IOWA STATE UNIVERSITY
Bioeconomy Institute






Autothermal Pyrolysis: Modular Processing at the Demonstration Scale

Lysle Whitmer, Ryan G. Smith, Robert C. Brown
Iowa State University
Joseph Polin
Frontline BioEnergy LLC

TCBiomass 2022
Denver, CO
April 19-21, 2022

Autothermal pyrolysis technology is emerging from the laboratory to demonstration-scale

Iowa State University is the technology provider

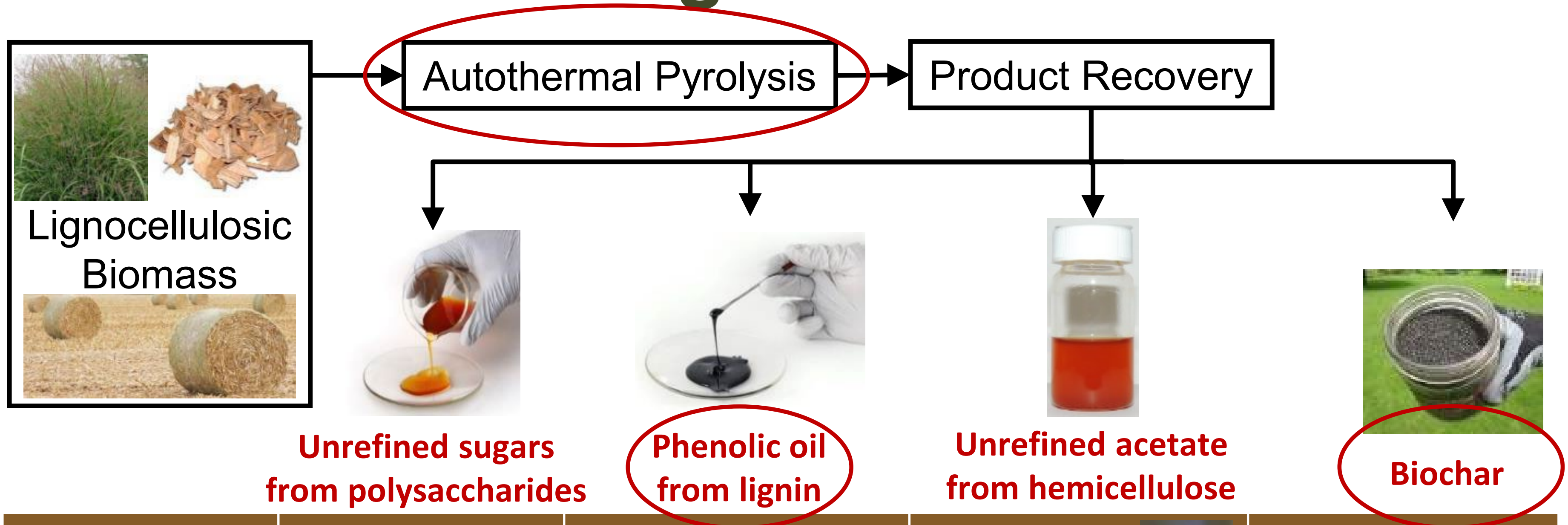
- 50 Ton Per Day Project (Redfield, IA)
  - Privately financed by Stine Seed Farms
  - Engineering, Procurement, and Construction provided by Frontline Bioenergy
  - Conversion of corn stover into phenolic oil and biochar

STINE®

FRONTLINE BIOENERGY, LLC

IOWA STATE UNIVERSITY
Bioeconomy Institute

Py refinery: Producing fuels and chemicals from lignocellulosic biomass



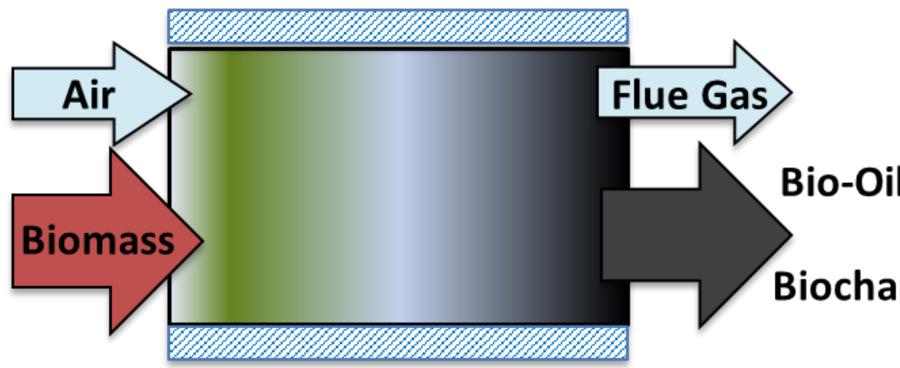
First Generation Products	Ethanol	Bio-asphalt	In-plant thermal energy	Soil amendment
Potential Future Products	-Pharmaceuticals -Polymers -Solvents	-Stationary diesel engine fuel -Drop-in fuels -Biobased chemicals	-Acetone -Acetic acid -Bio-cement -Alcohols	-Activated carbon

