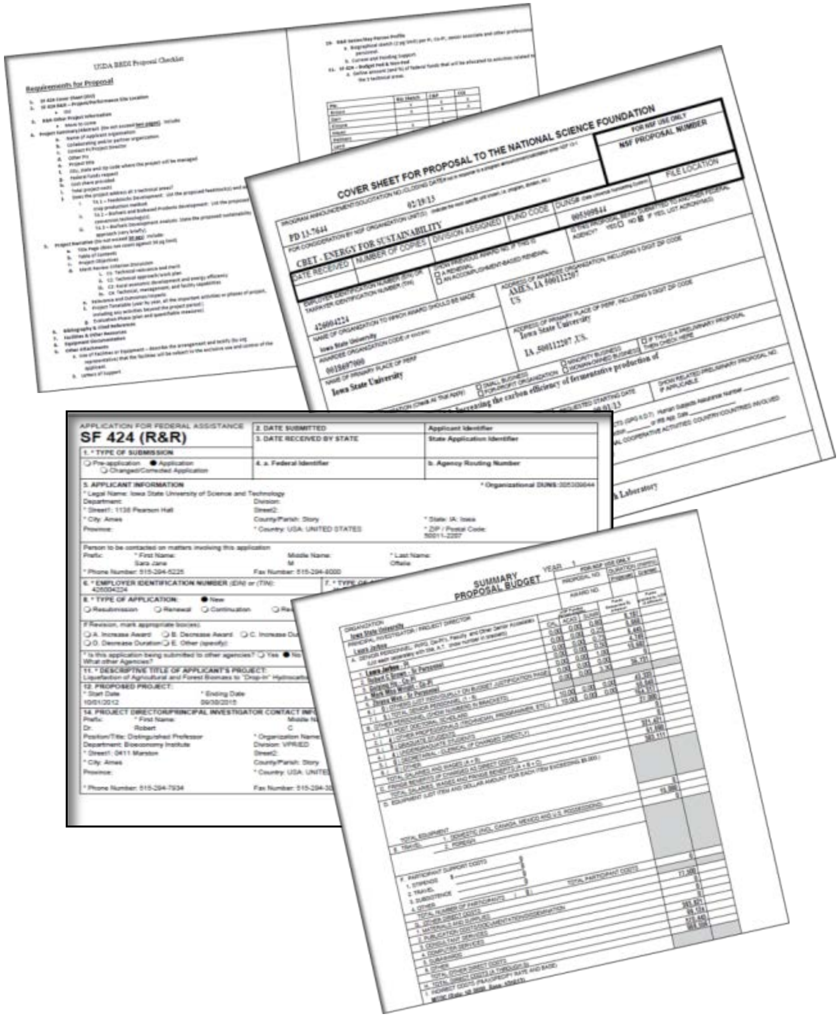
BEI Proposal & Award Services

- Assist faculty and staff
- Submittal and management
- Targeting proposals related to renewable energy, biobased products, sustainability,
- No cost to faculty



Examples of Assistance

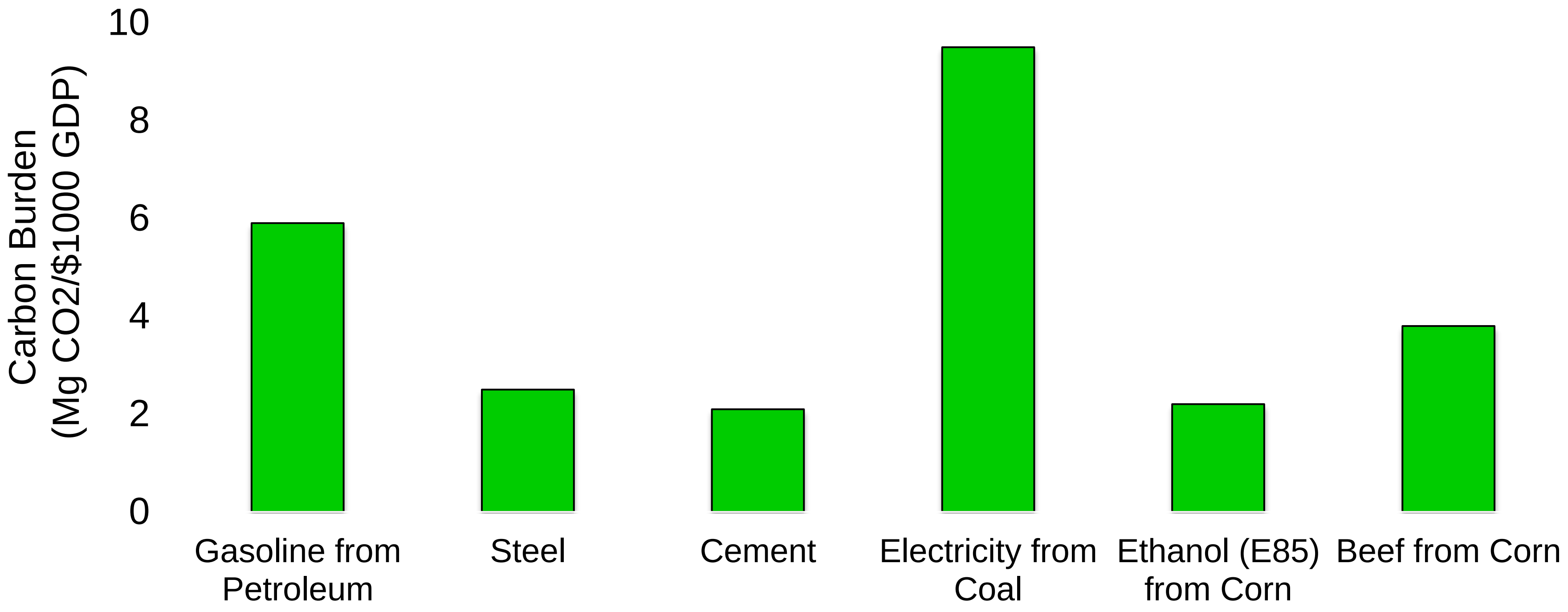
- Broader Impact guidance/resources
- Data Management Plans
- Coordination & Management Plans
- Post Doc Mentoring Plans
- BEI Facilities & Equipment
- Statement of Project Objectives (SOPO)
- Biosketch Templates
- Current and Pending Support Templates
- Conflict-of-Interest Templates



What is a Carbon Negative Economy?

- Economic activity reduces the amount of carbon dioxide in the atmosphere
- Distinct from goal of approaching carbon neutral status (that is, zero emissions of carbon dioxide)

