Torrefaction to Improve Biomass for Energy and Biofuels Production and Carbon Sequestion

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COOPERATIVE EXTENSION
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- US Forest Service
- NREL
- NETL

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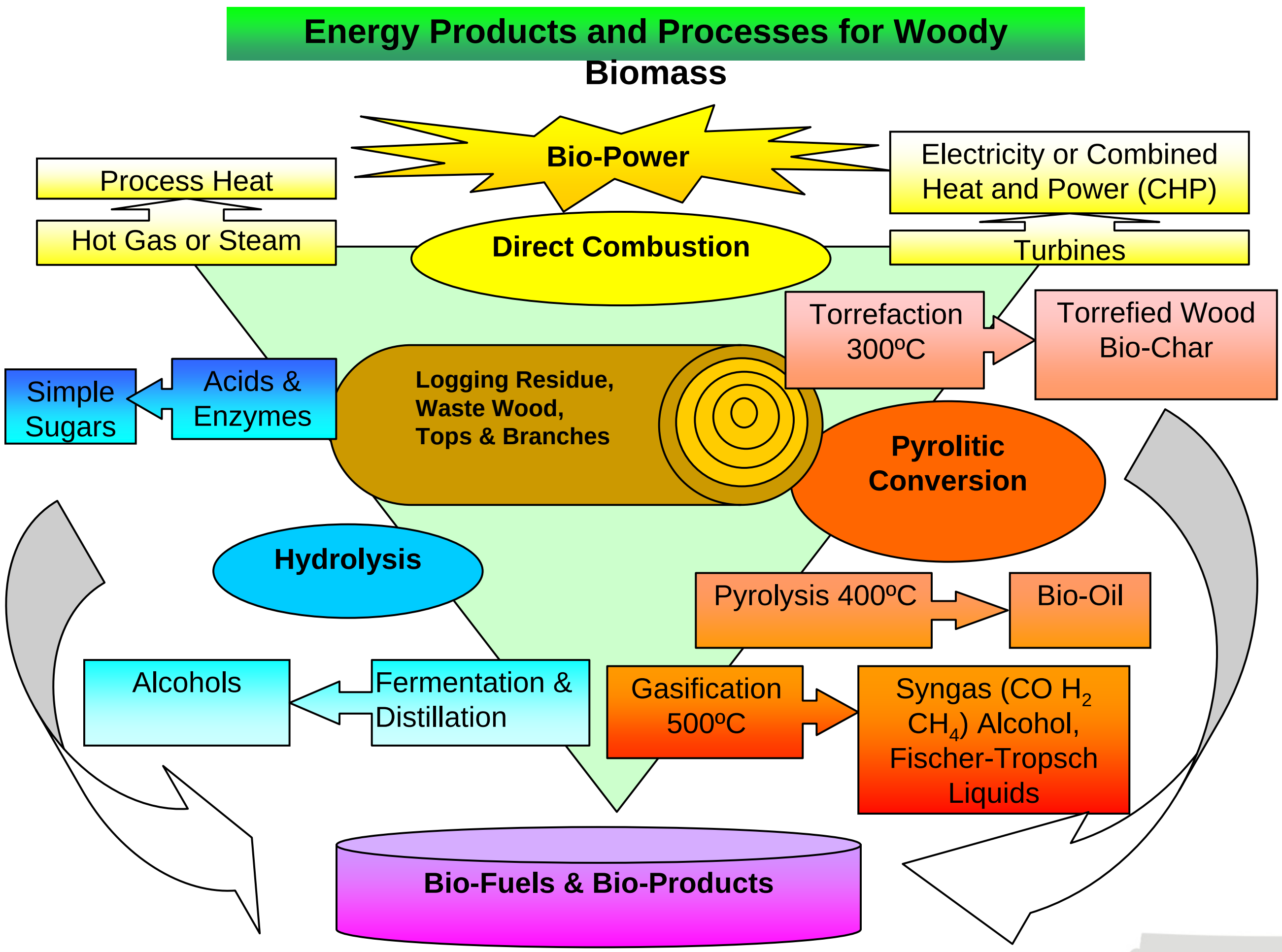
Woody biomass residue harvests may actually increase the overall sawtimber and pulpwood availability.