Enabling Technology: Autothermal Pyrolysis

Part of the biomass and/or pyrolysis products are oxidized to provide energy for endothermic pyrolysis reactions

- Advantages
  - Heat transfer no longer bottleneck
- Challenge
  - Preserve organic yields of bio-oil under partial oxidative conditions

Autothermal Pyrolyzer (adiabatic)



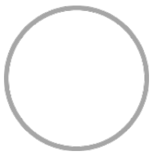
$$\phi = \frac{Air}{Air_{Stoich}}$$

Autothermal Pyrolysis $0.06 \leq \phi \leq 0.15$

Gasification $0.15 \leq \phi \leq 0.35$

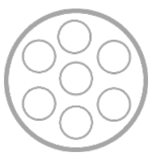
Process Intensification: Breaking the heat transfer bottleneck in pyrolysis

Heat transfer from reactor perimeter



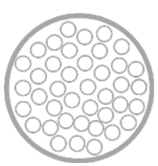
$\dot{Q} \sim 2\pi DL \sim D^2$

Heat transfer from tube (t) array



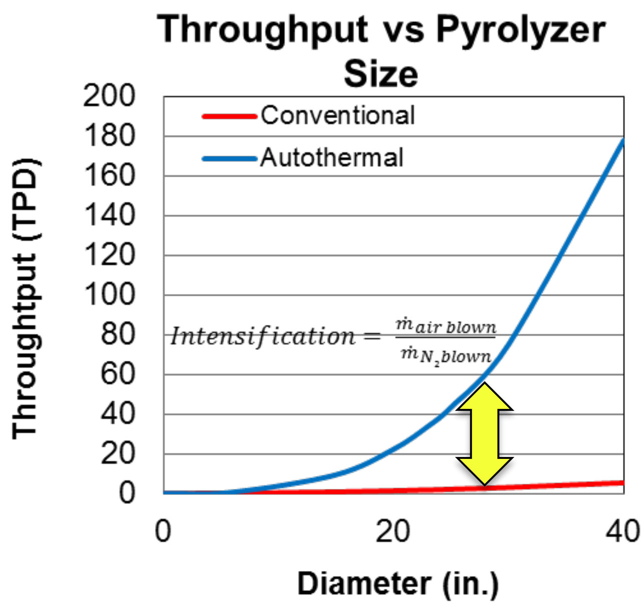
$\dot{Q} \sim (SA/t)(t/XS)\,\pi D^2 \sim D^2$

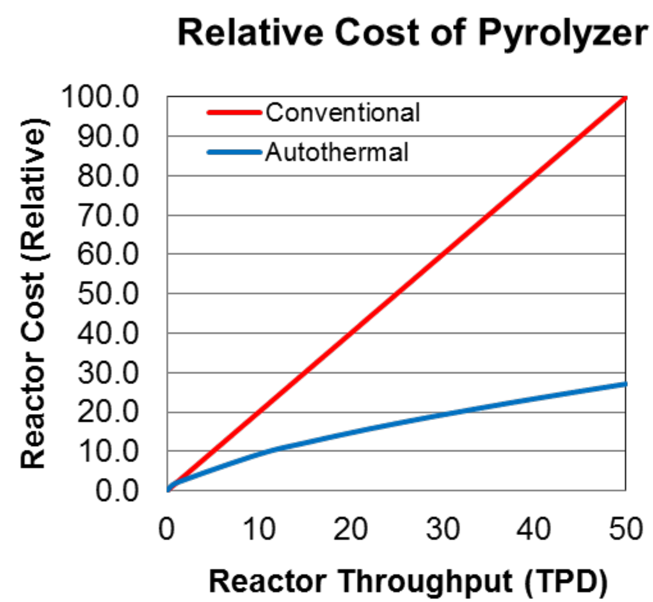
Heat transfer from granular heat carrier



$\dot{Q} \sim j_p(C_p \Delta T)\,\pi D^2 \sim D^2$

- Energy demand for an endothermic reaction is provided by energy release from an exothermic reaction
- *Heat transfer* scales as square of reactor diameter while *energy demand* for pyrolysis scales as cube of reactor diameter
- Providing enthalpy of pyrolysis through partial oxidation of products (autothermal pyrolysis) reduces size and cost of pyrolyzer compared to a heat transfer-limited reactor