All economic activity generates greenhouse gas emissions



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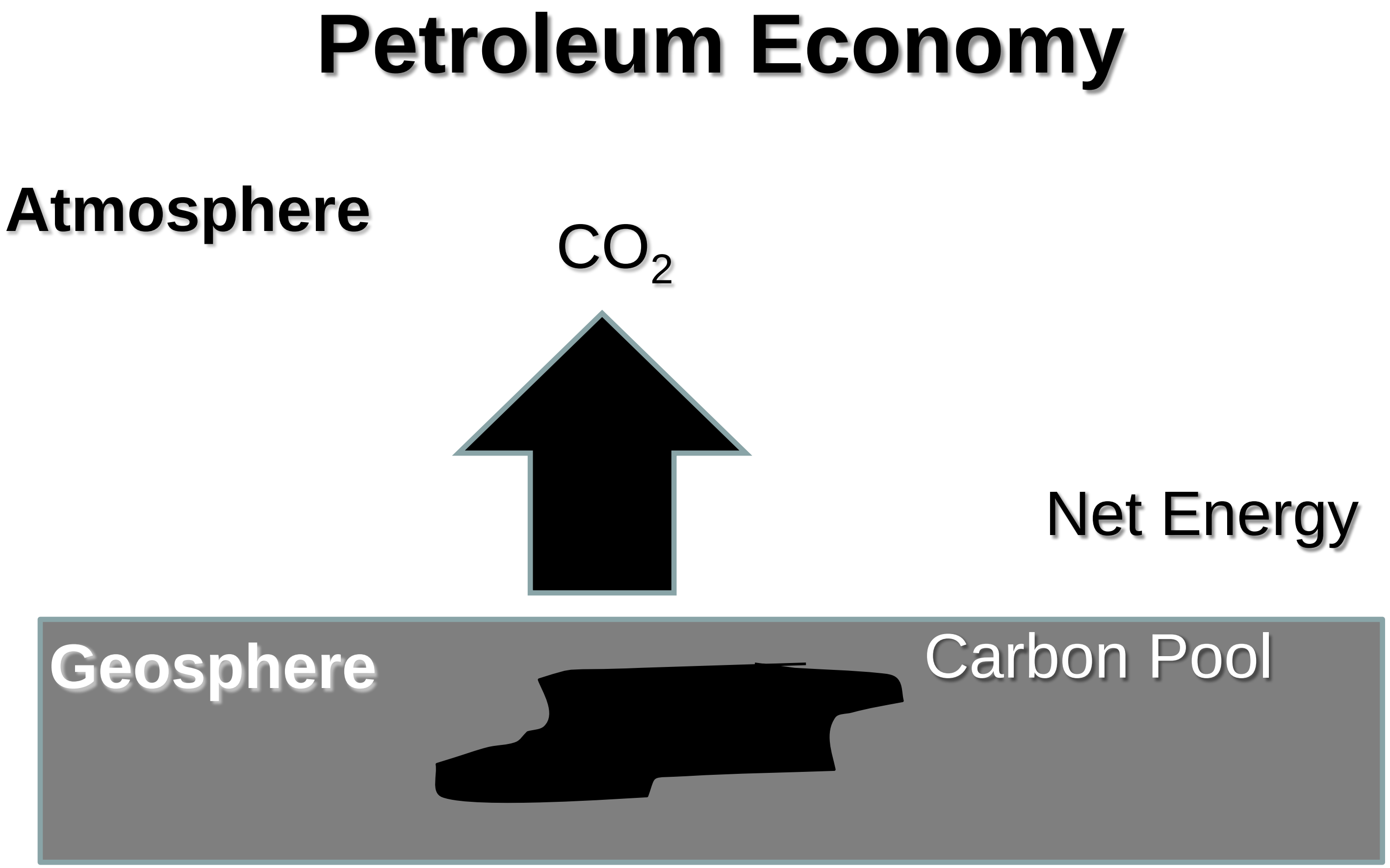
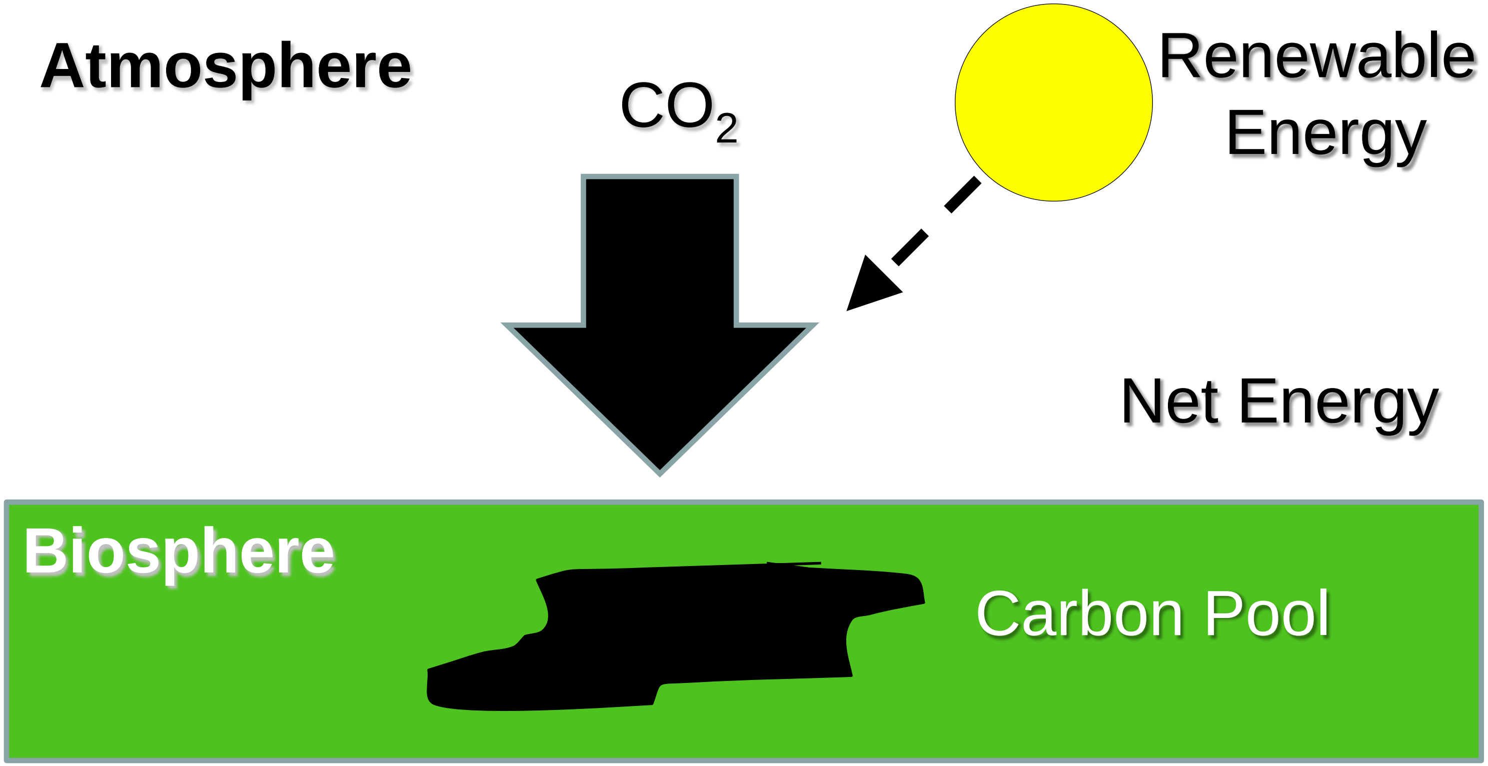
We Live in a Petroleum Economy



Reversing the Paradigm

Carbon Negative Economy



ISU's Approach to a Carbon Negative Economy

- Terrestrial plants or aquatic species fix carbon as *biomass*
- Biomass is harvested and pyrolyzed to *bio-oil and biochar*
- Bio-oil is upgraded to *drop-in fuels* and other *high value products* with attractive economics
- Biochar is returned to croplands where it *recycles nutrients, sequesters carbon and improves soil fertility*

Pyrolysis

Definition – thermal decomposition of organic compounds in the absence of oxygen

Temperatures in the range of 350-600 ^{0}C

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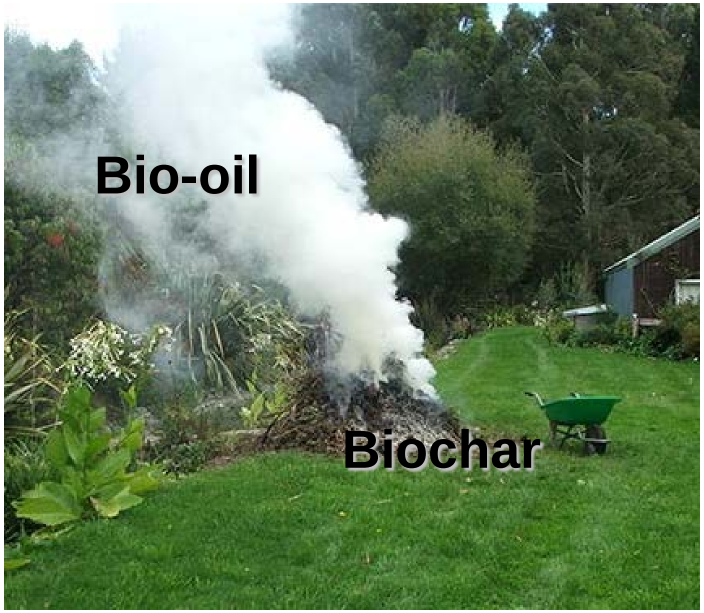
Py Products

- *Gas* – non-condensable gases like carbon dioxide, carbon monoxide, hydrogen
- *Solid* – mixture of inorganic compounds (including plant nutrients) and carbonaceous materials known as biochar
- *Liquid* – mixture of water and organic compounds known as *bio-oil* recovered from pyrolysis vapors and aerosols (smoke)



Definitions

- Char – any carbonaceous residue from pyrolysis including natural fires.
- Charcoal - char produced from pyrolysis of animal or vegetable matter in kilns for use in cooking or heating.
- Biochar – char produced specifically for application to soil for agronomic or environmental management.

Inspiration for ISU's CNE: Terra Preta in Amazon Basin

- Created hundreds of years ago by pre-Colombian inhabitants of Amazon Basin
- Result of slash and char agriculture
- Much higher levels of soil organic carbon
- Far more productive than undisturbed Oxisol soils

Oxisol

Terra Preta

Applied to the land, biochar serves as both soil amendment and carbon sequestration agent

