



# Carbon Negative Energy

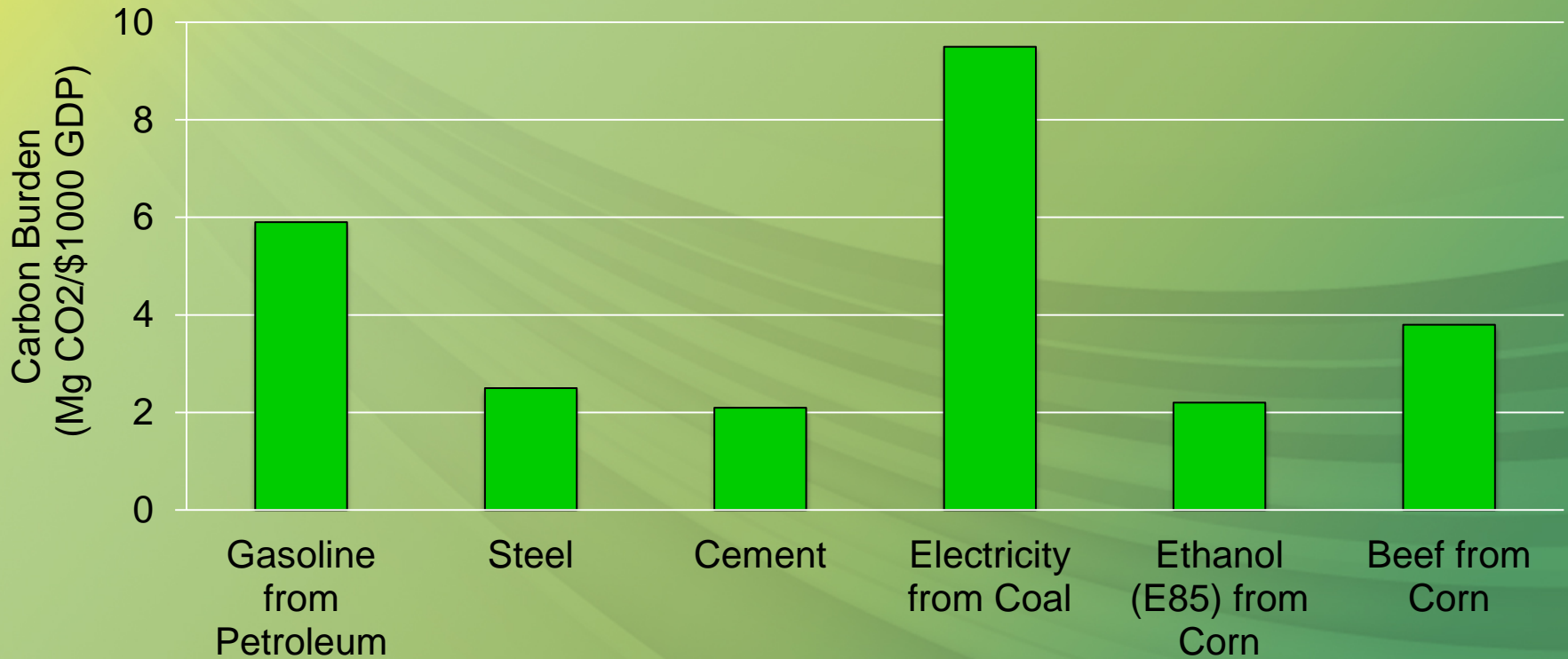
Robert C. Brown (ME) and David Laird (Agronomy)  
Iowa State University

A satellite view of Earth from space, showing the Americas and surrounding oceans. The text is overlaid on the image.

**Despite wide spread concern about global climate change, the U.S. Congress failed to pass greenhouse gas legislation in 2010.**

**Why?**

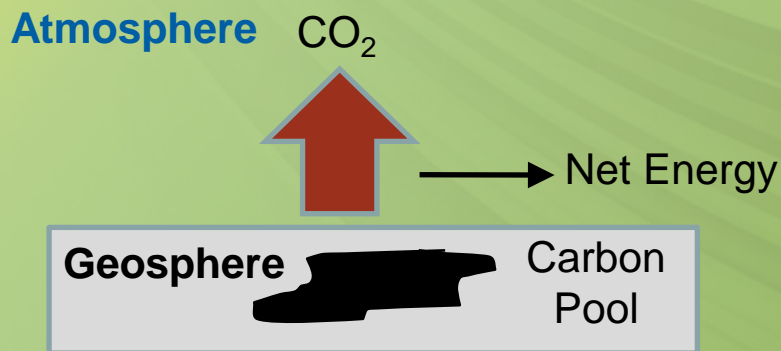
# How can you have economic prosperity without greenhouse gas emissions?



