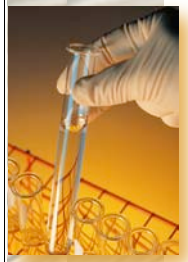


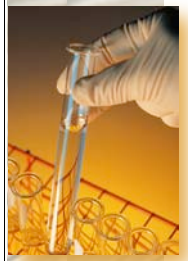

The Lignocellulosic Biorefinery: Vision and Implementation

American Institute of Chemical Engineers

Knoxville-Oak Ridge Section Meeting
Thursday, February 15, 2007

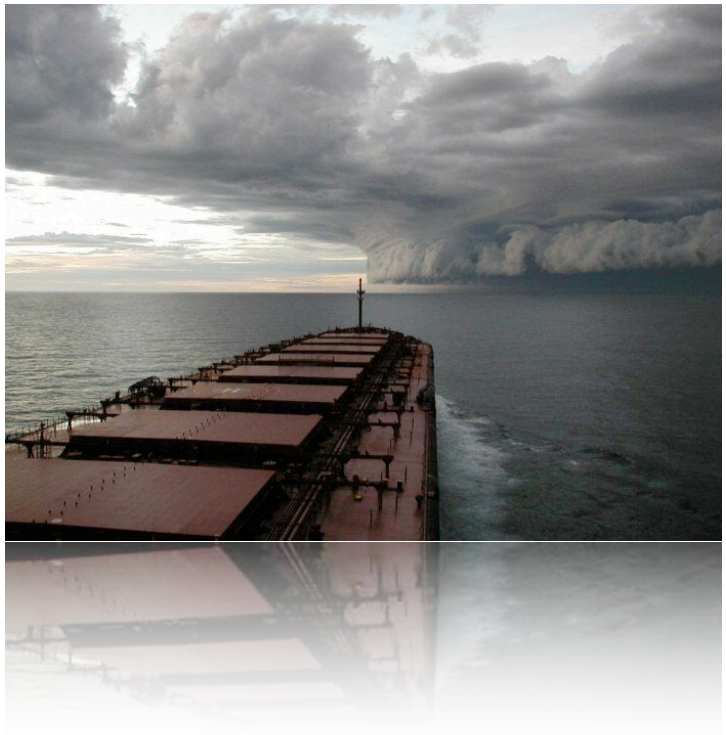
Timothy G. Rials, Director
Southeastern Regional Sun Grant Center

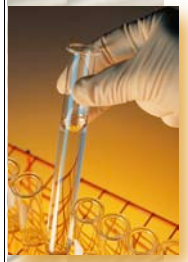
The University of Tennessee
2506 Jacob Drive
Knoxville, Tennessee 37996-4570