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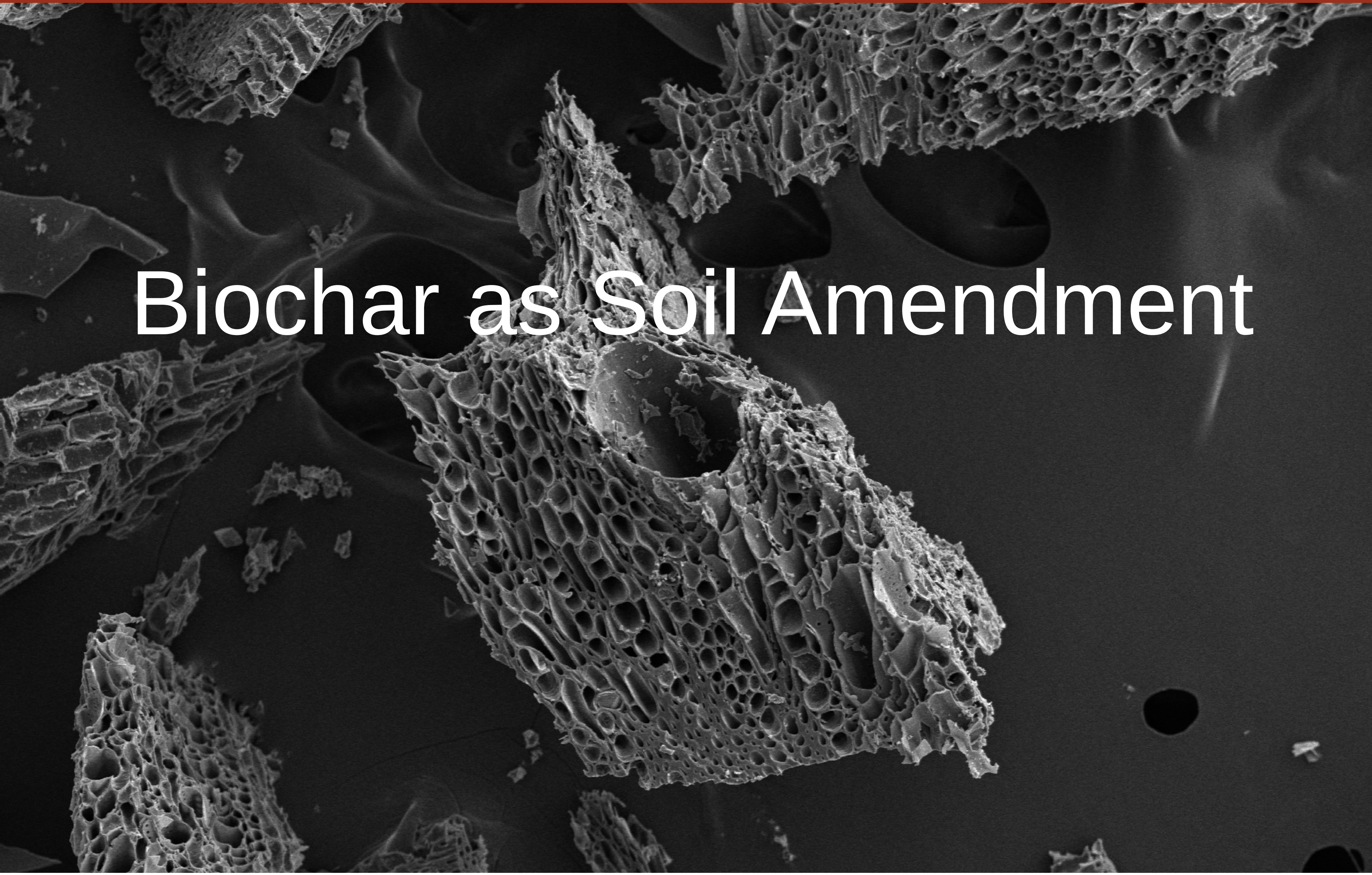
Glaser et al. 2001. Naturwissenschaften (2001) 88:37–41

Biochar as Soil Amendment

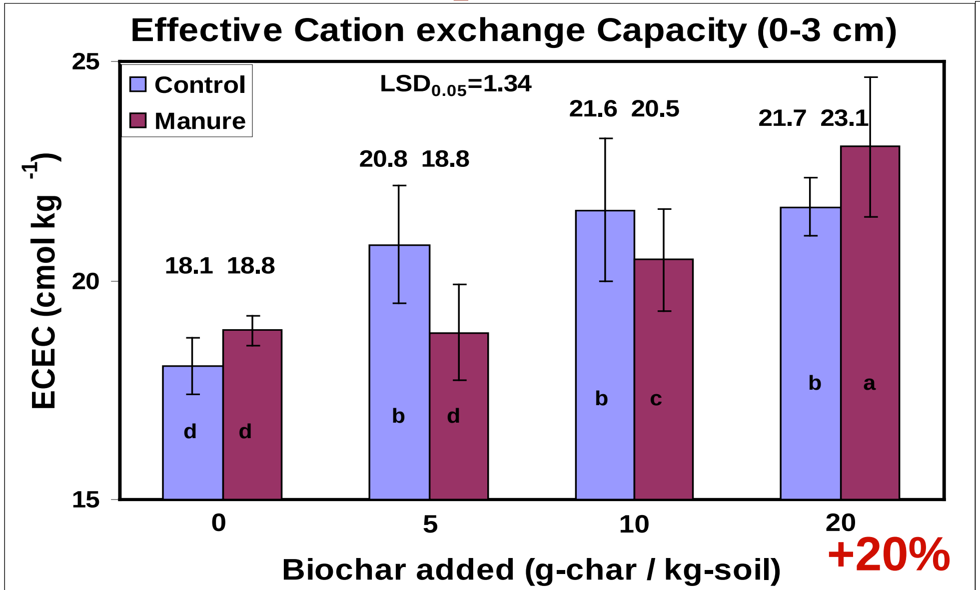


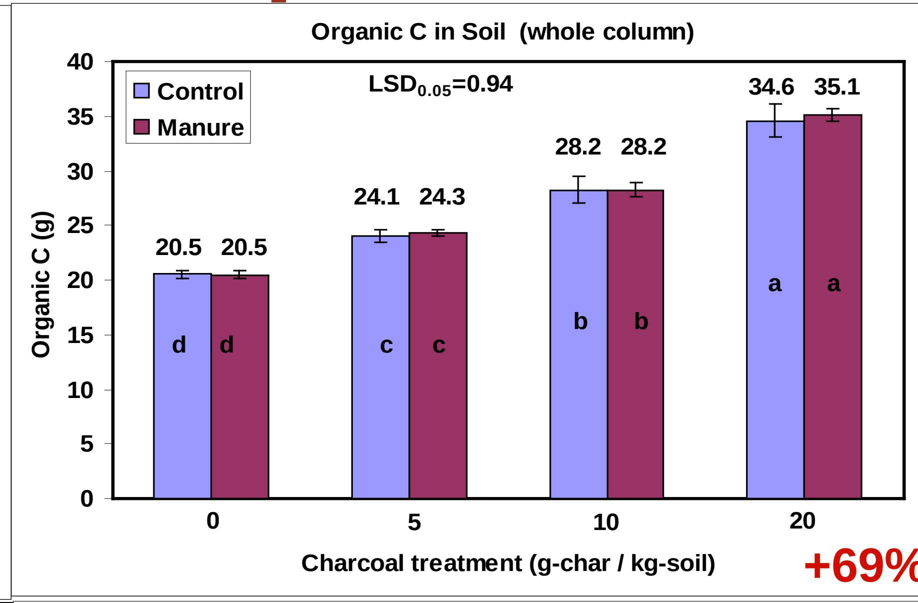
Slide courtesy David Laird, ISU Agronomy

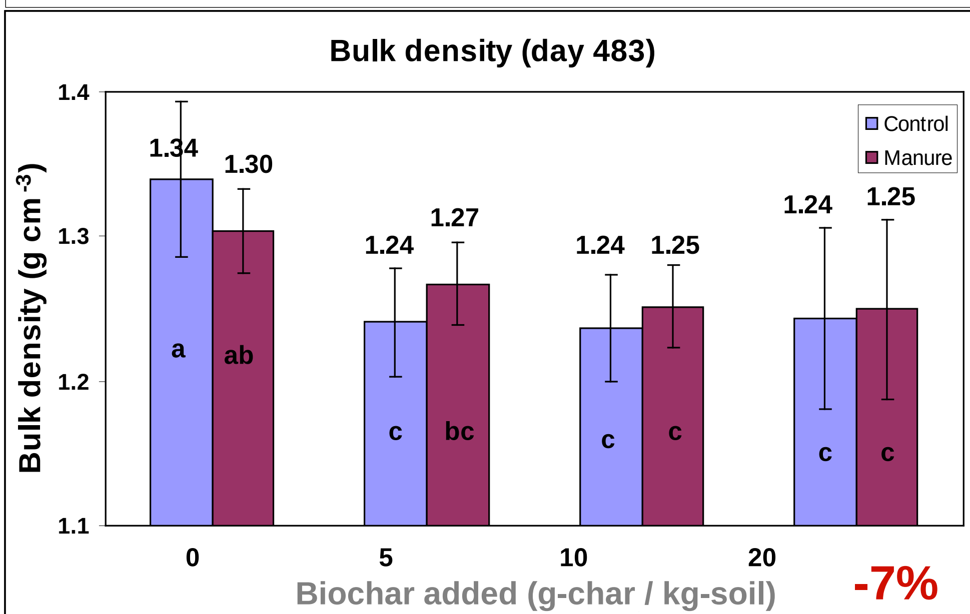
Purported Benefits of Biochar

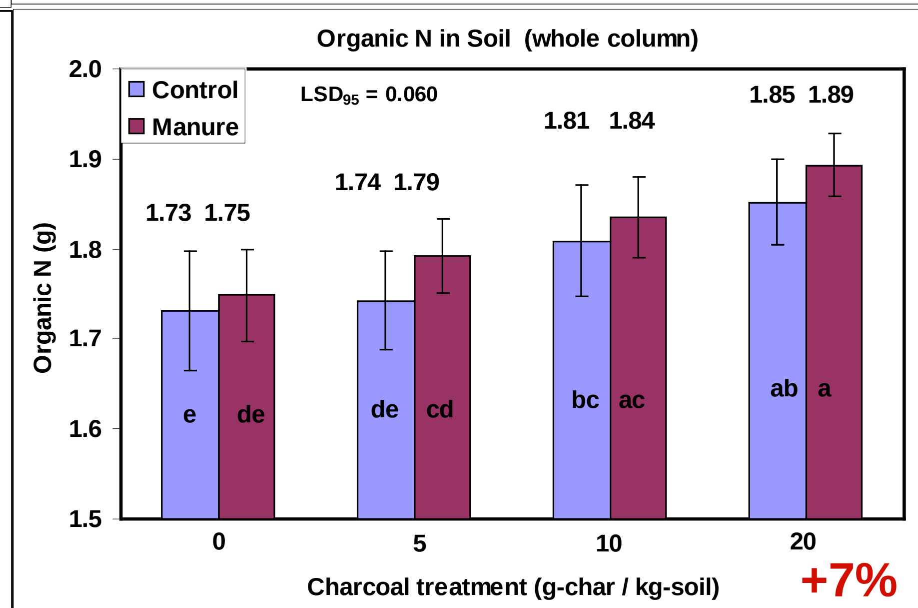
- Recycling of nutrients
  - Mostly K and P
  - Some N but it may be unavailable to plants
- Improved soil fertility
  - Enhanced cation exchange capacity (with time)
  - Improved water retention
  - Mycorrhiza enhancement
- Long-term carbon sequestration
  - Measured in hundreds or even thousands of years