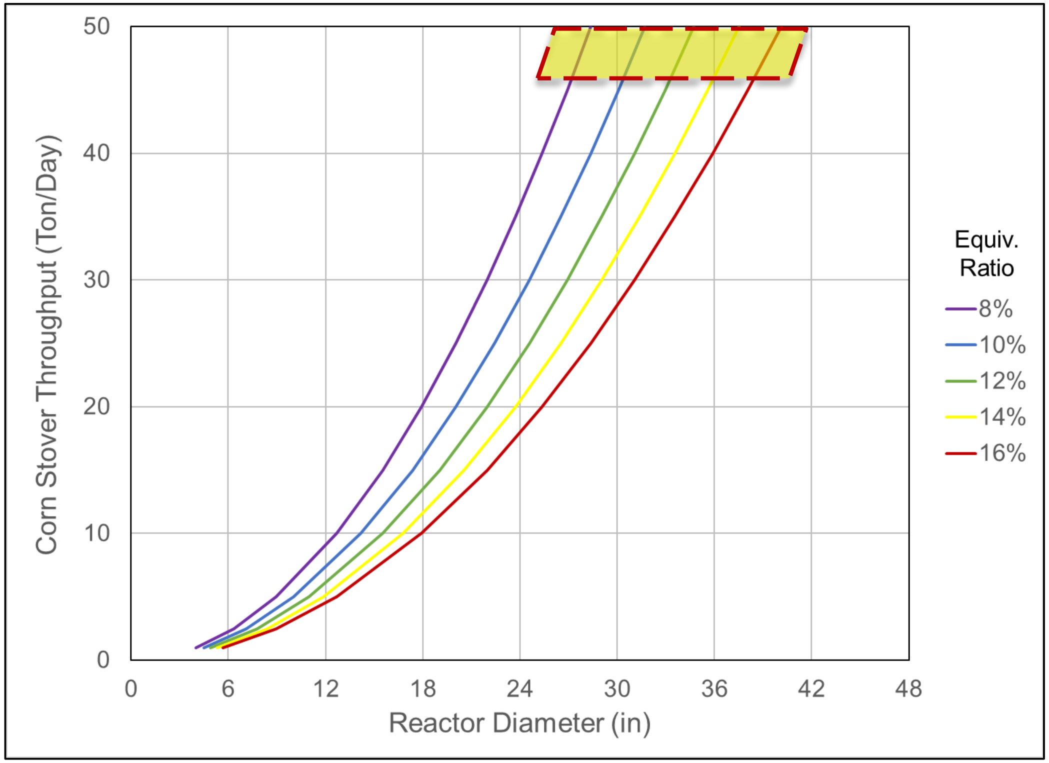




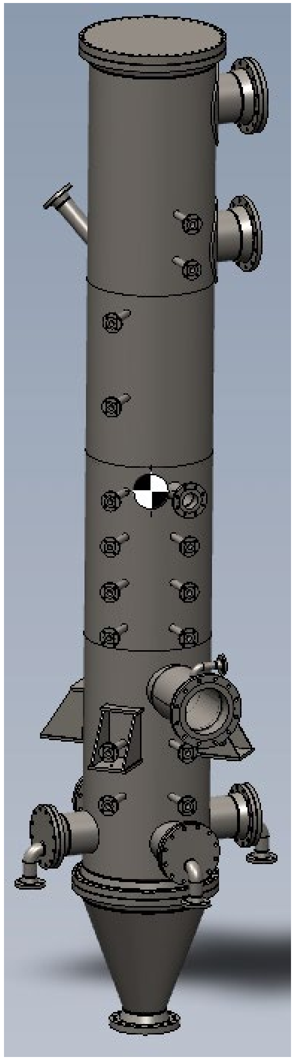
Scaling up Autothermal Pyrolysis to a Demonstration Unit