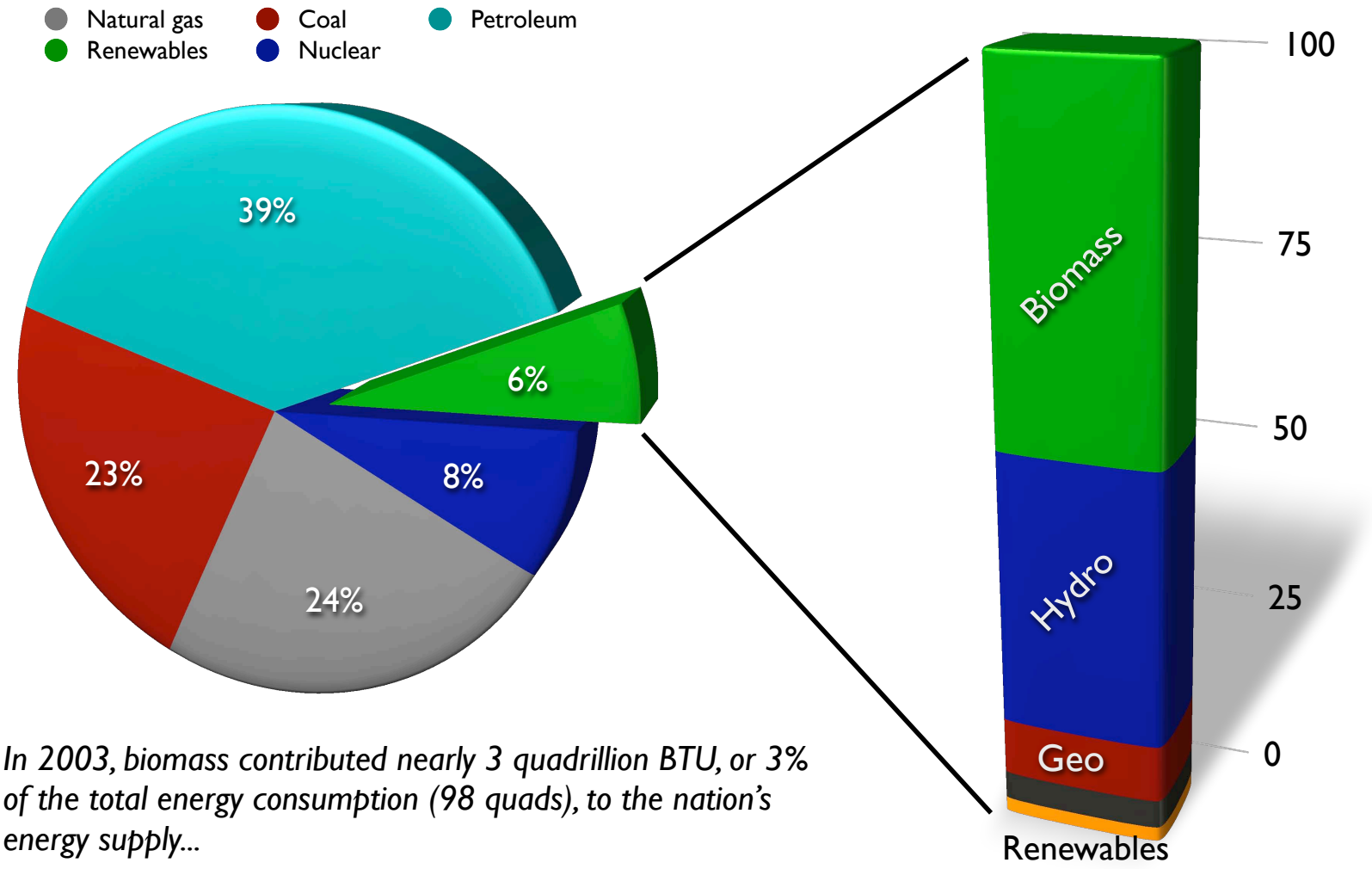
Why Bioenergy? Why Now?

- **Record Energy Prices**
  - Reflects demand from China & India
- **National Security**
  - America accounts for 25% of consumption, but holds 3% of reserves
  - 60% of reserves are in unstable regions
- **Economic Well Being**
  - In 2004, the ethanol industry added over $2B in additional tax revenue
  - Projected to add 15,000 jobs for every billion gals
  - Greatest impact on rural economy
- **Environmental Sustainability**
  - Fossil CO2 emissions from ethanol are 85% lower than gasoline
  - Projected Fossil Energy Ratio of 10.3 compared to 0.81 for gasoline
  - A renewable resource

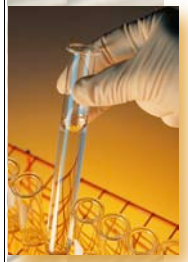





Where We Stand...