Improves Soil Properties



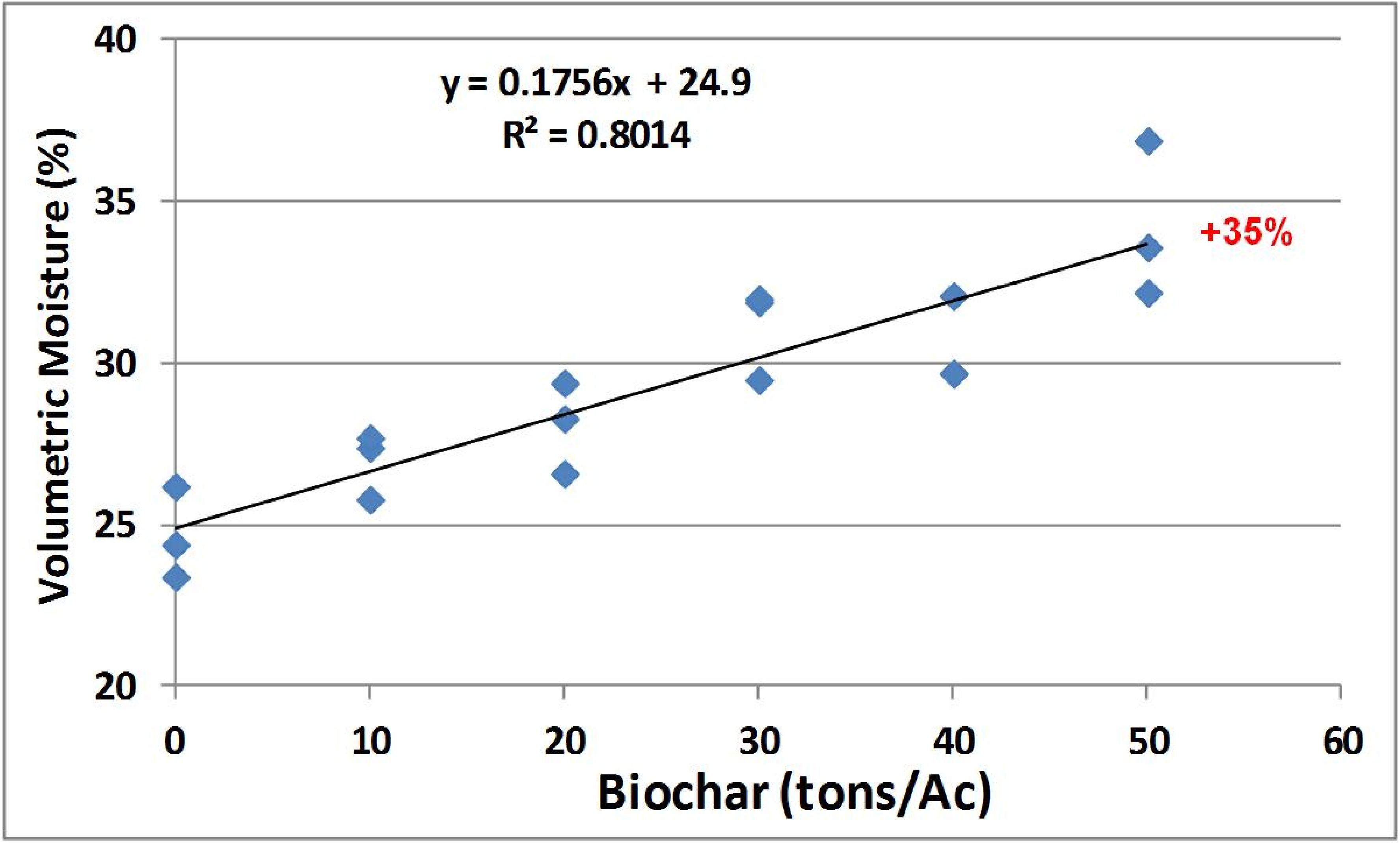






Improves Volumetric Soil Moisture

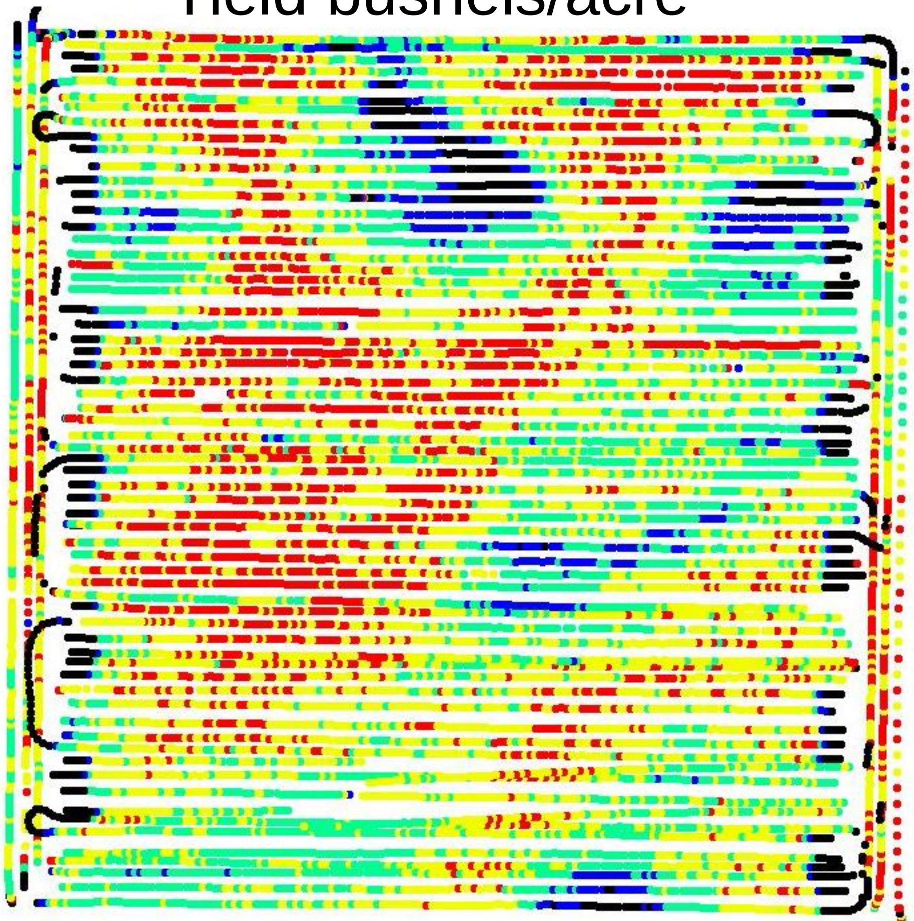
ISU Boyd Farm – moisture measured July 12, 2011



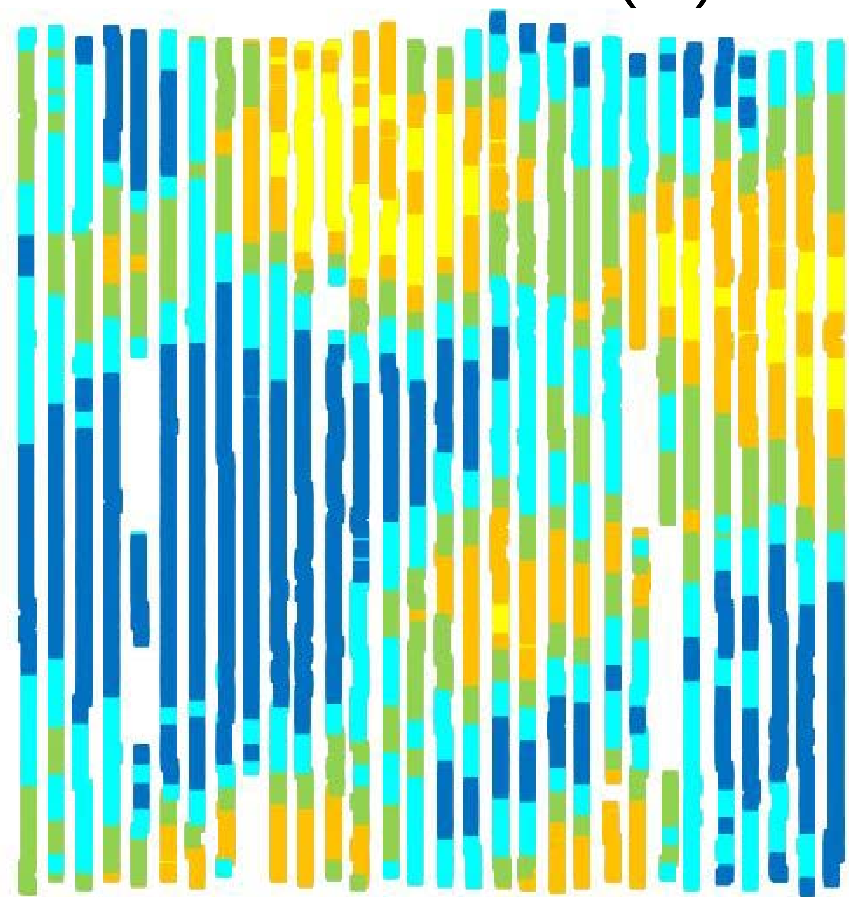
Slide courtesy David Laird, ISU Agronomy