Pilot

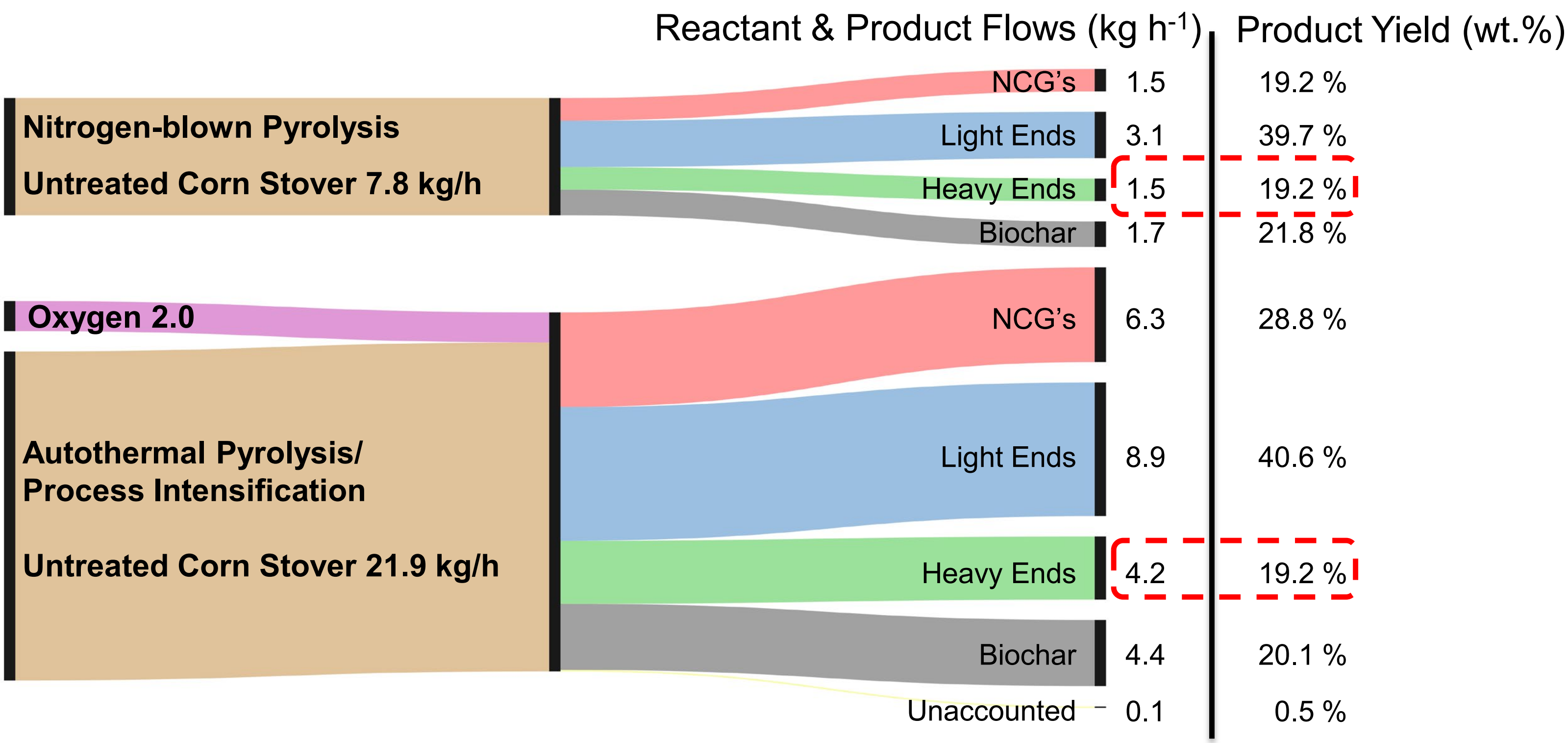
Estimating reactor size while maintaining flexible operating conditions



