• Problem statement
• Process overview
• Experimental retention time measurement
• Biochar activation process overview
• Results & Analysis
• Conclusions
• Inconsistency in source material for biochar

• Inconsistency in production settings in order to achieve desired product quality
  – Carbon content
  – Iodine number
  – Percent yield
  – Heating value
  – Bulk density
FEECO INDIRECT PILOT KILN:

- 6.5" Dia. x 84" Long (0.17 x 2.1m)
- Capable of operating at 400 – 1,800°F (204 – 982°C)
- Two electrically heated zones
- Thermocouples in each zone
- Adjustable speed and slope for altering bed profile and residence time
PROCESS OVERVIEW

- **EXHAUST GAS**
- **DRUM SHELL = 11’**
- **ZONE 2**
- **ZONE 1**
- **HEATED SECTION = 7’**
- **SCREW LENGTH = 30”**
- **NITROGEN**
- **WOOD CHIPS**
- **BIOCHAR**
• Used equations to predict retention time
  – Perry’s Chemical Engineers’ Handbook ¹
  – Passage of Solid Particles Through Rotary Cylindrical Kilns (United States of America, Department of Commerce) ²
  – Flow of granular material through an inclined, rotating cylinder fitted with a dam ³

• Equations were verified experimentally using a tracer

• Variables effecting retention time
  – Particle shape
  – Bulk density
  – Dynamic angle of repose
  – Slope of drum
  – Drum rotational speed

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40 minute retention time measurement

- Blue dye used as a tracer to measure retention time and bed distribution
- Wood chips were dyed and dried to the same moisture as un-dyed wood chips
- 0.25 lbs. of blue material was fed into the process when the process was at steady state and the heat was turned off
- Samples were taken at the discharge
- The “peak” or midpoint of the blue material being discharged was determined
**Retention Time** = 47.5 − (1.425 + 1.35 + 5) ≈ 40 minutes
BIOCHAR ACTIVATION PROCESS OVERVIEW

**FEECO INDIRECT BATCH KILN:**

- 10.5" Dia. x 24" Long (0.27 x 0.61m)
- Capable of operating at 400 – 1,800° F (204 – 982° C)
- Adjustable propane flame and drum rotation speed
- Thermocouples measuring shell and product bed temperature
- Saturated and superheated steam injection possible
1. Biochar made in the FEECO indirect pilot kiln was then placed in the batch indirect kiln
2. Heated up to 1650 °F with nitrogen
3. Saturated steam injected at ~5 lb/hr for 1 hour at >1500 °F
4. Cooled with nitrogen to <160 °F
5. Resulted in Iodine numbers of 1300+
The Iodine number is defined as the milligrams of iodine adsorbed by 1.0 g of carbon.

- Estimation of surface area and pore volume
- Effected by retention time and temperature

**RESULTS & ANALYSIS**

**IODINE # VS. TEMPERATURE FOR SOUTHERN PINE BIOMASS**

- Southern Pine
  - 40 min. Retention Time
- Southern Pine
  - 20 min. Retention Time
• Percent yield is assuming feed material is at zero percent moisture
• Indication of the rate of production
• Effected by retention time and temperature

RESULTS & ANALYSIS

YIELD VS. TEMPERATURE FOR SOUTHERN PINE BIOMASS

- Southern Pine
  40 min. Retention Time
- Southern Pine
  20 min. Retention Time
DIFFERENT WOOD SPECIES
20 MIN. RETENTION TIME
AT 600° F

- Lower percent yield for hard woods except for bark and balsam fir
- No significant change in iodine number
- Greater percent carbon for hard woods except for bark and balsam fir

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<thead>
<tr>
<th>WOOD</th>
<th>WOOD TYPE</th>
<th>PERCENT YIELD</th>
<th>PERCENT CARBON</th>
<th>IODINE #</th>
<th>ACTIVATED IODINE #</th>
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*Partial activation with limited steam for <10 minutes
## RESULTS & ANALYSIS

### PROCESS DATA – SOUTHERN PINE BIOMASS

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<th>TEMP. (°F)</th>
<th>RETENTION TIME (min.)</th>
<th>PERCENT YIELD</th>
<th>IODINE #</th>
<th>PERCENT CARBON</th>
<th>BULK DENSITY (lbs./ft.³)</th>
<th>HEATING VALUE (Btu/lbs.)</th>
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### Increase in Temperature
- Decrease in percent yield
- Increase in iodine number
- Increase in percent carbon
- Decrease in bulk density
- Increase in heating value

### Increase in Retention Time
- Decrease in percent yield
- Increase in iodine number
- No significant change in percent carbon
- No significant change in bulk density
- No significant change in heating value
CONCLUSIONS

• Critical product specifications vary significantly with changes in retention time, temperature, and feedstock.

• Product specifications should be optimized to meet target market specifications and maximize production.

• Similar studies should be done in order size commercial size equipment and optimize process to the feedstock.