Increase in Water Retention May be Most Important Benefit of Biochar Application to Soils

Yield bushels/acre



Moisture content (%)



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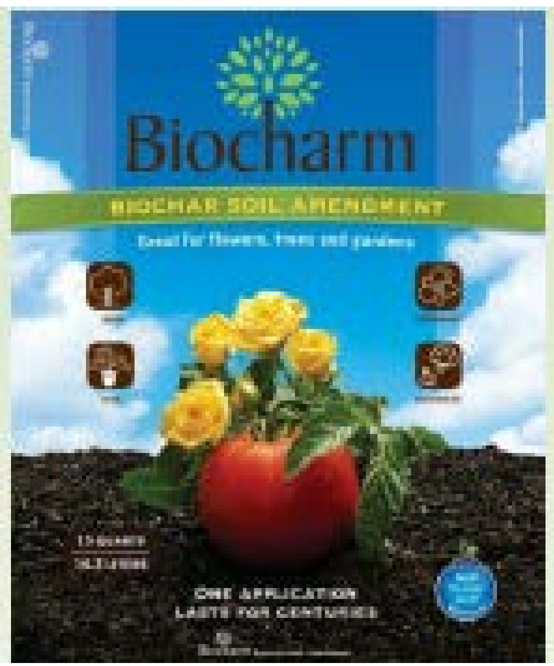
Horticultural Applications of Biochar are Near-term, High Value Opportunities

Biocharm
www.biocharm.com



Soil Reef
www.soilbiochar.com

GroChar
www.Carbongold.com

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Mine land reclamation is another important niche opportunity for early biochar applications

Biochar Solutions
www.biocharsolutions.com

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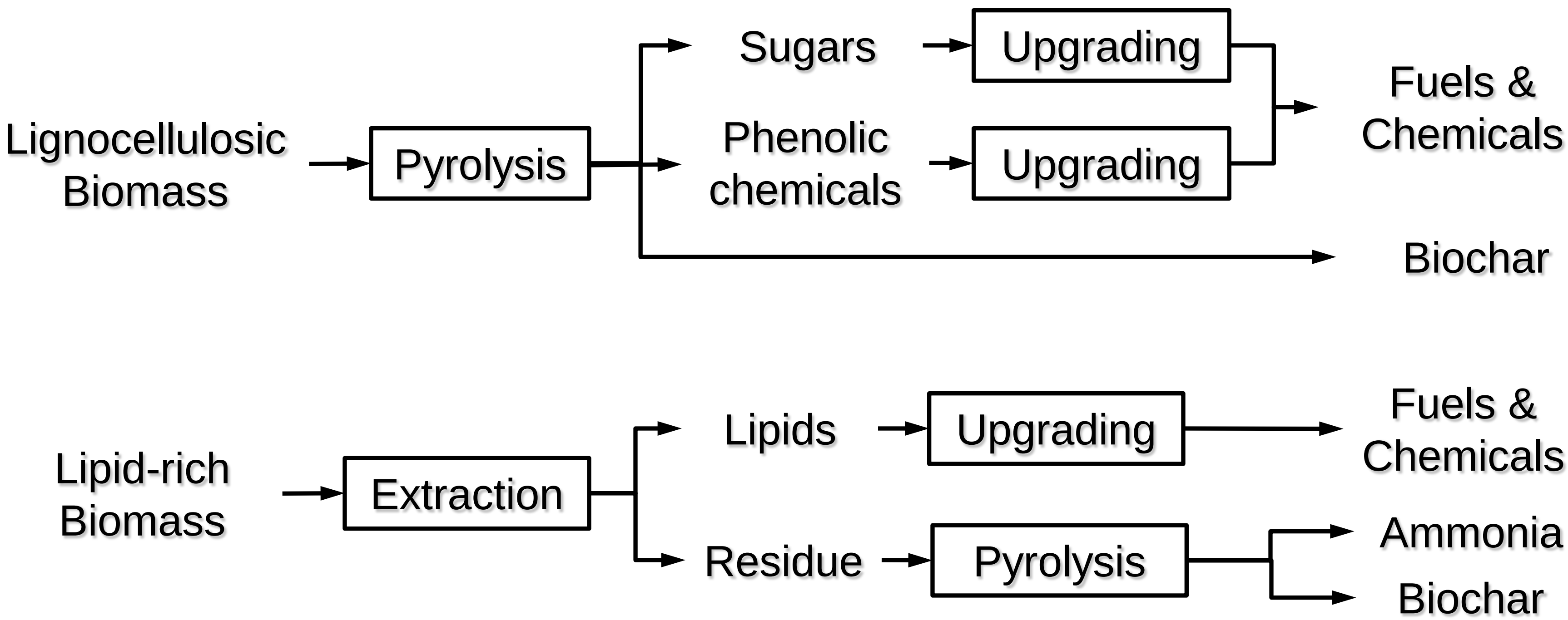
Two Major CNE Pathways Being Considered for Wide Scale Applications

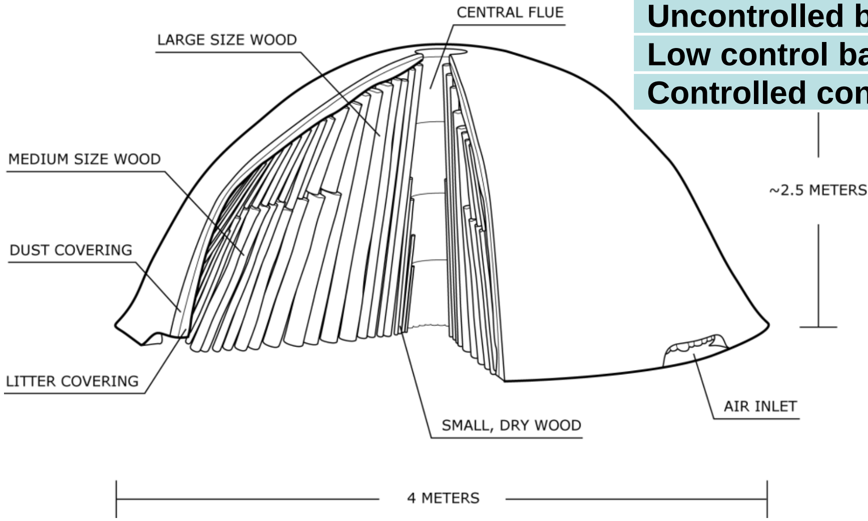


Production of Biochar

- Can traditional charcoal making be used to produce biochar?
- How do processing conditions affect yield and quality of biochar?
- Do we want processes that maximize yield of biochar?
- What technologies are available to sustainably produce biochar?

Traditional Charcoal Making Is Not Sustainable

Kiln type	CO (g kg-1)	CH_4 (g kg-1)	NMOC[1] (g kg-1)	TSP[2] (g kg-1)
Uncontrolled batch	160-179	44-57	7-60	197-598
Low control batch	24-27	6.6-8.6	1-9	27-89
Controlled continuous	8.0-8.9	2.2-2.9	0.4-3.0	9.1-30



- Contributes to deforestation: *Need to use residues*
- Generates air pollution: *Need to minimize emissions*
- Low carbon conversion: *Need to utilize more carbon*

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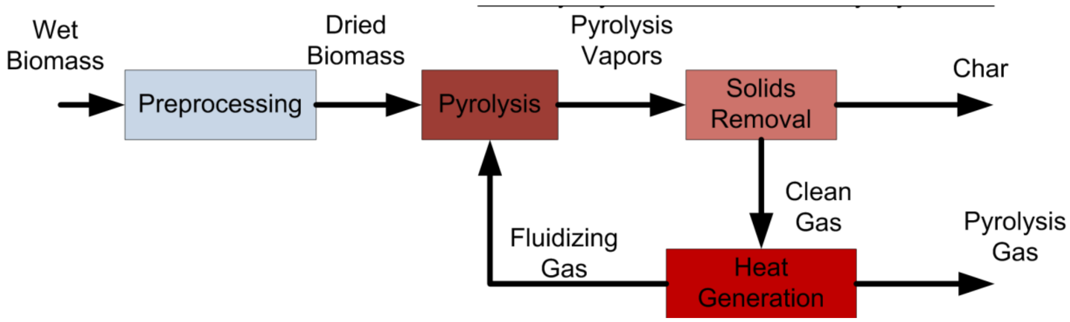
[1]NMOC – non-methane organic compounds
[2]TSP – total suspended particulates