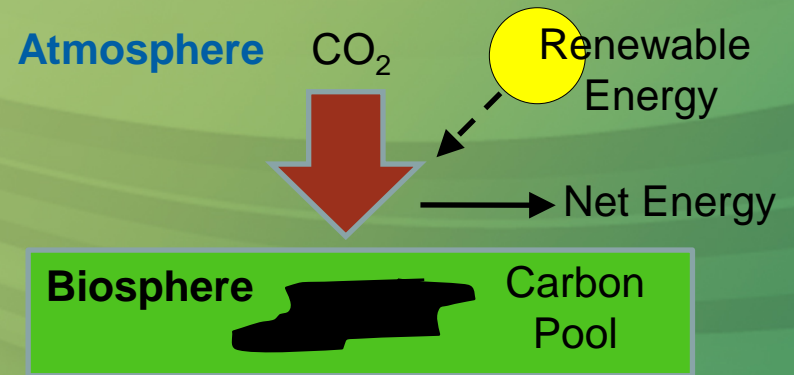


# Can we turn this paradigm on its head?

## Petroleum Economy



## Carbon Negative Economy



# Key Features of a Carbon Negative Economy

- Fixes carbon from the atmosphere
- Sequesters carbon in the biosphere (vs. the geosphere) potentially providing ecosystem services
- Generates co-products useful to human society (providing positive contribution to national economies)

# Our Concept: Pyrolysis-Based Carbon Negative Energy

- Terrestrial plants or aquatic species fix carbon as biomass
- Biomass is harvested and pyrolyzed to bio-oil and biochar
- Bio-oil is used as energy product for power production or upgraded to drop-in fuels, providing net economic return
- Biochar is returned to croplands where it recycles nutrients, improves soil fertility, and sequesters carbon



