From Whole-tree Feedstocks to Biofuel Via Pyrolysis

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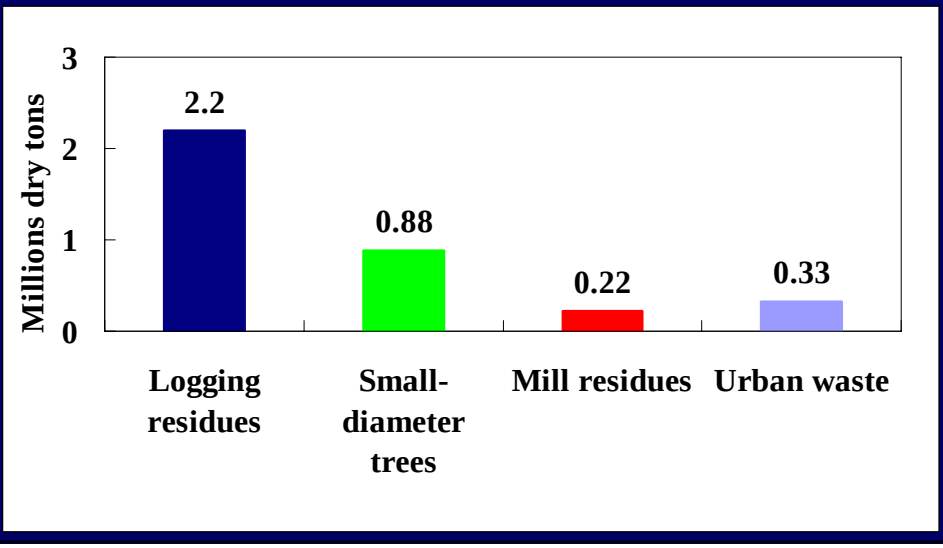
Estimated biomass feedstock availability in Mississippi, 2010:



Equipment to chip young trees on the ground have been tested for decades but new, cost-effective machines are required:

Harvest residue feed stocks can be readily collected:

There is little information available on characteristics of bio-oil produced from whole-tree or harvest residue feedstocks:

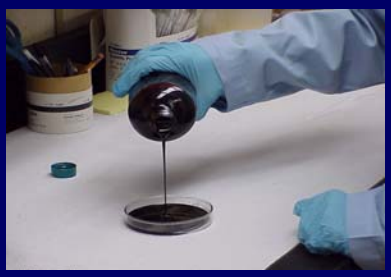
Bio-oil production:

- Bio-oil results from fast pyrolysis of cellulosic biomass
- Applied temperatures 400 to 650^{o}C
- Absence of oxygen
- Rapid cooling
- Particles are less than or equal to 2 mm

What are bio-oils?

- Bio-oils are water emulsive suspensions of thermally fractured biomass lignin, hemicellulose and cellulose. Each bio-oil contains over 100 chemical compounds.

- Not an oil as it is immiscible in petroleum oils



Our study: bio-oils were produced from several components of pine and cotton wood whole tree feed stocks:

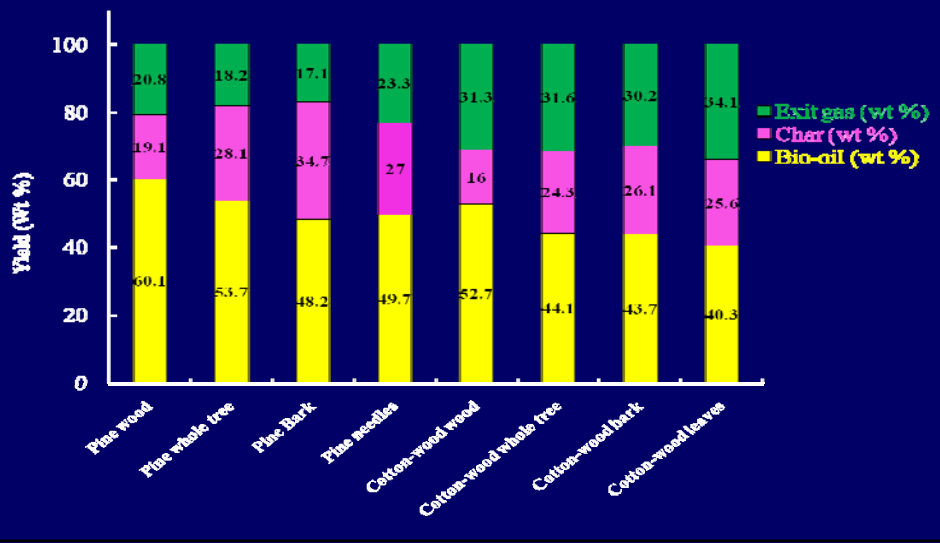
4-year old pine and cottonwood trees were harvested and components separated by type:

- Needles or leaves
- Bark
- Clear wood
- Whole tree

Feed stocks, bio-oils and pyrolysis exit gas were analyzed:

- Feed stocks
  - Ultimate and proximate analyses, components analysis
- Bio-oils
  - Physical properties
  - Chemical properties
- Exit gas
  - CO,CO_2,CH_4

Bio-oil, char and exit gas yields by biomass type:



Conclusions regarding bio-oil yields:

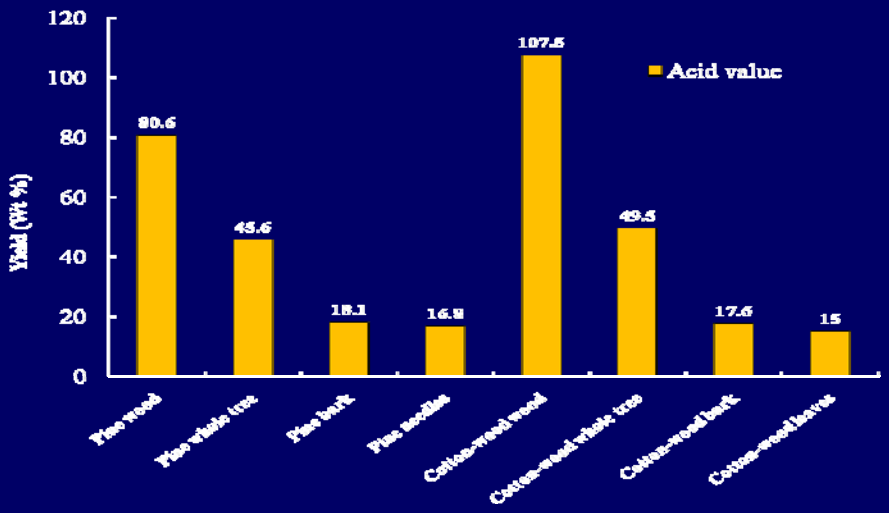
- Pine and cottonwood wood feed stocks had highest bio-oil yields (60.1 and 52.7%)
- Whole-tree bio-oil yields were lower (53.7 and 43.7%)
- Lower whole-tree bio-oil yields were caused by the low-yields of bark (48.2 and 43.7) and needles or leaves (49.7 and 43.7)

Conclusions regarding gas and char yields:

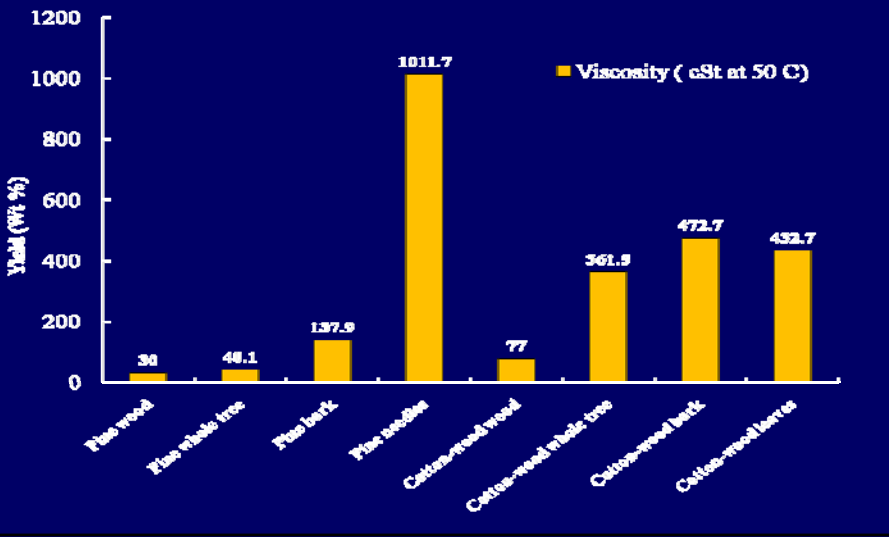
- The exit gas component for pine and cottonwood had relatively constant yields by species (range = 17.1-23.3) and (range = 30.2-34.1)
- The char component increased for pine and cottonwood bark and needles or leaves; this increased the mean pine whole tree char yield

Acid value: Number of ml of 0.1 mole NaOH required to achieve a pH of 8.5

Acid value by feed stock type:



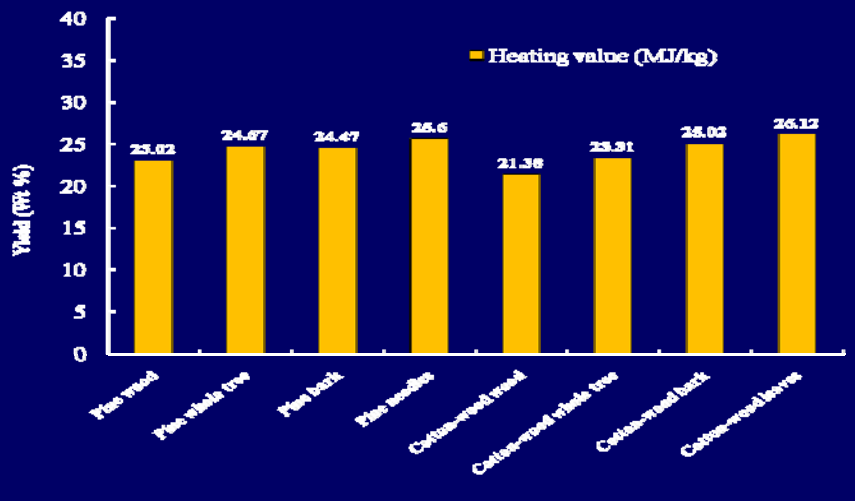
Bio-oil viscosity by feed stock type:



Conclusions regarding viscosity and molecular weight:

- Both pine needles and cotton wood leaves give bio-oils with very high viscosities
- These high viscosities increased the viscosity of the whole-tree bio-oils.
- Viscosity of pine bio-oil is acceptable; that of cottonwood is much too high

Higher heating value by feed stock type:



Harvest residue feed stocks can be readily pyrolyzed to bio-oil: slash bundler tested on Potlatch forest lands:

Slash yield was 20%; bio-oil quality good; biomass ash content surprisingly low at about 3 times that of clear wood

Bio-oil quality from pine whole tree and harvest slash feed stocks:

- **Viscosity slightly higher than clear wood**
- **Ash content somewhat higher due to entrained dirt**
- **Both whole-tree and slash feed stocks are acceptable feedstocks for bio-oil production**

• Upgrading bio-oil by hydrodeoxygenation (HDO):

Hydrogen

Oxygen

Water + HDO bio-oil

HDO bio-oil yield:

• 35% yield by weight (72% of energy) in a 60 min. batch autoclave run

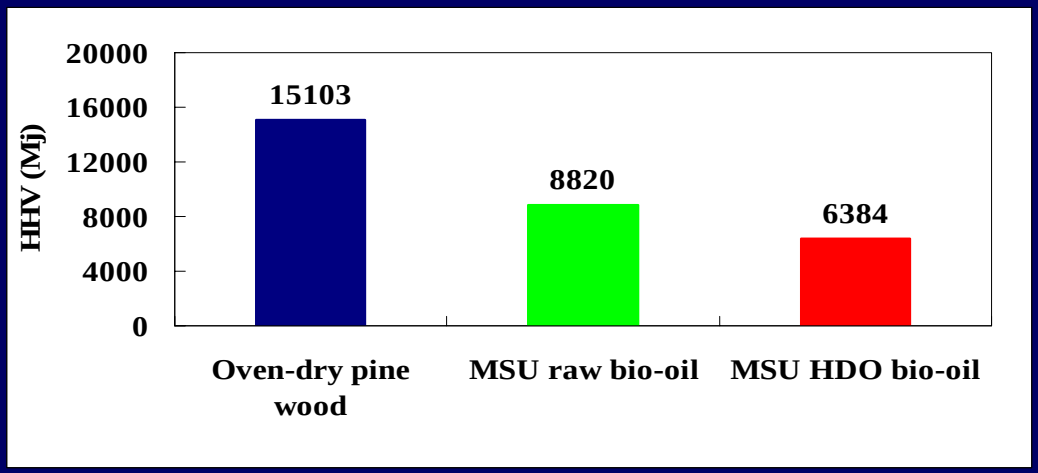
HDO bio-oil properties compared to those of raw bio-oil:

Parameters	Raw bio-oil	HDO bio-oil
Water (wt %)	20	5
Acid value	97	32
Viscosity at 40^0C (cSt)	12.0	10.4
pH	3.2	4.0
Ash (wt %)	0.04	0.04