Woody Biomass as an Energy Product

- Woody biomass, as an energy source for combustion, has some advantages over fossil fuels:
  - Carbon neutral (if taken from continuing forestry operations)
  - Low in sulphur and mercury emissions
- and disadvantages:
  - Requires specialized boiler and handling systems
  - Is prone to glazing of boilers if soil is included in feedstock
  - Not energy dense (expensive to transport)
- Moisture content of fresh woodchips is about 50%
  - 20-50% of delivered cost is in transportation, so
  - 10-25% of delivered cost is in transportation of water

Energy Conversion Technologies



Technologies to Improve Woodchips for Energy

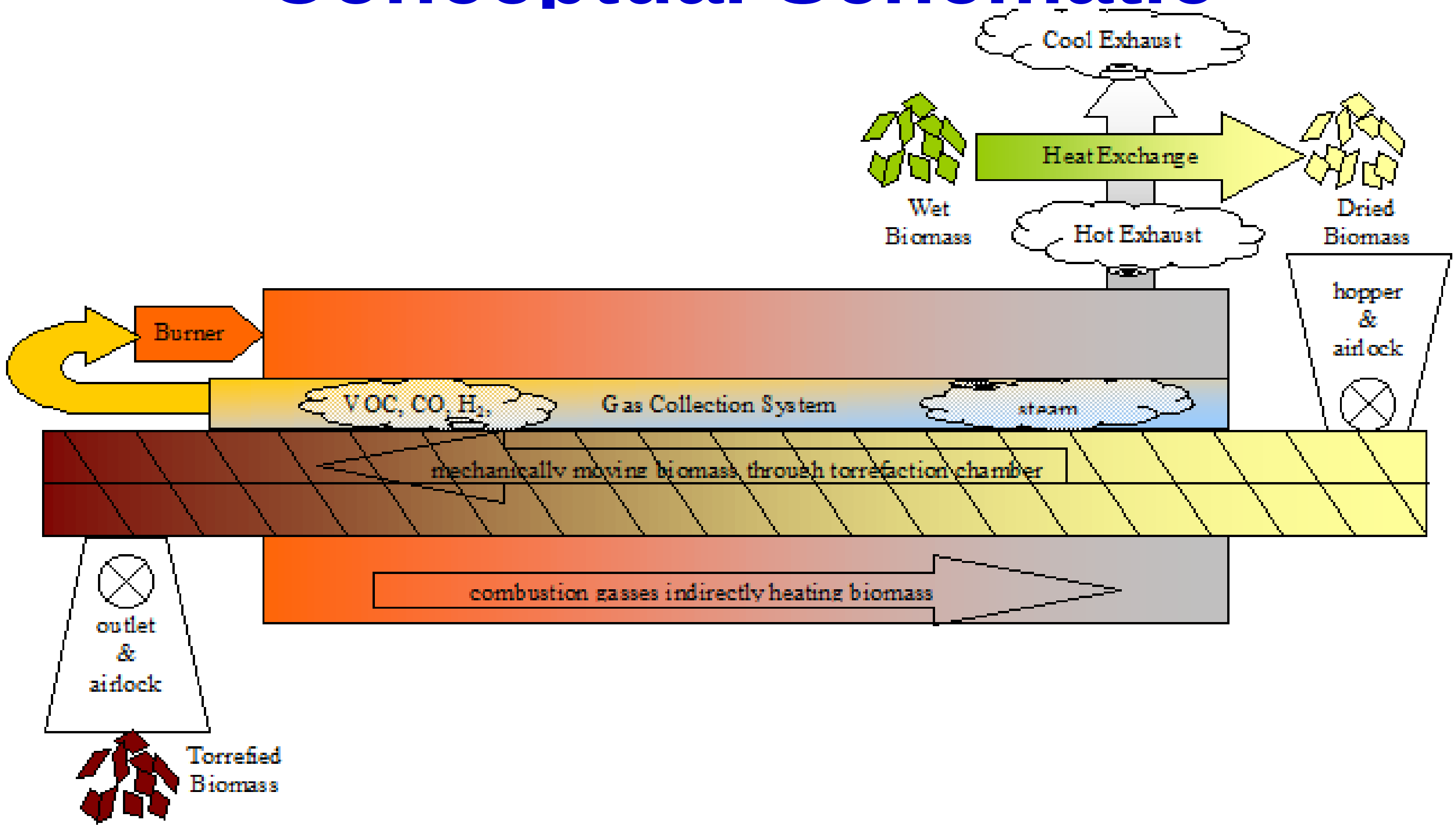
- **Drying** (100-300° F, for solid fuel)
- **Torrefaction**(400-600° F, for solid fuel)
- **Pyrolysis** (600-1000° F, for liquid fuels, solid by-product)
- **Gasification** (>1000° F, for liquid or gaseous fuel)

Torrefaction seemed to be the most feasible for in-woods operations but no manufacturer ready to go.