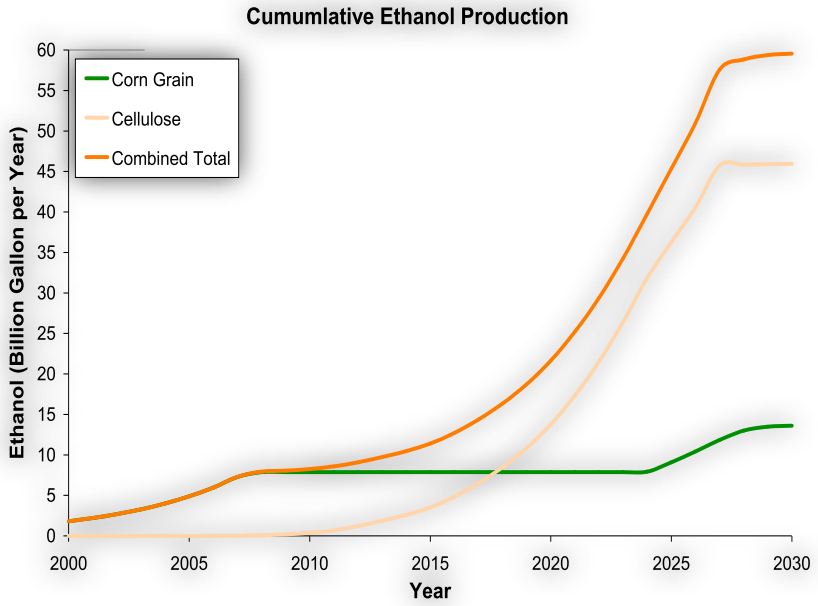


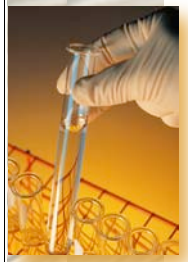
In 2003, biomass contributed nearly 3 quadrillion BTU, or 3% of the total energy consumption (98 quads), to the nation's energy supply...



Biomass & Energy

- Unique source of liquid fuels and chemicals
- Conversion Platforms
  - Thermochemical (pyrolysis; gasification)
  - Biochemical (sugars)
- Current biochemical focus
  - Corn starch
  - Corn starch & stover
  - Lignocellulosics
- Projections for 2030
  - Grain ethanol 13-14B gal
  - Cellulosic ethanol 40-50B gal (400-500 Million tons)