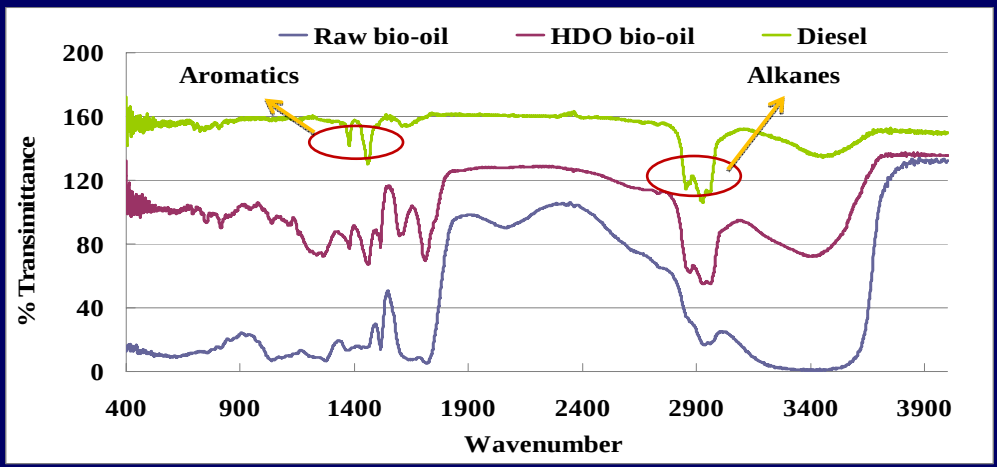
Conclusions on HDO bio-oil properties:

- Percentage water is radically reduced from 20 to 5%; we have deveped a method to reduce to zero
- Acid value is reduced from 97 to 32 (a 2/3s reduction; we have developed a method to reduce AV to a neutral value

Comparison of HHV values of pine wood, raw bio-oil and HDO bio-oil per dry ton of wood. 72% of raw bio-oil energy maintained in HDO bio-oil:



FTIR spectrum; diesel vs raw and HDO bio-oils:



Relative annual potential production volume of bio-oil in Mississippi based on the availability of 3.6 million dry tons:

- 470 million gallons raw bio-oil (120 gal/dt)
- 150 million gallons HDO bio-oil (42 gal/dt)
- The 150 million gallons of HDO bio-oil has an energy equivalent of 338 million gallons of raw bio-oil

HDO bio-oil can be: blended with hydrocarbons; refined in current petroleum refineries:

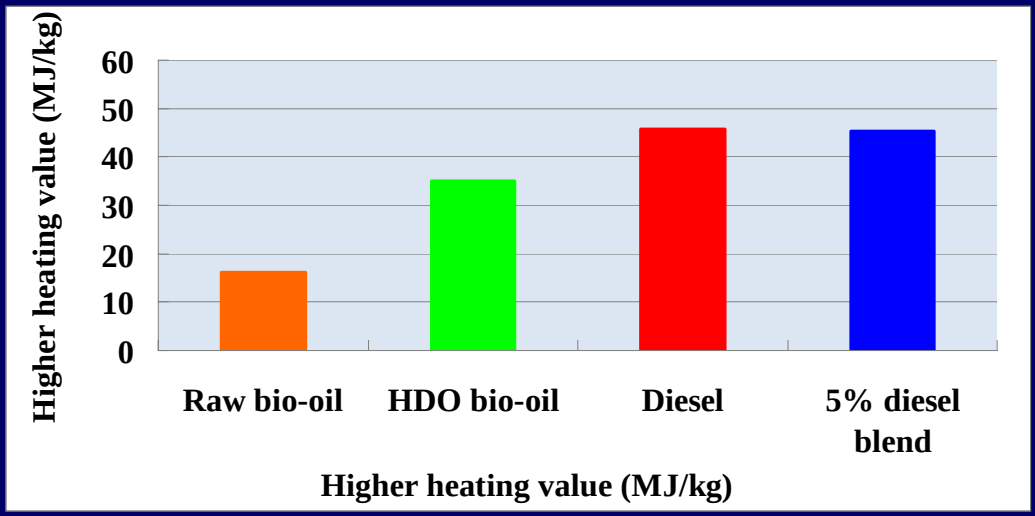
Refined in petroleum refineries

Blended with petroleum hydrocarbons

100% diesel

5% HDO

Relative HHV values by fuel type:



- We have successfully performed informal diesel engine testing with a 5% HDO/diesel blend and will initiate more controlled engine tests over the next year.

Summary:

- By far the most abundant woody biomass types in the SE will be logging residues and small diameter timber
- Both pine whole-tree and harvest residue feedstocks are suitable for bio-oil production; cottonwood feedstocks are not
- Pine slash harvest residue yield is 20% of stand merchantable volume

Summary:

- Raw bio-oils can be hydrotreated to an HDO bio-oil with good fuel qualities
- HDO bio-oil can be refined at petroleum refineries or potentially may be blended with petroleum fuels

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