Effects of pyrolysis heating rate and temperature on biochar

- Heating rate affects biochar yields
  - Slow pyrolysis yields 25-40 wt% char
  - Fast pyrolysis yields 12-10 wt% char
- Pyrolysis temperature affects biochar quality
  - Biochar produced at very low temperature is not recalcitrant to mineralization
  - Biochar produced at very high temperature can be phyto-toxic at least in first season of application
  - Best quality biochar produced at 400-600°C

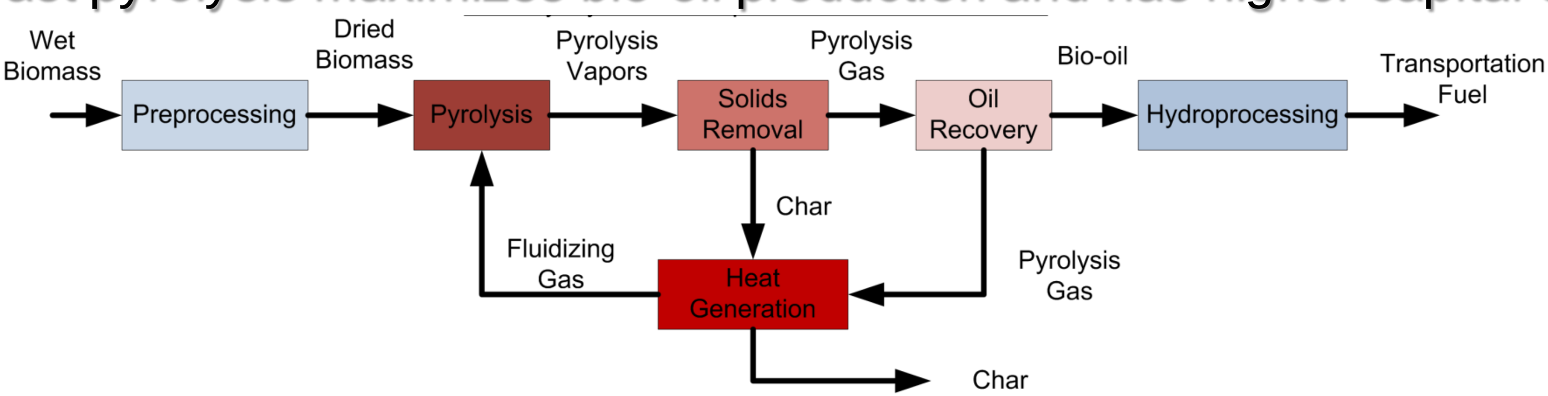
Do We Want to Maximize Char Production to Build a CNE?

Slow pyrolysis maximizes char production and has lower capital costs



Pyrolysis gas substitutes for natural gas

Fast pyrolysis maximizes bio-oil production and has higher capital costs



Bio-oil upgraded to gasoline & diesel

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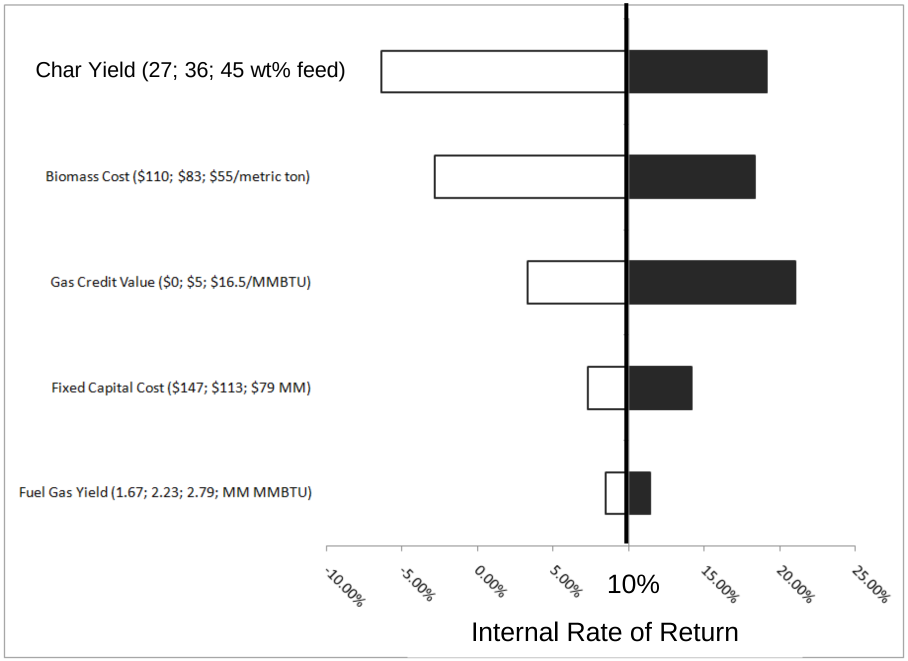
Not if We Want to Make a Profit

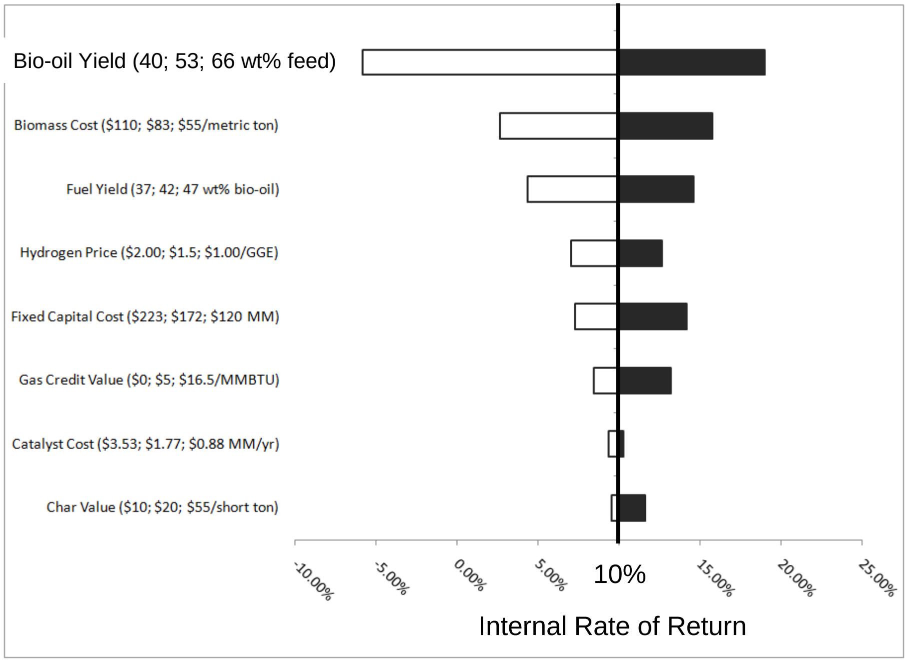
Slow Pyrolysis

To achieve 10% IRR, product biochar would have to sell for $346 per metric ton (no thanks)



Fast Pyrolysis

To achieve 10% IRR product gasoline would have to sell for $2.68 per gallon (sounds like a deal)



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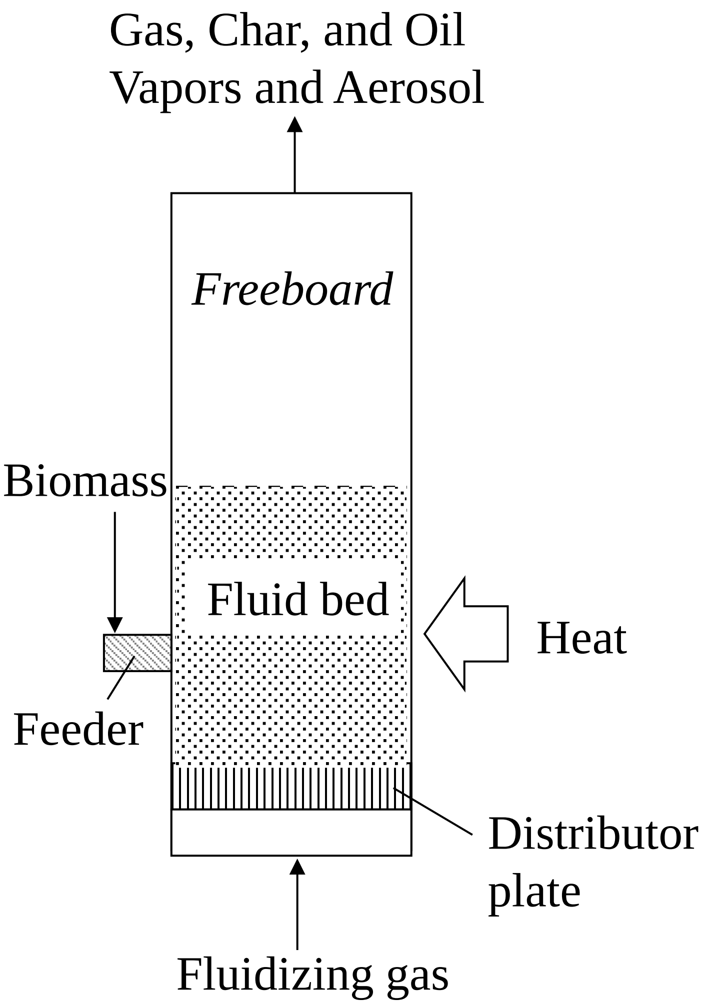
Modern Pyrolyzers: Bubbling Fluidized Bed

- Heat supplied externally to bed
- Good mass & heat transfer
- Gas residence times shorter than char residence times