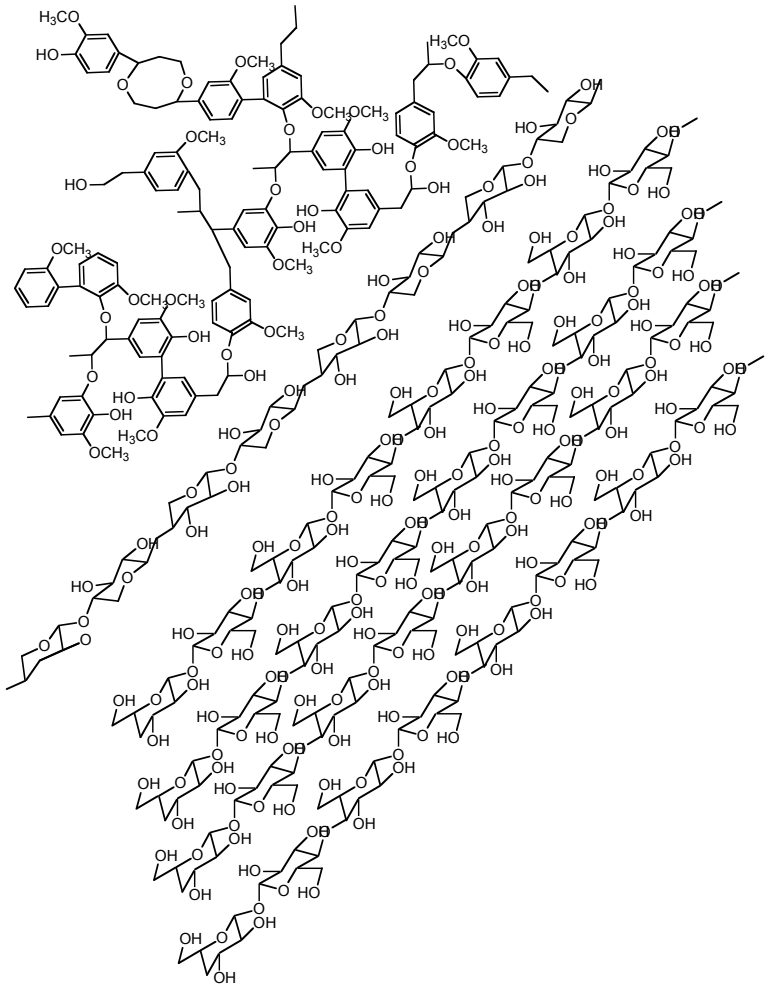


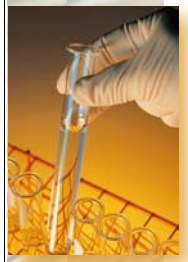
(Ligno)cellulosic Biomass

Lignin - 11-25%

Hemicellulose - 8-40%

Cellulose - 30-57%



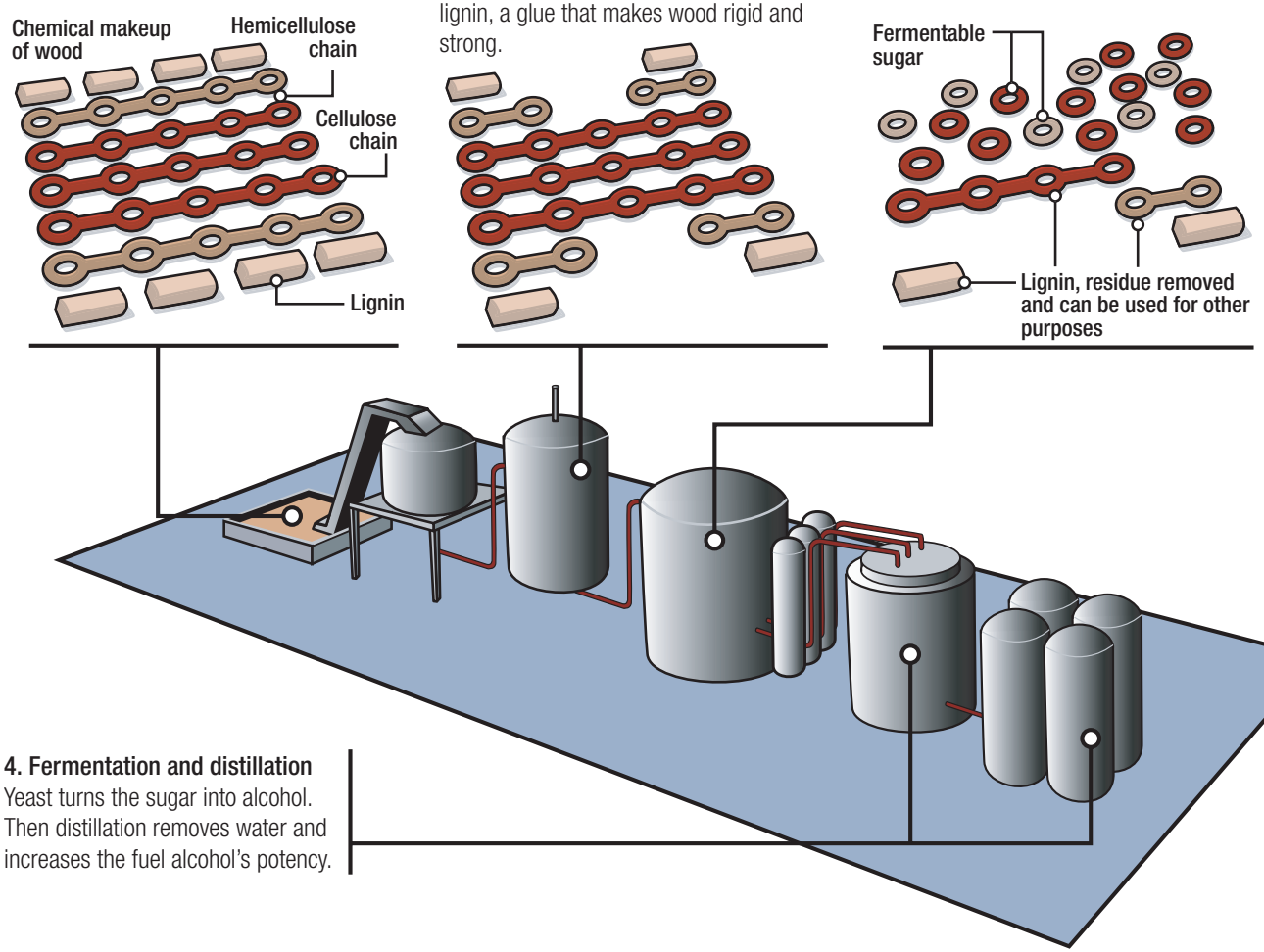


The Cellulosic Ethanol Process

1. Delivery
Wood Chips, cornstalks and yard waste are collected and delivered to the ethanol plant and shredded.

2. Pretreatment
Steam and acid separate the shredded biomass into three components: cellulose; hemicellulose, a chemical relative; and lignin, a glue that makes wood rigid and strong.

3. Hydrolysis
Enzymes or acid is added to break apart the cellulose and hemicellulose into sugar, which can then be fermented.



4. Fermentation and distillation
Yeast turns the sugar into alcohol. Then distillation removes water and increases the fuel alcohol's potency.

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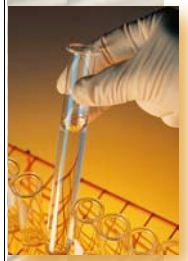