Demo

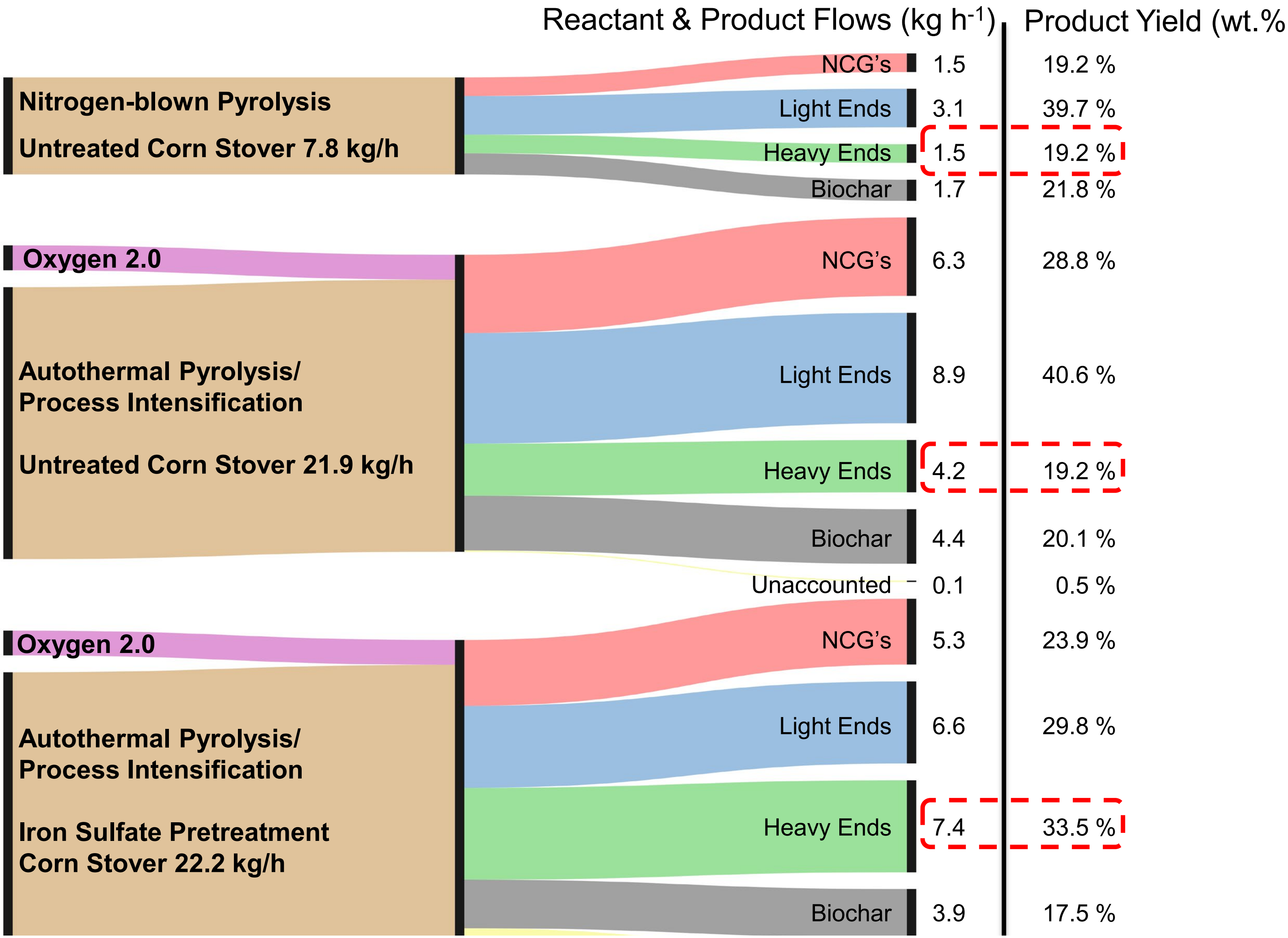


Process Intensification in Corn Stover Pyrolysis



Polin, et al. (2019) Conventional and autothermal pyrolysis of corn stover: Overcoming the processing challenges of high-ash agricultural residues, Journal of Applied and Analytical Pyrolysis 143, 104679.

Sugar Production from Corn Stover Pyrolysis

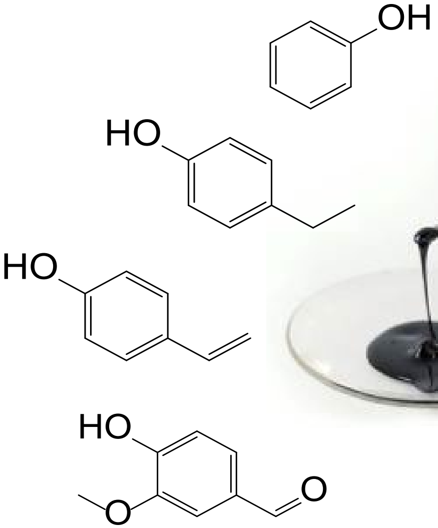


Polin, et al. (2019) Conventional and autothermal pyrolysis of corn stover: Overcoming the processing challenges of high-ash agricultural residues, Journal of Applied and Analytical Pyrolysis 143, 104679.

Phenolic oil

- Product of the fast pyrolysis of woody or herbaceous biomass
- Derived from the lignin in biomass
- Heating value is much higher than whole bio-oil
- Contains both phenolic monomers and oligomers
- Challenge: High viscosity and instability in storage and under heating