Bubbling Fluidized Bed Pyrolyzer at ISU

(includes fractionating bio-oil recovery system for value-added products)

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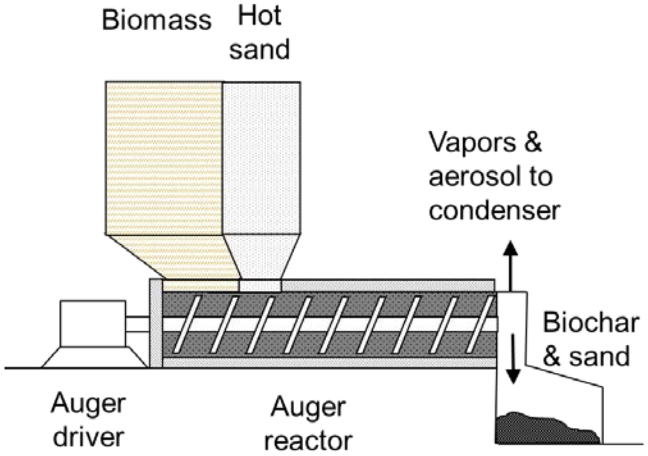
Modern Pyrolyzers: Auger Reactor

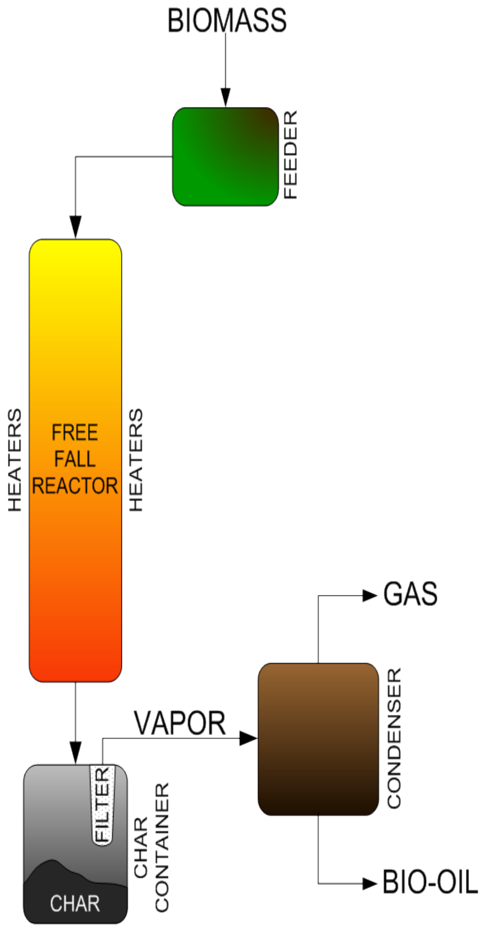
- Heat carrier and biomass mixed by auger
- Suitable for small scale
- Requires heat carrier heating and circulation system



Dual co-currently rotating screws mix and convey heat carrier and biomass

Modern Pyrolyzers: Free Fall Reactor

- No heat carrier
- Little to no carrier gas
- Simple design –no moving parts
- Requires small biomass particles
- May be suitable for distributed pyrolysis operations and small scale



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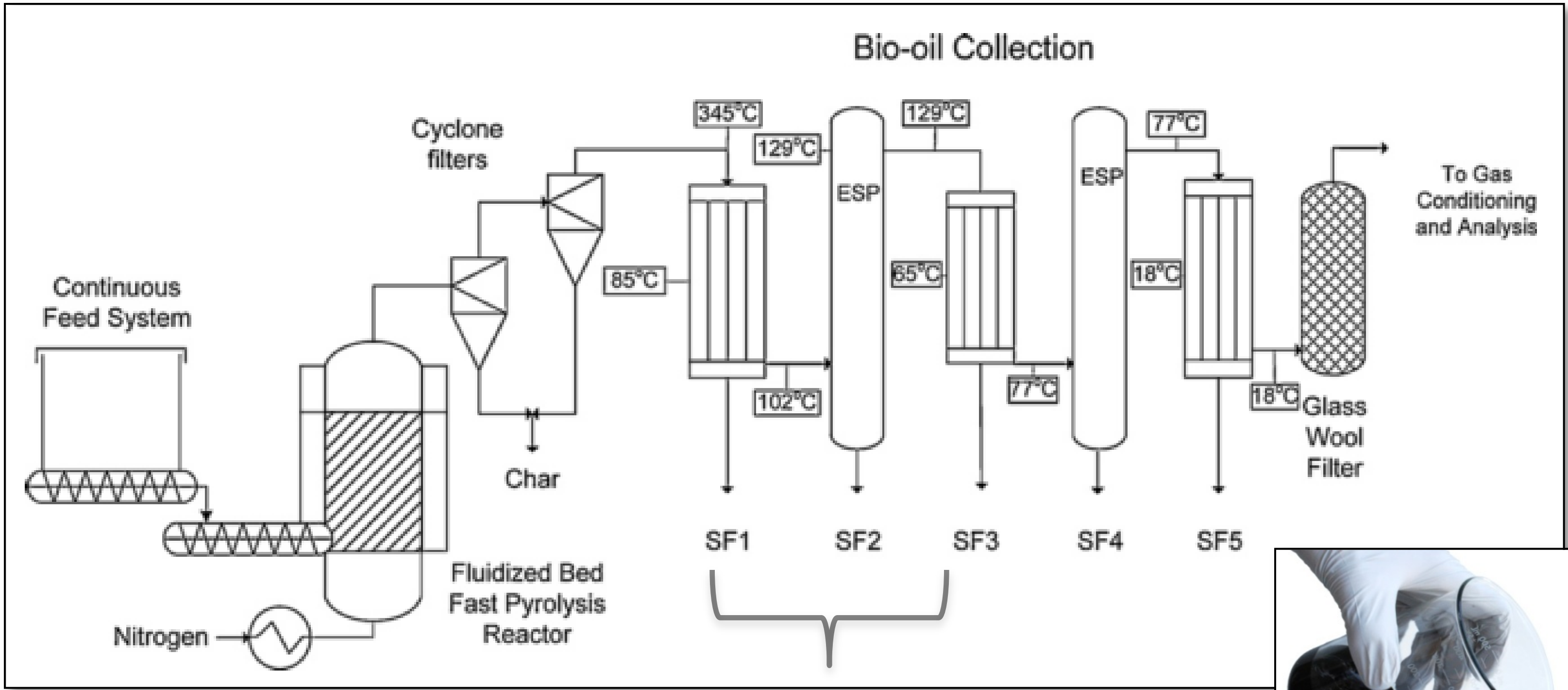
Recovery of Bio-oil as Stage Fractions



Stage fractions have distinctive physical and chemical properties

Value-Added Applications of Bio-Oil Fractions

- Phenolic oligomers from lignin
  - Green gasoline and diesel
  - Bio-asphalt
  - Bio-oil co-firing fuel
- Sugars from polysaccharides
  - Fermentation substrate
- Light ends from polysaccharides
  - Fermentation substrate
  - Gelled fuel

Catalytic upgrading to green gasoline and diesel

Bio-Oil Co-firing Fuel

Paving bike path with bio-asphalt

Gelled fuel (acetate + alcohol)

Pyrolysis sugars

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ISU’s Initiative for a Carbon Negative Economy

- Established in 2011 with support from the ISU College of Engineering Venture Fund
- Purpose is to secure significant funding of interdisciplinary research into CNE
- Initiative has won $2 million from the Stanford Global Climate and Energy Program to model agronomic, engineering, and economic aspects of CNE
- Launching CNE demonstration at pilot-scale

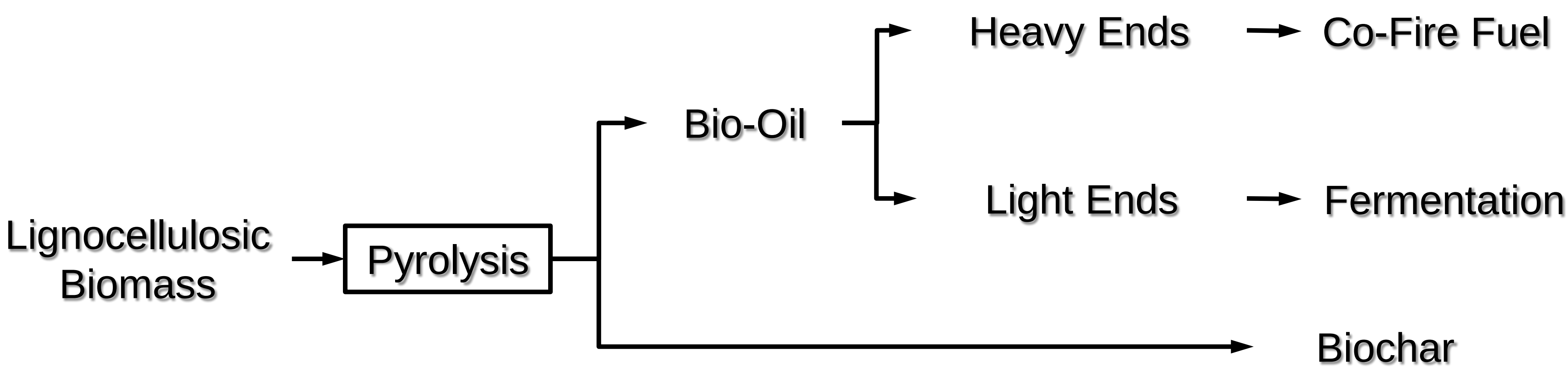
Outline of CNE Demonstration

- Bio-oil and biochar produced at Stine Seed Co. pyrolyzer (after retrofit)
- Bio-oil used to produce co-fire fuel for ISU physical plant
- Biochar applied to farm fields in cooperation with Soybean Promotion Board
- First-phase funding provided by Iowa Energy Center, Iowa legislature, and Stine Seed