The Integrated Biorefinery

Biomass

Corn
Wood
Switchgrass
Ag residues
Soybeans
Stover
Sugar cane
Potatoes

Chemical fractionation

Thermal processes

Pyrolysis

Gasification

Carbohydrates

Cellulose
Hemicellulose
Monosaccharides

Aromatics

Lignin

Hydrocarbons

Oleochemicals

Thermal conversion

Bio-oil
Syngas

Ethanol, Butanol, other

Biobased nanostructual products

Carbon fibers

Chemical transformations

Catalysis

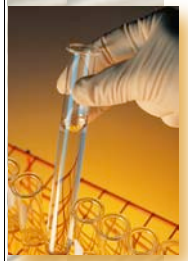
Novel reaction media

High selectivity pyrolytic processes

Extrusion for new materials

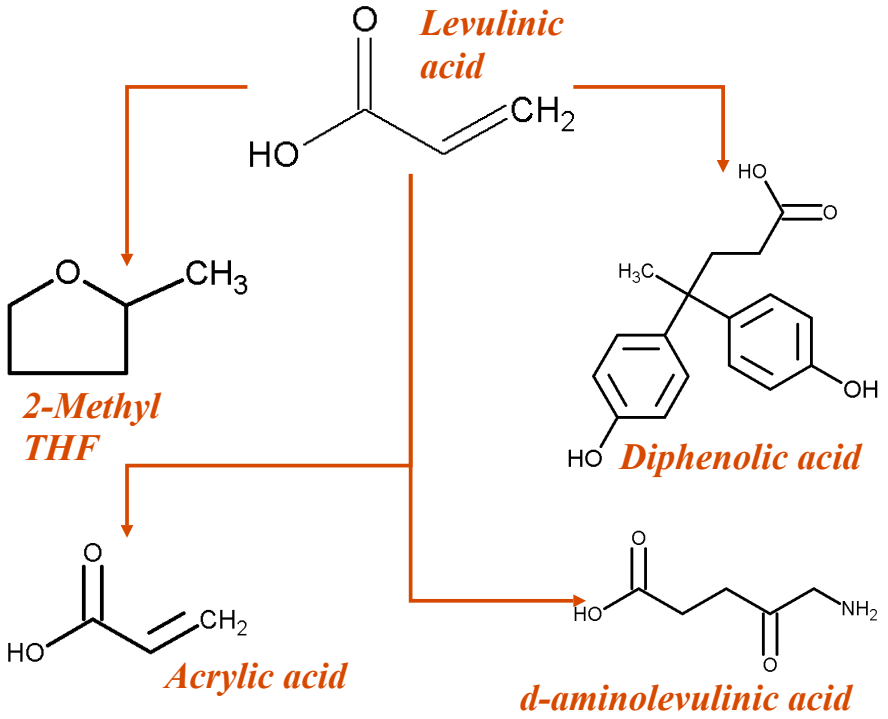
Biochemical transformations

Green chemistry

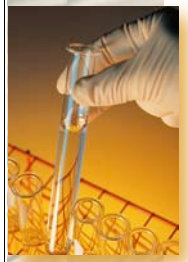


Biorefinery Co-Products

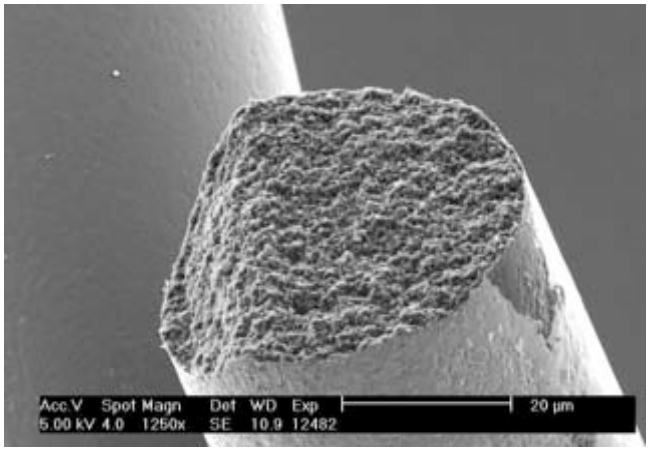
The Top Sugar-derived Building Blocks
1,4 diacids (succinic, fumaric and malic)
2,5 furan dicarboxylic acid
3 hydroxy propionic acid
Aspartic acid
Glucaric acid
Glutamic acid
Itaconic acid
Levulinic acid
3-hydroxybutyrolactone
Glycerol
Sorbitol
Xylitol/arabinitol

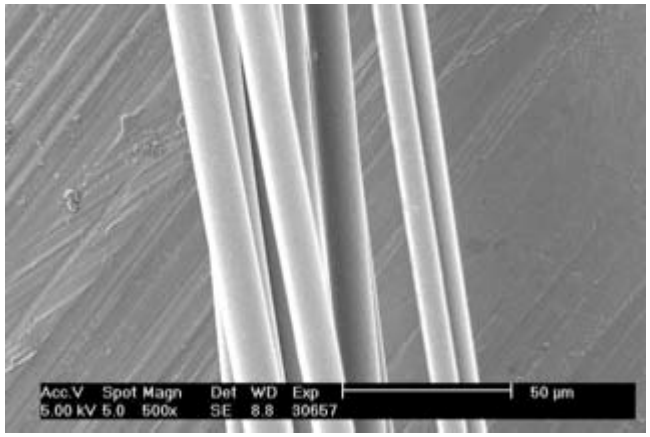


Produced from both C5 and C6 sugars, levulinic acid's family is broad and targets several large volume chemical markets.