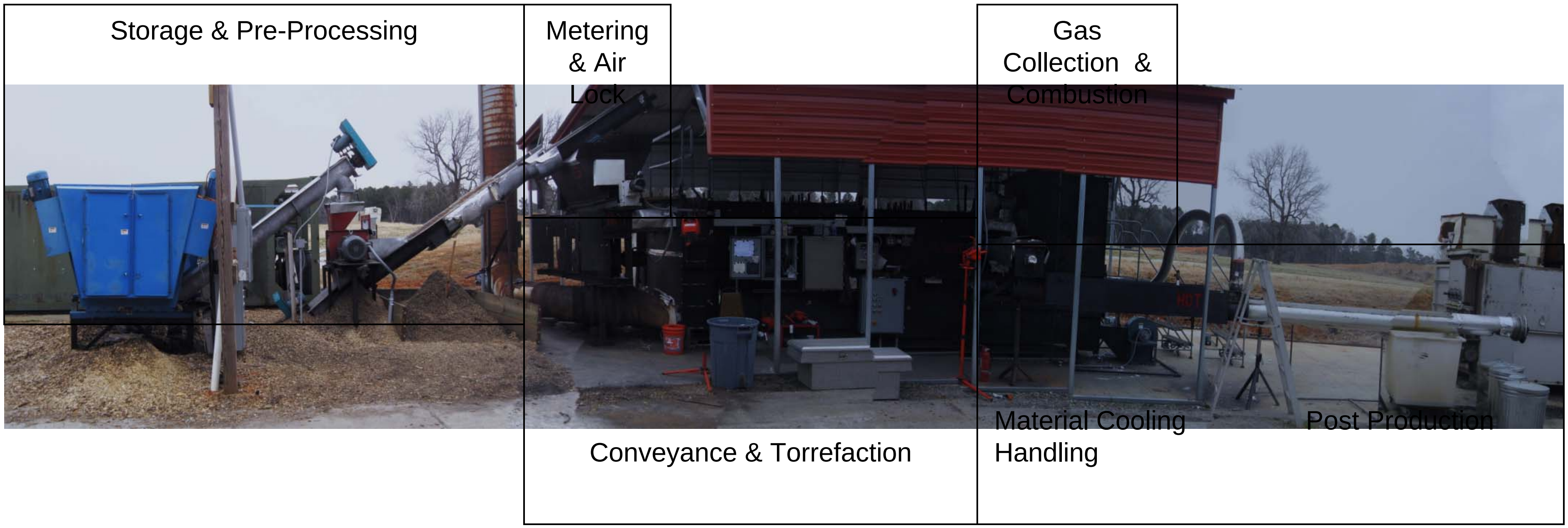
Torrefaction: Adding Value and Reducing Transportation Cost/BTU

- Woody Biomass is:
  - Bulky
  - Moist
  - Fibrous
  - Perishable
  - Waste
  - Expensive to transport
- Torrefied Wood (TW) is:
  - Dense (if pelletized)
  - Dry, water resistant
  - Easily crushed
  - Does not rot
  - Valuable Fuel
  - Energy Dense