Bio-oil co-firing fuel

Land application of biochar

Pathway for CNE Demonstration



Partnership with Stine Seed

- Stine Seed has informally collaborated with ISU for several years
  - Biochar demonstrated on Stine farms
  - Company has experimented with prototype 30 tpd fast pyrolyzer
- Stine Seed has agreed to:
  - Let ISU use his pyrolyzer for research
  - Pay for retrofits to pyrolyzer
  - Provide 1-2 operators
  - Provide discounted feedstock
  - Work with ISU on field demonstrations

Working with ISU Physical Plant

- David Miller and Jeff Witte indicate that bio-oil co-fire fuel (BCF) would require no retrofit of ISU boilers
- Agreed to have evaluate co-firing performance of BCF using their boiler model
- President Leath has endorsed the project

Comparing CO_2 Emissions

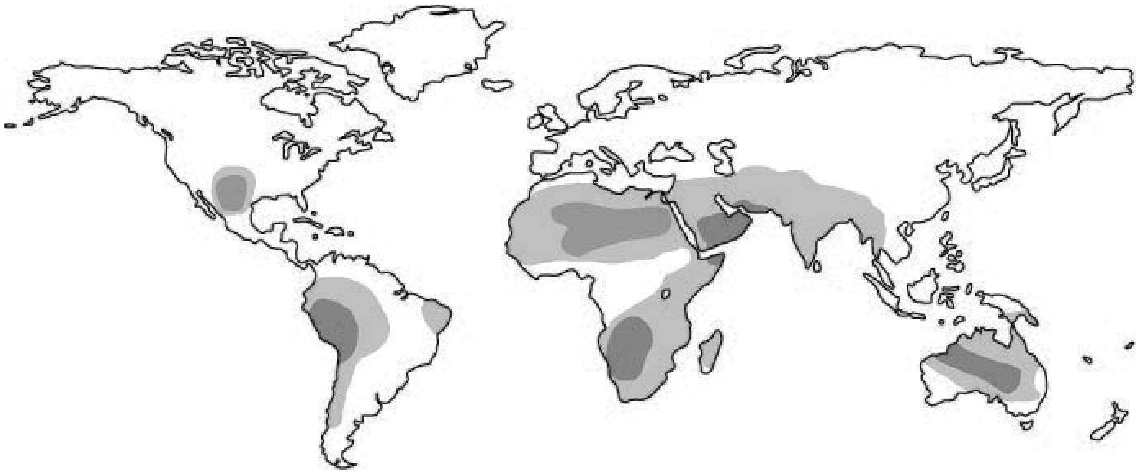
Fuel type	Kg CO_2eq / kg Oil
Residual Oil	0.543
Fuel Oil	0.622
Biofuel oil (with biochar sequestered to agricultural lands)	-2.85

Note 1: Bio-fuel oil is the heavy ends of bio-oil; the light ends are used for acetate-based products

Note 2: Burning Bio-fuel Co-firing product would result in a 56% reduction in CO2 emissions relative to burning coal.

Where Should We Grow Biomass?

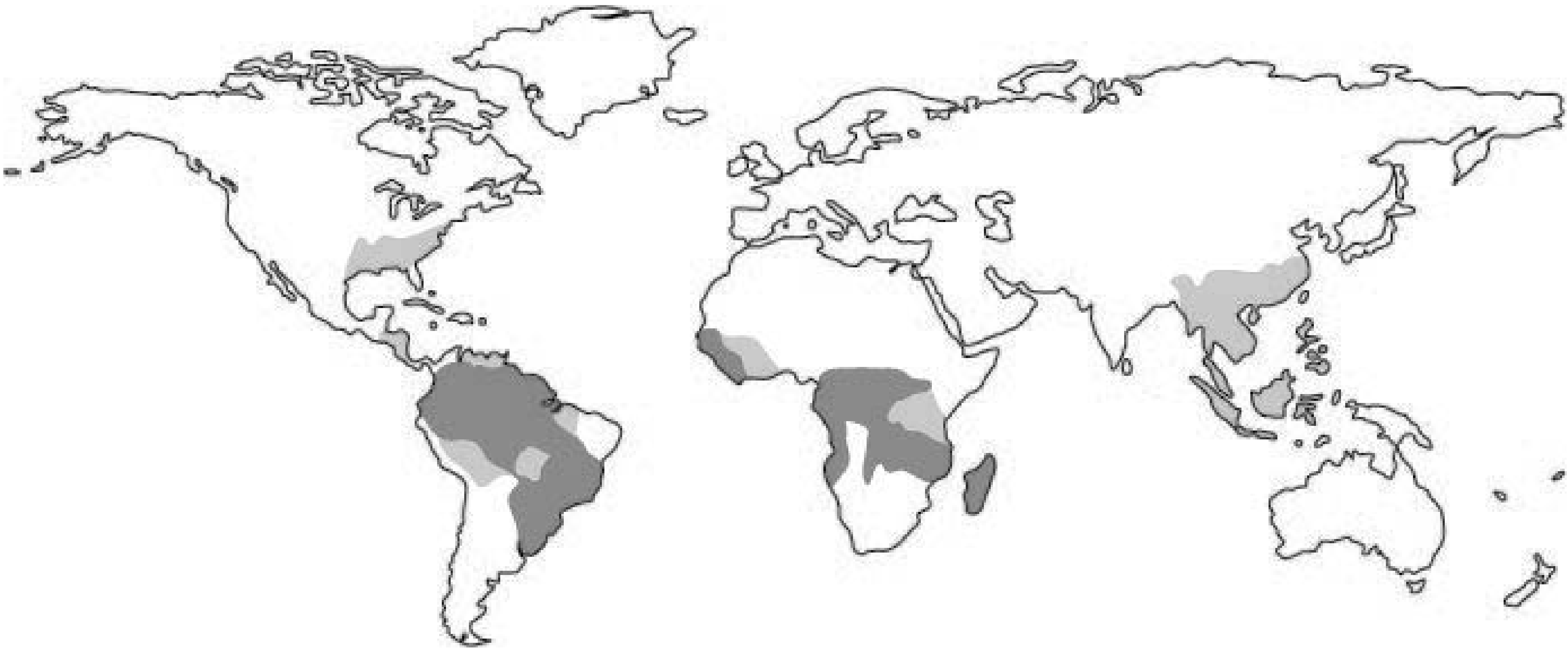
Highest Annual Solar Irradiance



Highest Annual Precipitation

Tropics Have Limited Soil Fertility

Shaded areas contain some of the most weathered and leached soils in the world

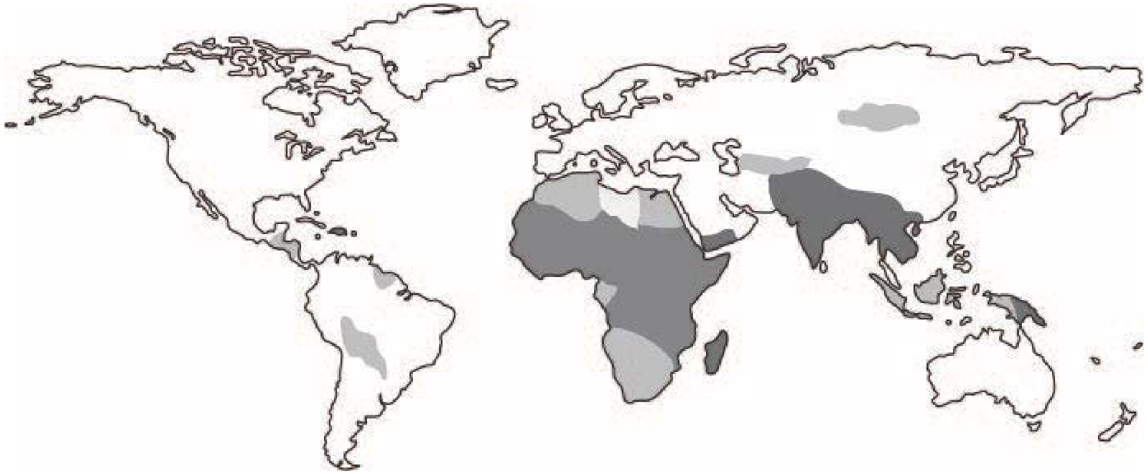


Where the CNE really pays off

‘Much of the current debate on bioenergy […] obscures the sector’s huge potential to reduce hunger and poverty …If we get it right, bioenergy provides us with a historic chance to fast-forward growth in many of the world’s poorest countries, to bring about an agricultural renaissance and to supply modern energy to a third of the world’s population.”

–Jacques Diouf, Director-General, UN Food and Agriculture Organization

Highest Human Development Need



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Backyard Biochar Horticulture

Red Pots: Biochar
Yellow Pots: Control

R. C. Brown, 2012

Biochar-treated tomato plants matured three weeks earlier than untreated plants

Additional Resources on Pyrolysis and Biochar