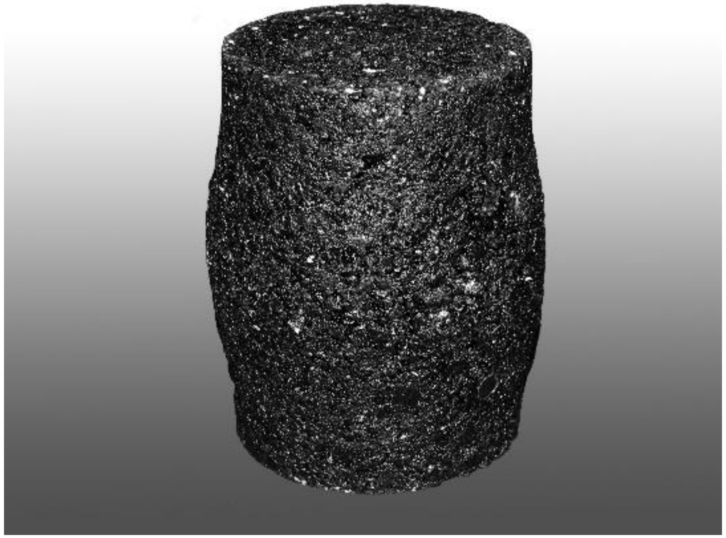
Lignin in its natural habitat



Examples of phenolic monomers found in phenolic oil

Exploiting the challenges of phenolic oil: Turn it into bio-asphalt

Test sample of bio-asphalt from red oak



Paving Des Moines bicycle path (2010)

Still in use today (2020)

Successful formulations of bio-asphalt binder blends using phenolic oil

- Phenolic oil (PO) heated at 110°C to drive off moisture
- Blend of 90% PO and 10% ground recycled tire rubber heated at 120°C for 1 hr
- PO and tire rubber blend mixed with PG 58-28 asphalt binder

Performance Grade ↑ ↑ ↑ Minimum pavement design temperature (°C)*

Average 7-day maximum design temperature (°C)

PG58-28 Asphalt Binder	Phenolic Oil	Ground Tire Rubber	PG High (°C)	PG Low (°C)	AASHTO Rated Performance Grade
100% (control)	0%	0%	60.4	-30.4	P 58-28
90%	9%	1%	60.5	-28.5	P 58-28
80%	18%	2%	61.9	-27.9	P 58-22
70%	27%	3%	72.5	-27.7	P 70-22

* Minimum temperature is negative degrees Centigrade

Biochar as a Soil Amendment

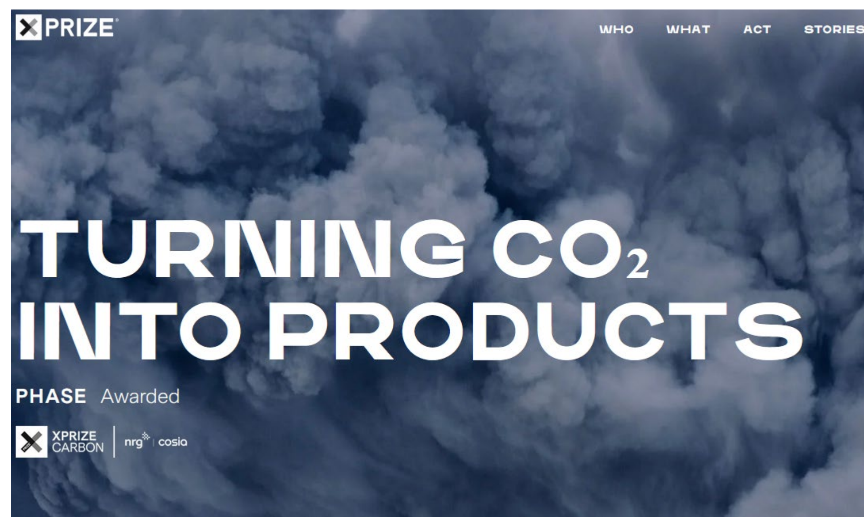
- Biochar has several benefits for soil
  - Enables moisture management in various soil types
  - Returns much of the inorganic content of biomass to the soil
  - Enhances beneficial microbial activity
  - Can be used to adjust soil pH
  - Carbon sequestration agent
  - Work in progress to formulate as slow- release P and N fertilizer
- Tests confirm that biochar from auto-thermal pyrolysis has no negative effects on seed germination
- Preliminary plot studies have shown benefits
- Market value is challenging to determine

Biochar from fast pyrolysis is dusty

Granulated biochar improves storage and field application

Biochar for Carbon Removal

- Stine Pyrolyzer expected to sequester 4000 tons CO_2 equivalent per year from pyrolysis of 50 tons of corn stover into biochar as carbon sequestration agent
- Carbon XPRIZE grand prize, sponsored by Elon Musk, requires 1000 tons of CO_2 removed and durably stored within one year
- "Phase 1 Milestone Prize" application submitted



Techno-Economic Analysis

- Previous pyrolysis AspenPlus and AspenHYSYS models modified to reflect changes in equipment, yields and assumptions due to autothermal operation, biomass pretreatments, and modular manufacturing
- GREET, SimaPro and EcoInvent used for GHG emission analysis
- Plant capacity is 250 tpd corn stover
- Nominal Minimum Sugar Selling Price (MSSP) is estimated to be $218
- Carbon removal rate estimated to be 0.32kg of C/kg of C in the biomass
- Due to lower pretreatment requirements and higher product yields, modular autothermal pyrolysis biorefinery using wood biomass will have higher profitability than corn stover used in this analysis