Torrefaction Machine Conceptual Schematic



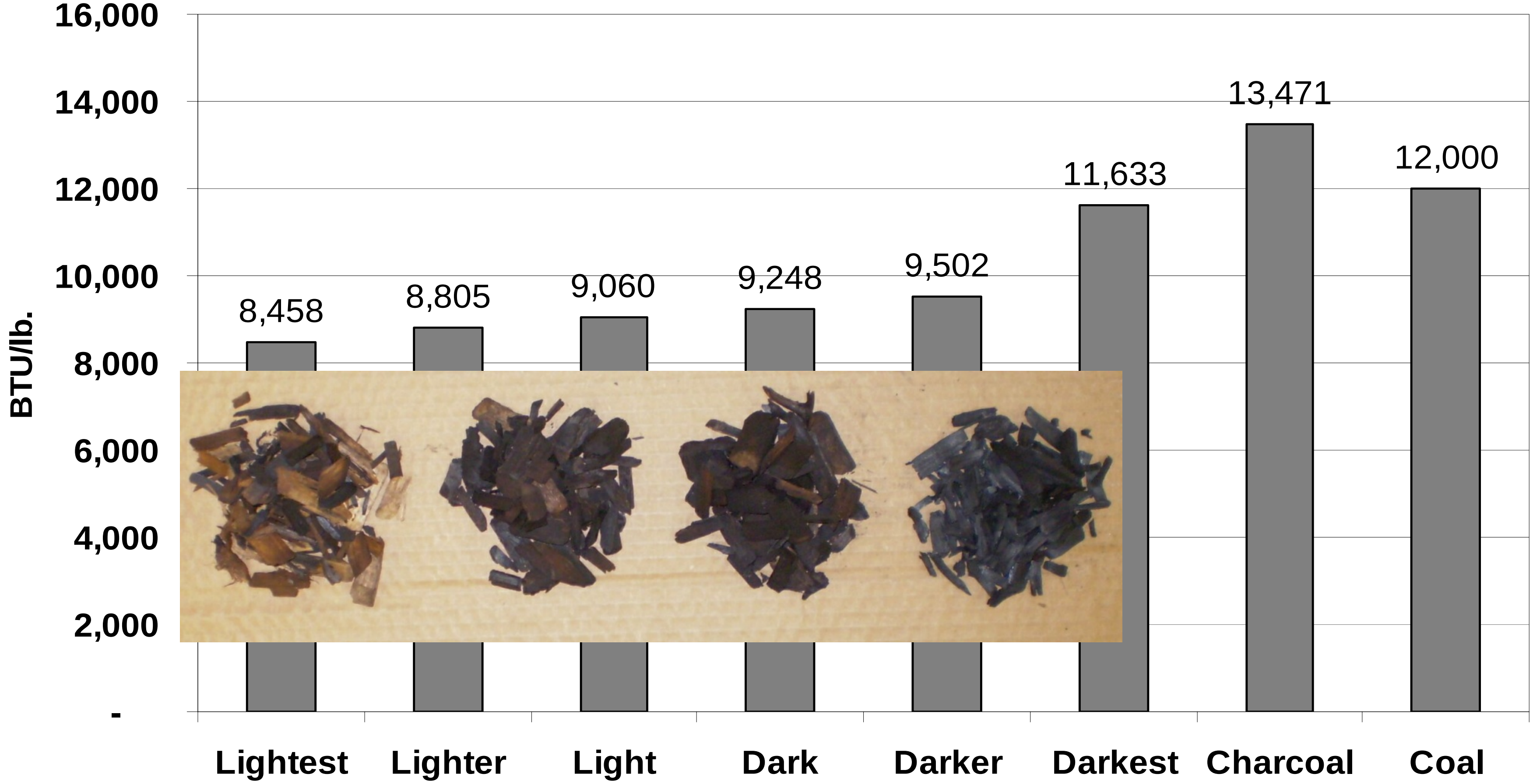
Panoramic Image of Torrefaction Machinery at NCSU



Torrefaction Process

- Torrefaction (300-400º C) liberates water, volatile organic compounds (VOC), and hemicellulose (HC) from the cellulose and lignin.
- The VOC and HC are combusted to generate process heat.
- TW can easily replace coal in combustion or be a feedstock for further pyrolysis or gasification for combined heat and power or Fischer-Tropsch liquids.
- The warm lignin may act as a binder when the torrefied wood (TW) is pelletized.