# The ISU Team

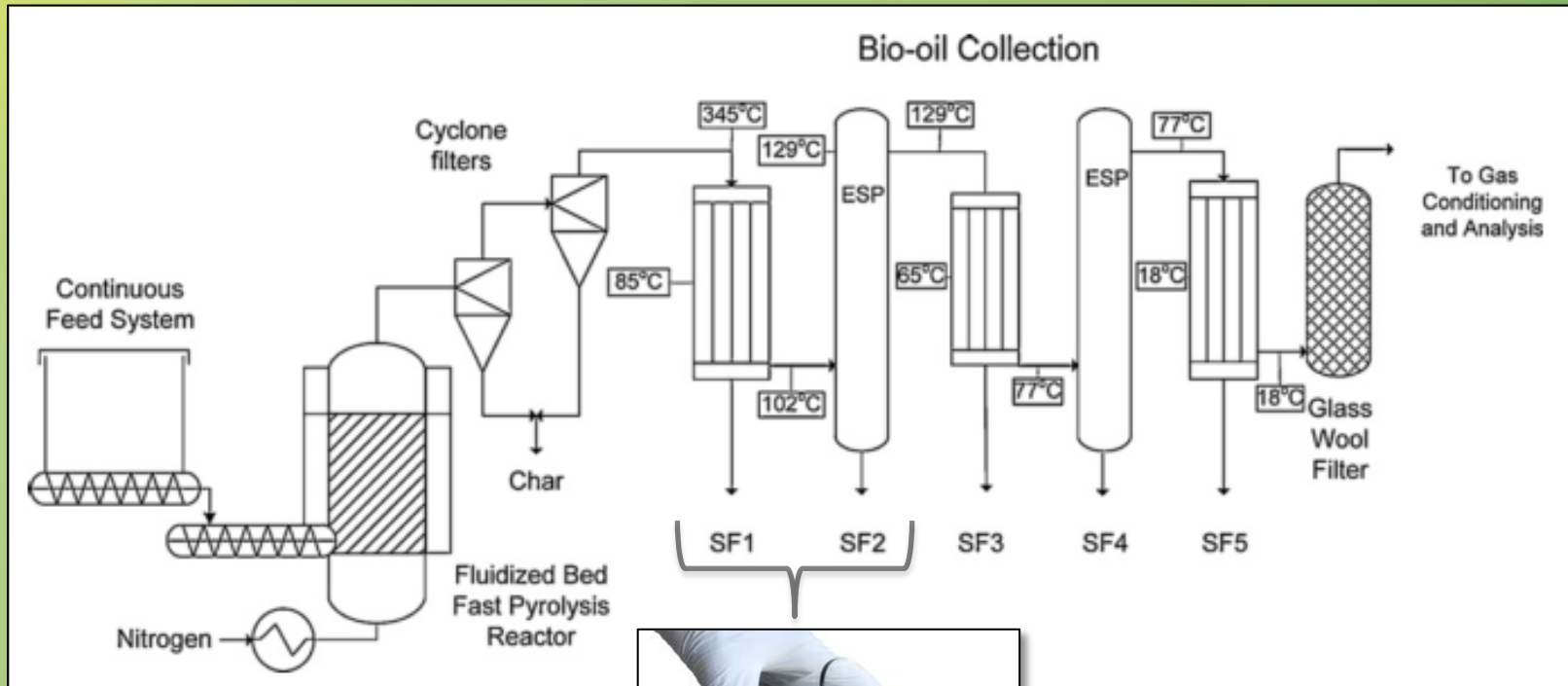
Thrust Area	Faculty member	Department	Role
Carbon fixation	Ken Moore	Agron	Cellulosic biomass production
	Martin Spalding	GDCB	Photosynthetic metabolism
Carbon negative fuels	Robert Brown	ME	Thermochemical conversion
	Brent Shanks	CBE	Catalytic upgrading
Carbon sequestration	David Laird	Agron	Biochar utilization
Carbon Policy	Bruce Babcock	Econ	Energy economics and policy
	Dermot Hayes	Econ	Economic considerations