Assumptions on Product Value and Yield

Product	Value ($/tonne)	Yield (kg/kg corn stover)*
Sugars	327	0.118
Phenolic Oil	500	0.181
Biochar	80	0.14

*Moisture free basis

Operating Cost Assumptions (Nominal)

Material/ Energy	Price
Corn Stover	$41/tonne*
Natural Gas	$5.68/MMBtu
Ferrous Sulfate	$550/tonne
Process Water	$0.20/tonne
Electricity	$0.067/kWhr

*Sesmero et al. (2015) *J. Ag and Resource Econ*. 40(3):425-441

Demonstration Plant: 3D Solid Model

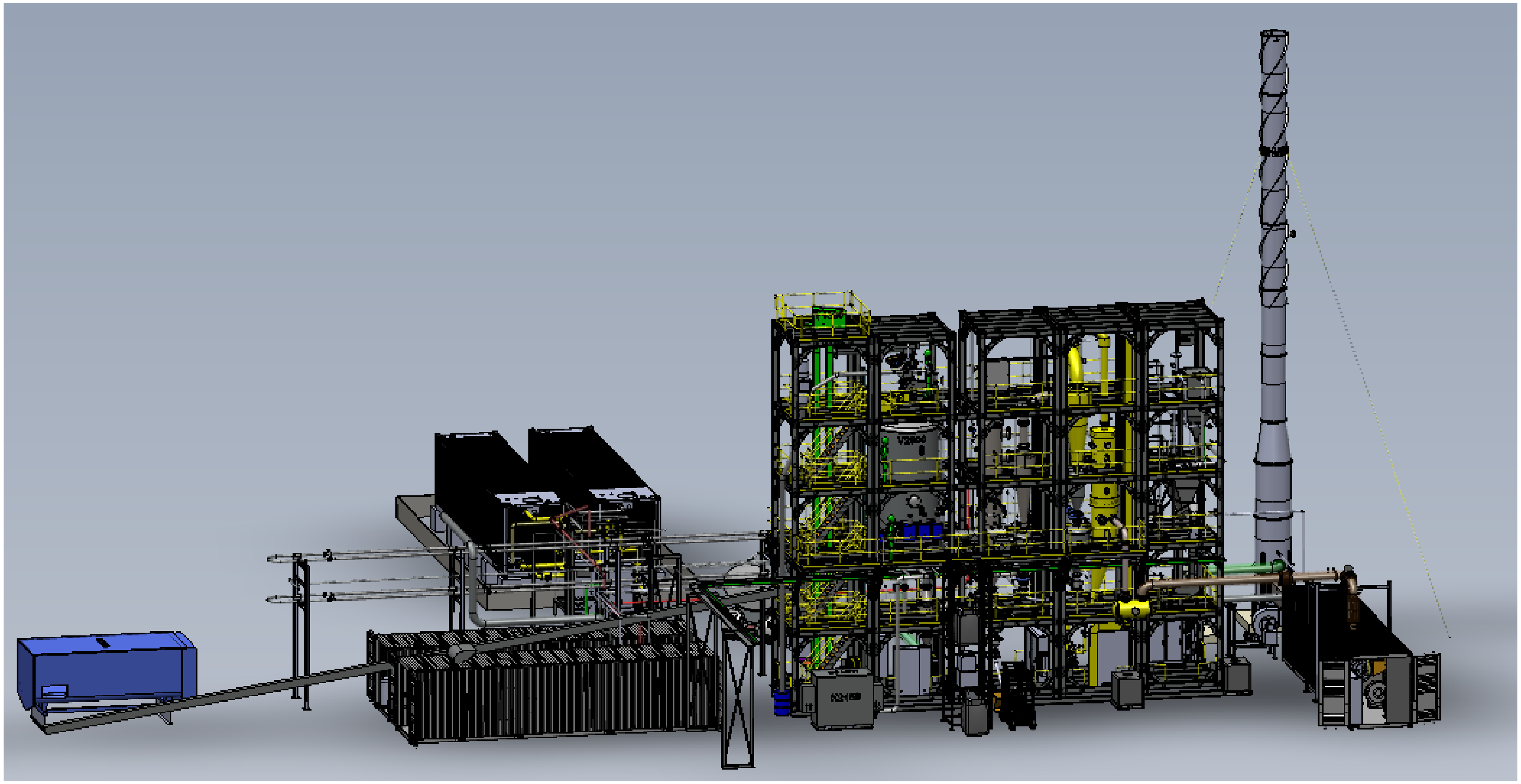


Image courtesy of Frontline Bioenergy

Modular Construction

Photos courtesy of Frontline Bioenergy