Higher Heating Value of Torrefied Wood, Charcoal and Coal: Color Approximately Indicates Heating Value

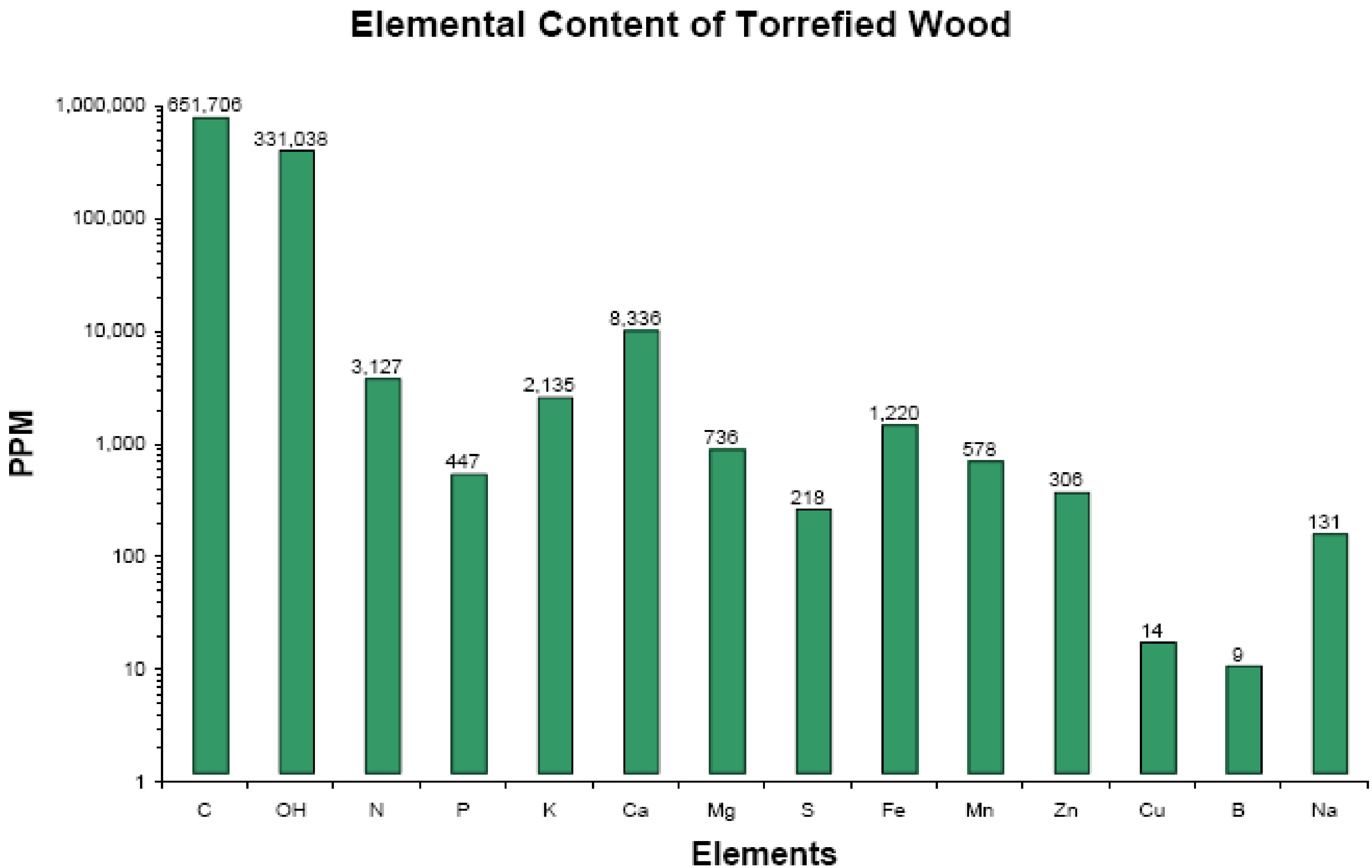


Chemistry of Torrefaction

- At torrefaction temperatures, hemicellulose is the primary wood polymer that is degraded into:
  - Permanent gases include H_2, CH_4, aromatics, CO, CO_2, C_xH_y
  - Condensable liquids include acids, ketones, furans, alcohols, terpenes, phenols, waxes, tanins, water
  - Solids include char, new and existing sugar structures and new polymers and ash.
- All of the wood polymers undergo dehydration reactions that destroy –OH groups that are responsible for hydrogen bonding with water: this may limit the ability of torrefied wood to retain water.