# ISU Experience in Pyrolysis





# ISU Fractionating Bio-Oil Recovery System



Produces distinctive heavy ends derived from lignin in biomass

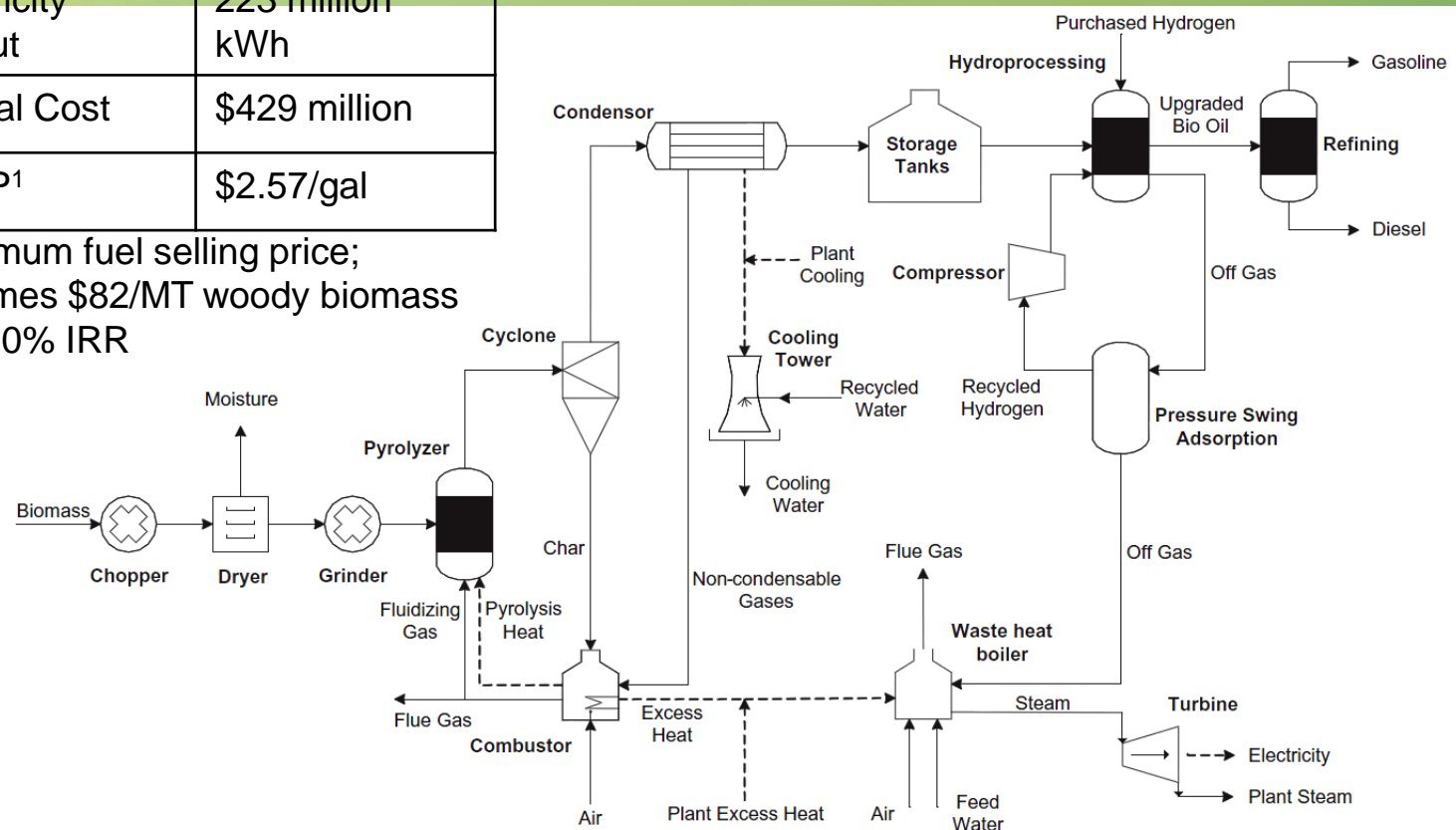


# ISU Experience in Technoeconomic Analysis

## Biomass Pyrolysis and Bio-Oil Upgrading (2000 MTPD)

Fuel Output	57.4 MGY
Electricity Output	223 million kWh
Capital Cost	\$429 million
MFSP <sup>1</sup>	\$2.57/gal

<sup>1</sup>Minimum fuel selling price; assumes \$82/MT woody biomass and 10% IRR





# ISU Experience in Biochar





# Outline of Iowa CNE Project

- Demonstrate CNE at ISU
  - Instead of producing motor fuel, use bio-oil as substitute for coal at physical plant
  - Apply biochar to farm fields in cooperation with Soybean Promotion Board
- Produce bio-oil and biochar at Harry Stine's pyrolysis pilot plant (after retrofit)



Bio-Oil Co-Firing Fuel  
(30% "pyrolytic lignin"+  
70% coal)

# Partnership with Harry Stine

- Stine has informally collaborated with ISU for several years
  - Demonstrated biochar on his farms
  - Experimented with prototype 30 tpd fast pyrolyzer
- Stine 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