Modular Transportation

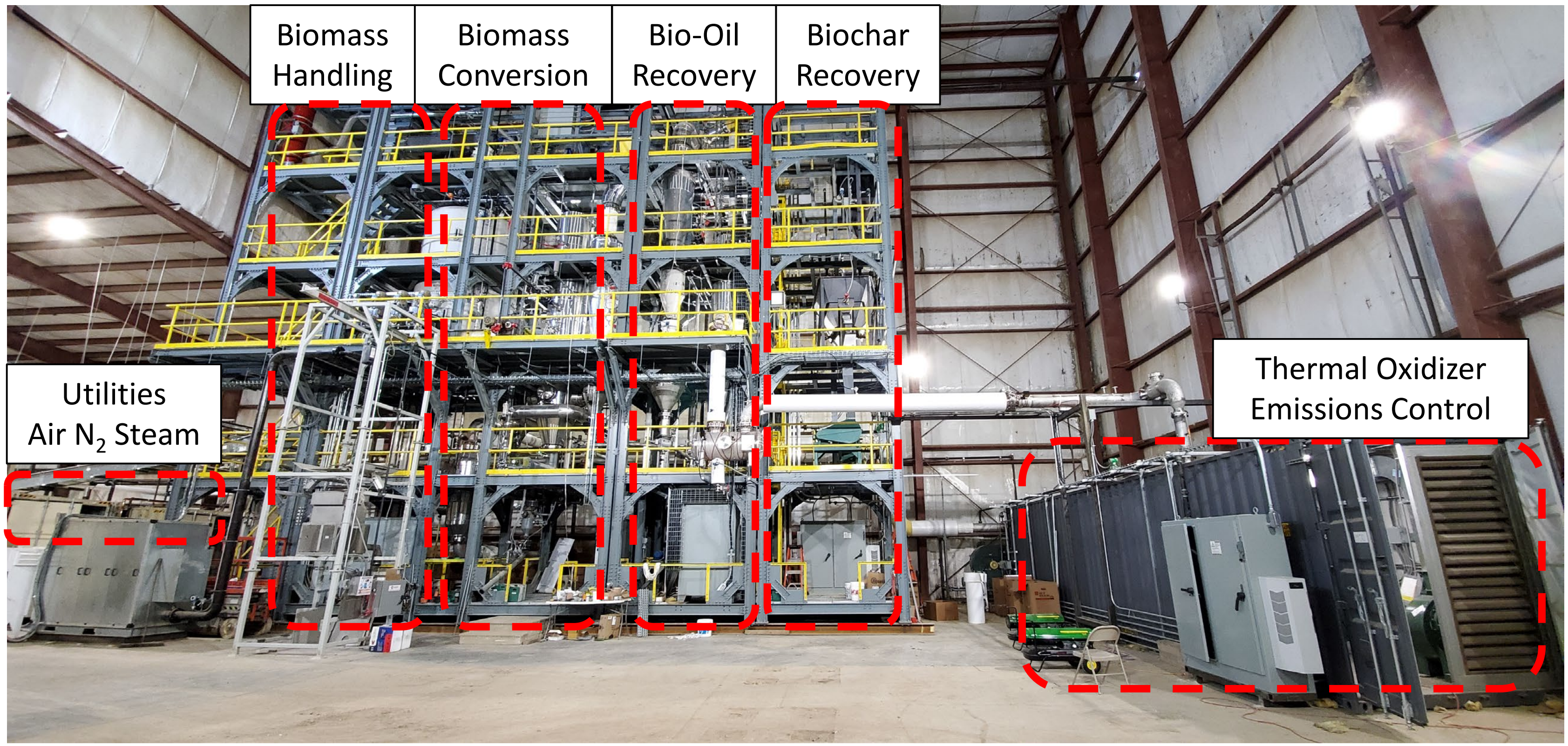
Photos courtesy of Frontline Bioenergy

Modular Transportation

Photos courtesy of Frontline Bioenergy

Onsite Construction

Overall System View



Photos courtesy of Frontline Bioenergy

Onsite Construction

Outdoor Equipment

Photos courtesy of Frontline Bioenergy

For more information :

BEI Webpage: http://www.biorenew.iastate.edu/

Lysle Whitmer – Sr. Research Engineer, BEI

Phone: 515-296-6309

E-mail: lwhitmer@iastate.edu

Joseph Polin – Frontline BioEnergy, LLC

Phone: 515-292-1200 x109

E-mail: jpolin@frontlinebioenergy.com