Mass and Energy Balance of Torrefaction

- Published results indicate mass and energy balance of .8 and .9 respectively (for dry wood).
  - This is consistent with the loss of the lower energy VOC and hemicellulose and retention of higher energy lignin and cellulose.
- Assuming
  - 50% MC wood,
  - HHV of 8700 Btu/lb for dry wood,
  - 1000 Btu/lb latent heat of water,
  - .4 Btu specific heat for wood and 1 Btu specific heat for water,
  - Starting temperature of 75 F and exit temperatures of 500° F.
- ~800 Btu used in processing, this energy is approximately equal to that of the hemicellulose.
- ~3575 Btu left in remaining torrefied product, which weighs ~.33 lbs, for a HHV of 10,800 Btu/lb.


Elemental Content of Torrefied Wood
PPM
1,000,000
100,000
10,000
1,000
100
10
1
651,706
331,038
3,127
447
2,135
8,336
736
218
1,220
578
306
14
9
131
C
OH
N
P
K
Ca
Mg
S
Fe
Mn
Zn
Cu
B
Na
Elements

Pulverizing Torrefied Wood

- Torrefied wood can be ground to a particle size similar to that of pulverized coal with the same or less energy use.
- Torrefied wood is a much better fuel for co-firing than untreated wood.
- Unteated wood requires many times the energy use in grinding (by a factor of 7.5 to 15) to achieve a similar particle size.

Pelletization of Torrefied Wood

- At torrefaction temperatures, the lignin in wood becomes plastic and can actually become a binder for individual wood particles.
- Pellets made from torrefied wood may withstand 1.5 to 2 times the crushing force of normal wood pellets.
- Torrefied pellets show little water uptake on immersion (7-20% of mass), unlike normal pellets.
- University research in the 1930s and 1940s details methods for pelletizing torrefied wood.

Density of Various Biomass Fuels

Fuel	BTU / lb	Density lbs / ft^3	Specific Gravity	BTU / ft^3	GJ / m^3
Green Wood Chips	4500	21.29	0.341	95,804	3.57
Wood Pellets	7300	40.00	0.641	292,000	10.88
Torrefied Wood	11000	12.57	0.202	138,314	5.15
Pulverized Torrefied Wood	11000	23.69	0.380	260,545	9.70
Pelletized Torrefied Wood (sample)	11000	28.41	0.455	312,456	11.64
Pelletized Torrefied Wood (Bergman)	8545	46.82	0.750	400,085	14.90
Baled Corn Stover (25% MC)	6076	9.38	0.150	56,961	2.12
Baled Switchgrass (15% MC)	6722	7.43	0.119	49,940	1.86
			Cargo		
Chip Van (25 tons, 120 yards)			0.247		
Bulk Shipping (Grain)			0.600		


Designed for 600 lbs/hour input, 200 lbs/hour output
Throughput with poultry litter about 25% higher
Originally Sized for Transport (21' length main box)
Energy Output/Input >30
(propane pilot light and electricity)

Bio-Char in Soil

- Bio-Char is a product of the pyrolisis (or torrefaction) of biomass.
- *Terra preta* or *agrichar* soils are found in former settlement and agricultural areas in the Amazon.
- The original Amazonians added char to these soils to improve soil fertility 500-7000 years ago.
- These soils still retain their carbon and fertility.

Bio-Char in Soil Increases Soil Fertility

- Increased CEC (cation exchange capacity, ability to buffer nutrients),
- Increased pH,
- Improved soil structure and tilth,
- Greater water retention (in sandy soils), and
- Support material and refuge for soil mycorrhizae.

Thoughts on Application of Research to North Carolina

– According to Johannes Lehmann, the leading researcher in bio-char:
  - Small amounts of char (<8 tonnes C/ha) improve overall fertility (20-80% increase in yield over control)
  - Piedmont soils are sufficiently similar to tropical Oxisols and Ultisols so that the tropical results can be used for regional estimates

Size of NC Carbon Problem

- **NC CO_2 emissions** in 2005 are about 120 MMT or **35.5 million tons carbon**
- 309 billion tons of total human caused carbon emissions through history.
- NC has about 0.14% of world population and 0.176% of world's arable land.
- **NC** "owns" about **434 million tons** of the **historical carbon** (population basis).