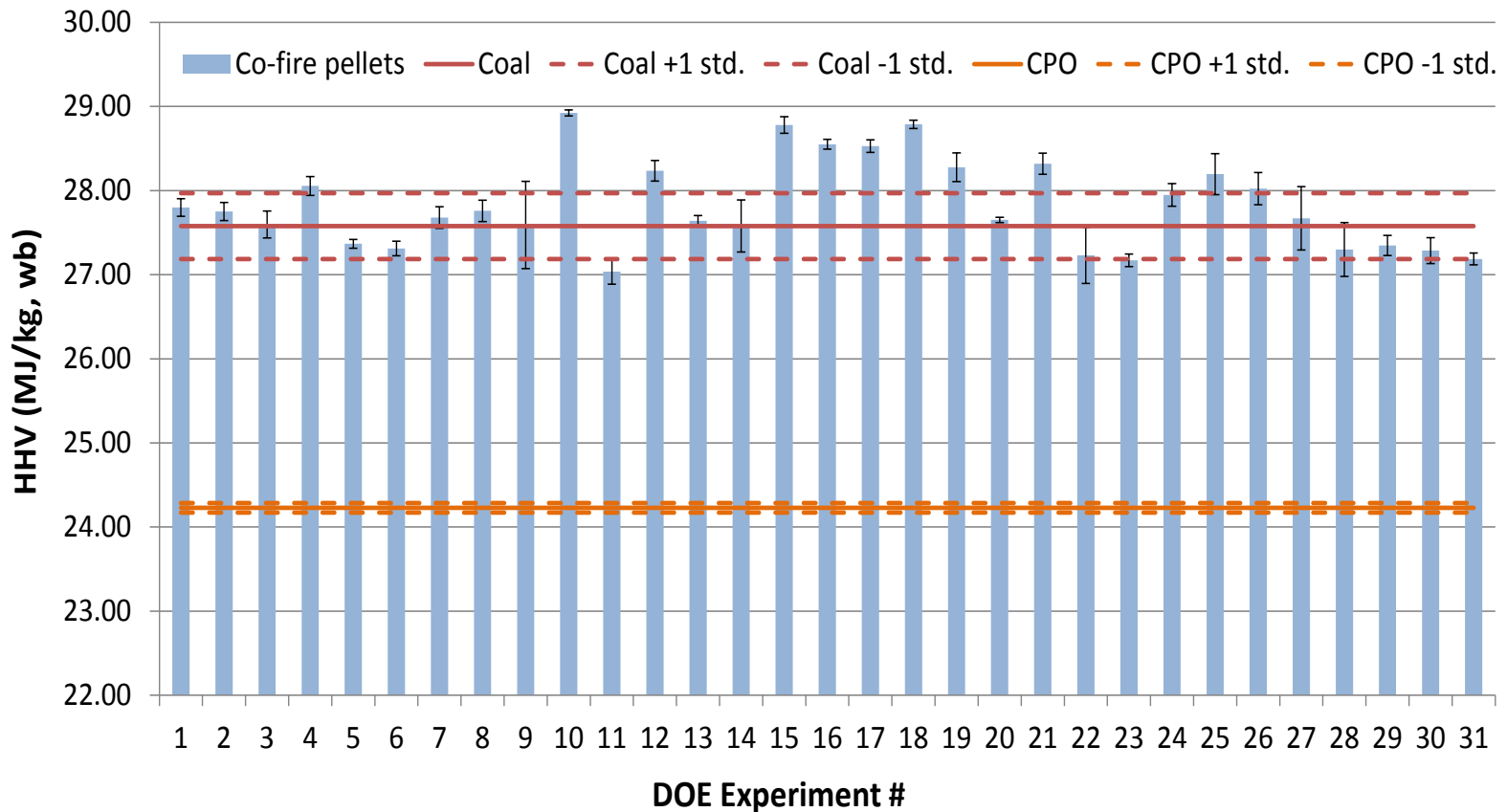
# Additional Project Support

- Iowa Energy Center has provided funds for ISU to design pyrolyzer retrofits
- State of Iowa “Leading the Bioeconomy” funds provided to:
  - Install and operate equipment to produce bio-oil co-firing fuel (BCF) and store biochar
  - Transport and handle BCF and biochar
  - Initiate field trials with biochar



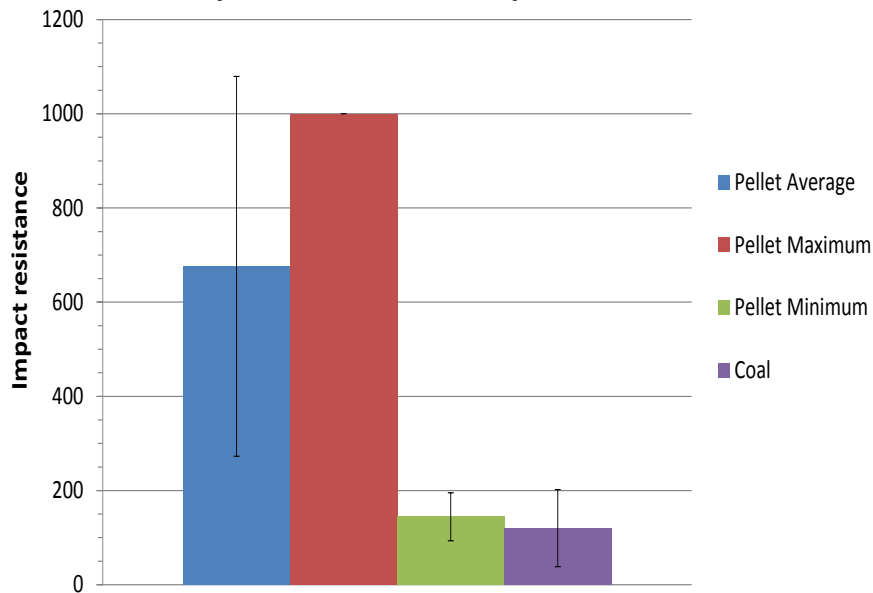
# Heating Value of Co-Fire Fuel Almost Identical to Coal