Size of NC Bio-Char Solution

Land Types	Acres	Bio-Char tons/acre to Offset NC Annual CO2 Emissions	Bio-Char tons/acre to Offset NC Share of Anthropogenic Emissions
Cropland	5,065,500	10.78	131.81
Total Agriculture	7,677,800	7.11	86.96
Timberland	17,684,000	3.09	37.76
Forests & Agriculture	25,361,800	2.15	26.33
All Land	31,174,000	1.75	21.42

Biochar Study at Lake Wheeler Field Laboratory

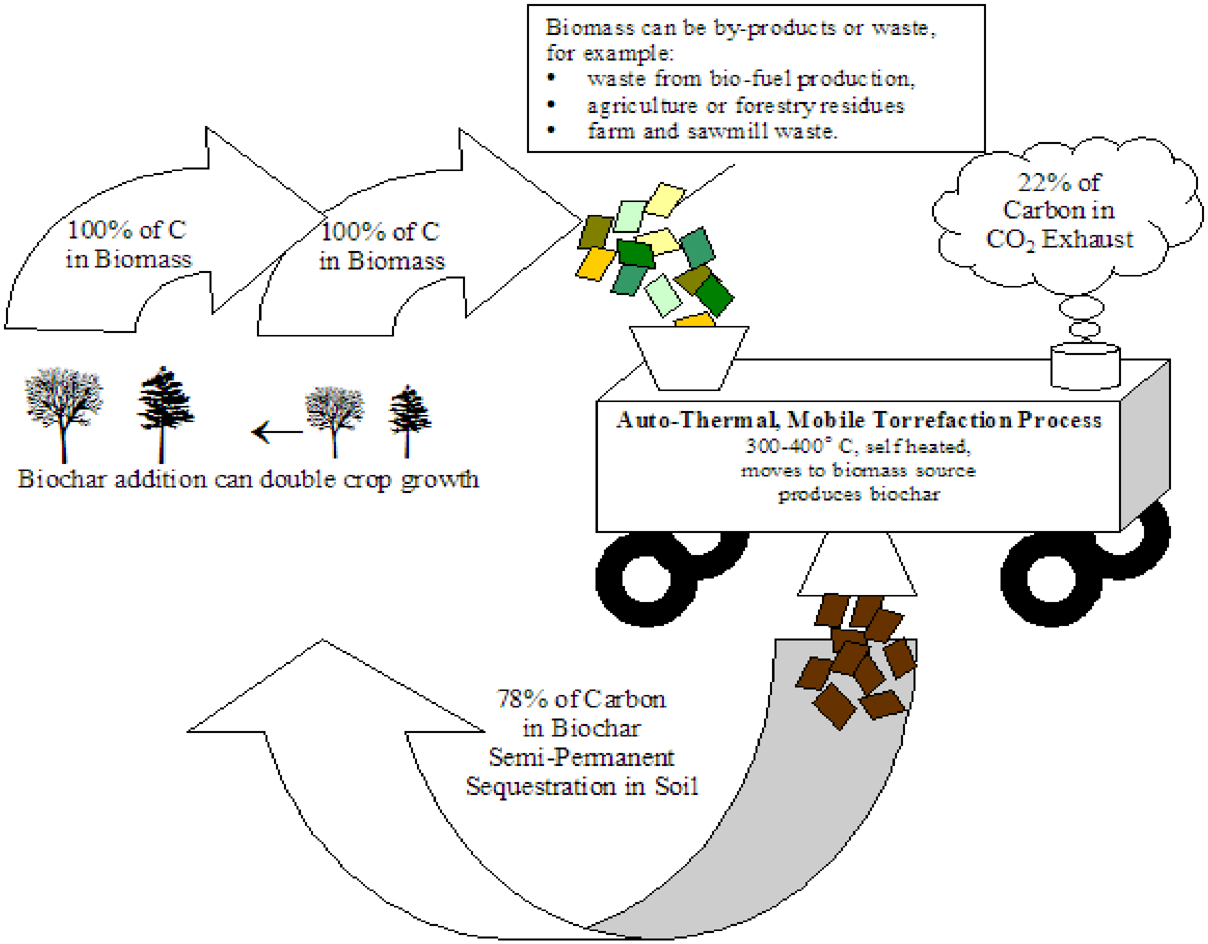
- 4 target levels of biochar application (50, 10, 2, 0 tons carbon/ha) and
- 3 levels of fertilizer (100%, 25% and 0% of recommended levels for corn)
- Total of 12 treatments.
- Plot size for each treatment will be 1 by 2 meters with a 1 meter buffer between and around all the plots.
- There will be 4 repetitions of the full set of treatments.
- Corn (Roundup Ready) will be planted over the entire study area at 40 cm between rows, 30 cm between plants.

	No Fertilizer	25% Standard Fertilizer Rate	100% Standard Fertilizer Rate
No Biochar			
2 tons C/ha			
10 tons C/ha			
50 tons C/ha			

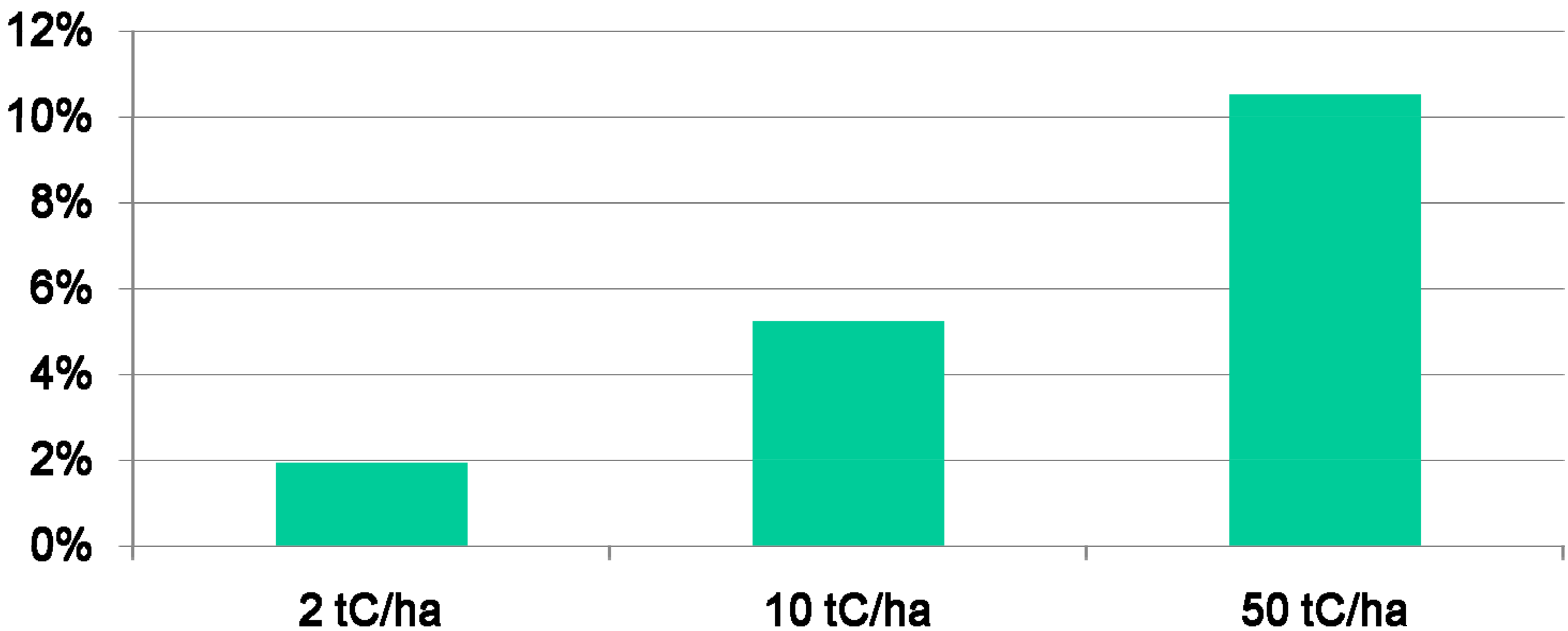
Biochar Results at Lake Wheeler

- 2008 growing season saw no significant differences among biomass production on plots
- 2009 saw significant effects of both fertilizer and char on growth

Biochar Production Cycle



Average Biomass Yield Increase Over Control from Biochar Addition, 2009 Growing Season, Lake Wheeler Field Lab



Do you have any questions?

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A short torrefaction clip:

http://www.youtube.com/watch?v=auGpOEgdBFg