## Co-fire pellet higher heating value

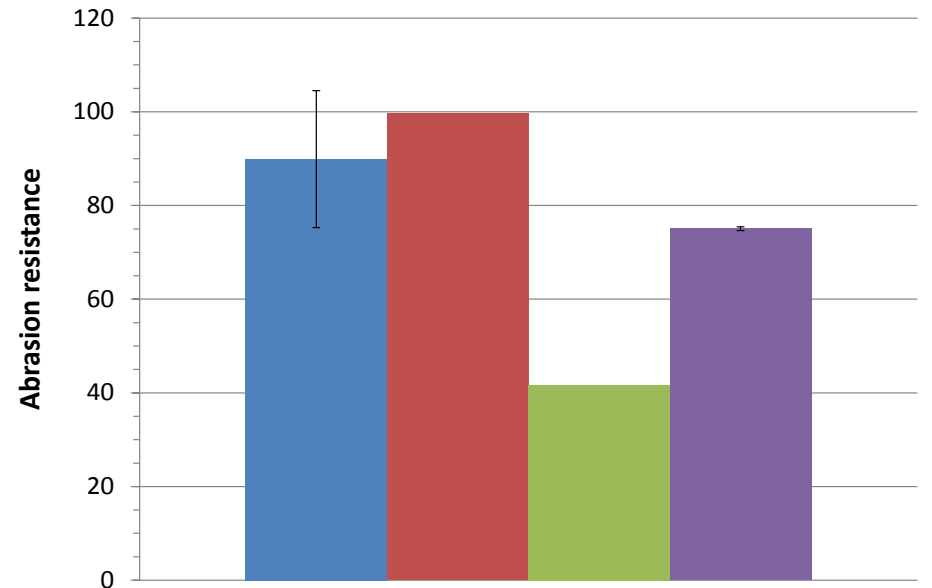


# Impact and Abrasion Resistance of Co-Fire Pellet Superior to Coal

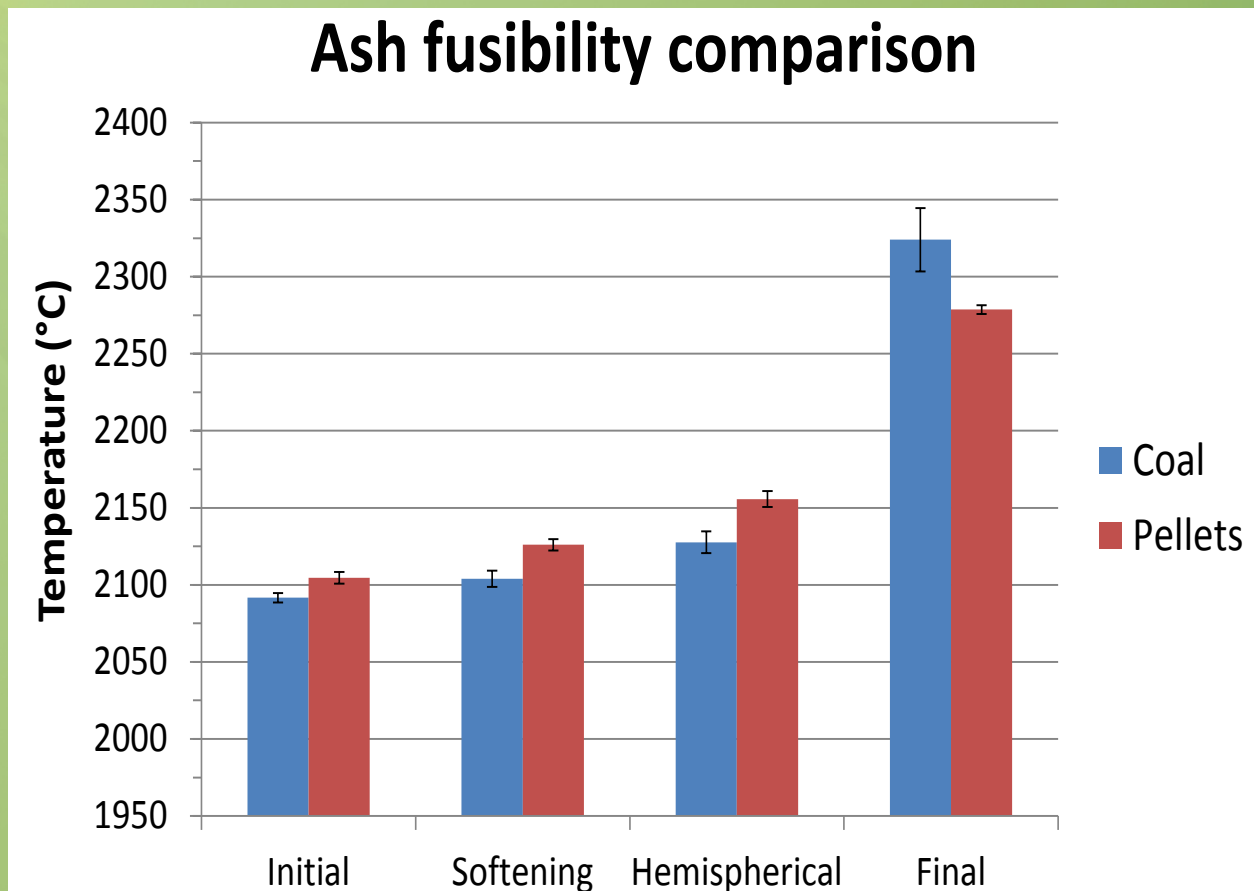
## Impact resistance comparison



## Abrasion resistance comparison

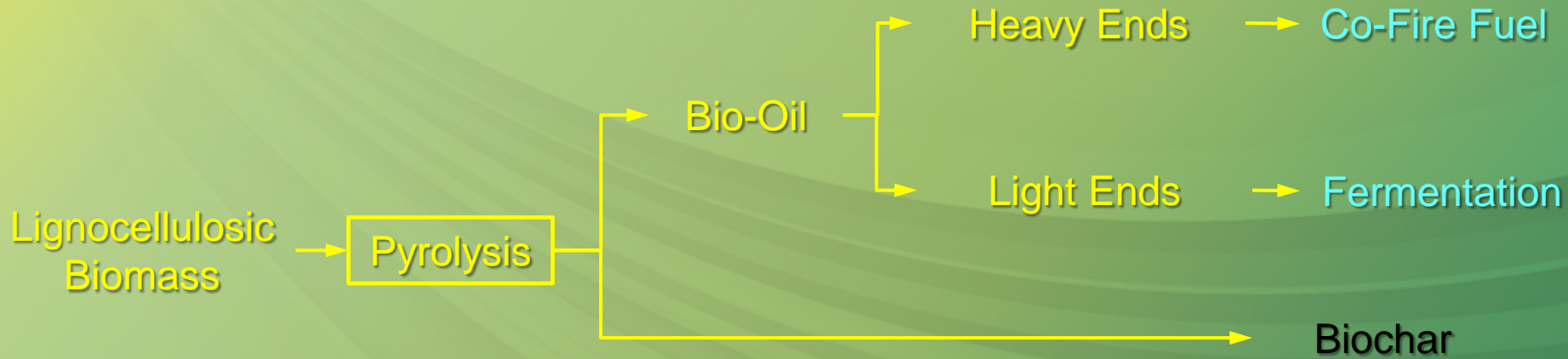


# Ash Fusibility of Co-Fire Fuel Comparable to Coal





# Carbon Negative Energy Pathway Being Pursued



# Comparing CO2 Emissions

Fuel Type	kg CO2eq/kg oil
Residual Oil	0.543
Fuel Oil	0.622
Bio-fuel oil (with biochar sequestered to agricultural lands)	-2.85

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

# 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





# Questions?