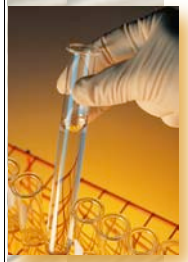


Biorefinery Lignins



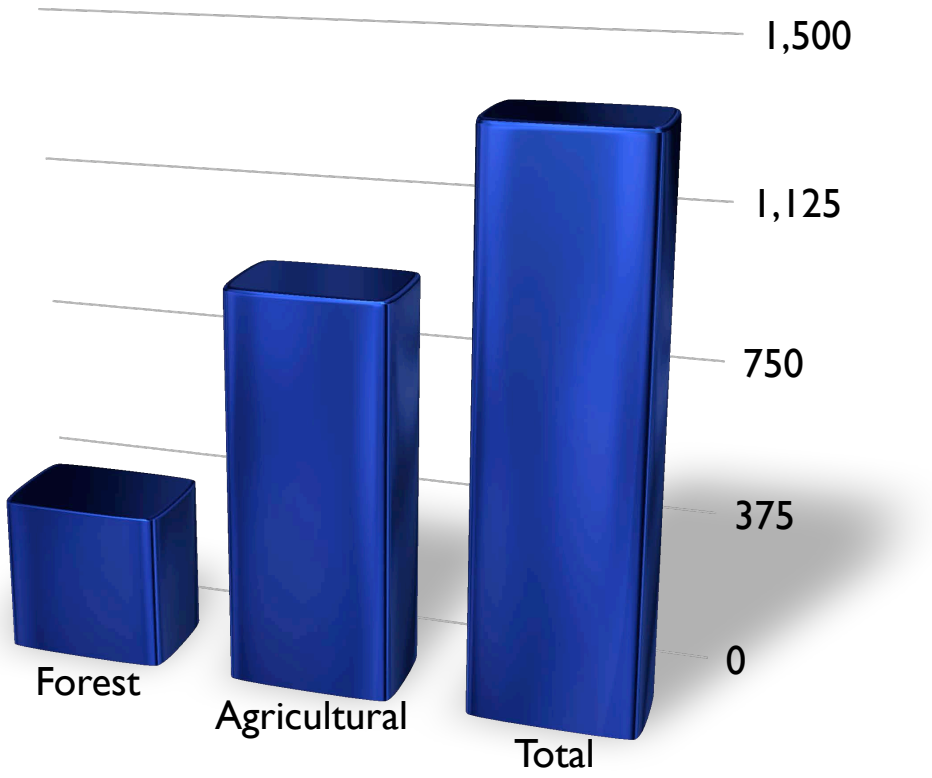


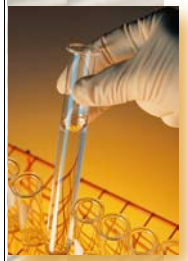
- Approximately 20 weight percent of biomass, on average (2nd most abundant polymer)
- Value-added markets, like carbon fiber, can generate additional revenue
- 1.2 million tons @ $5/lb = $12 Billion market (automotive & light truck)
- In producing 1 lb of carbon fiber
  - 2 lbs of biomass could replace 3 lbs of PAN derived from 6 lbs of petroleum



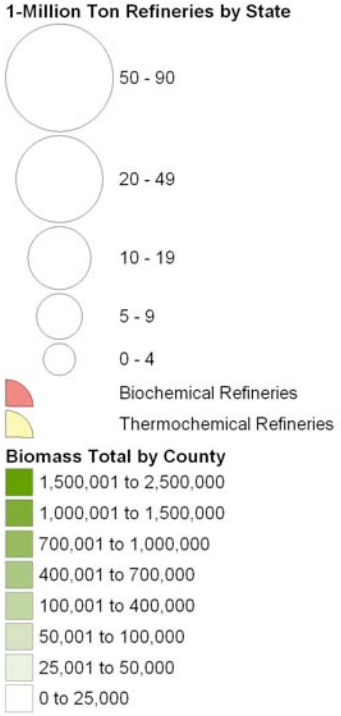
Biomass Availability

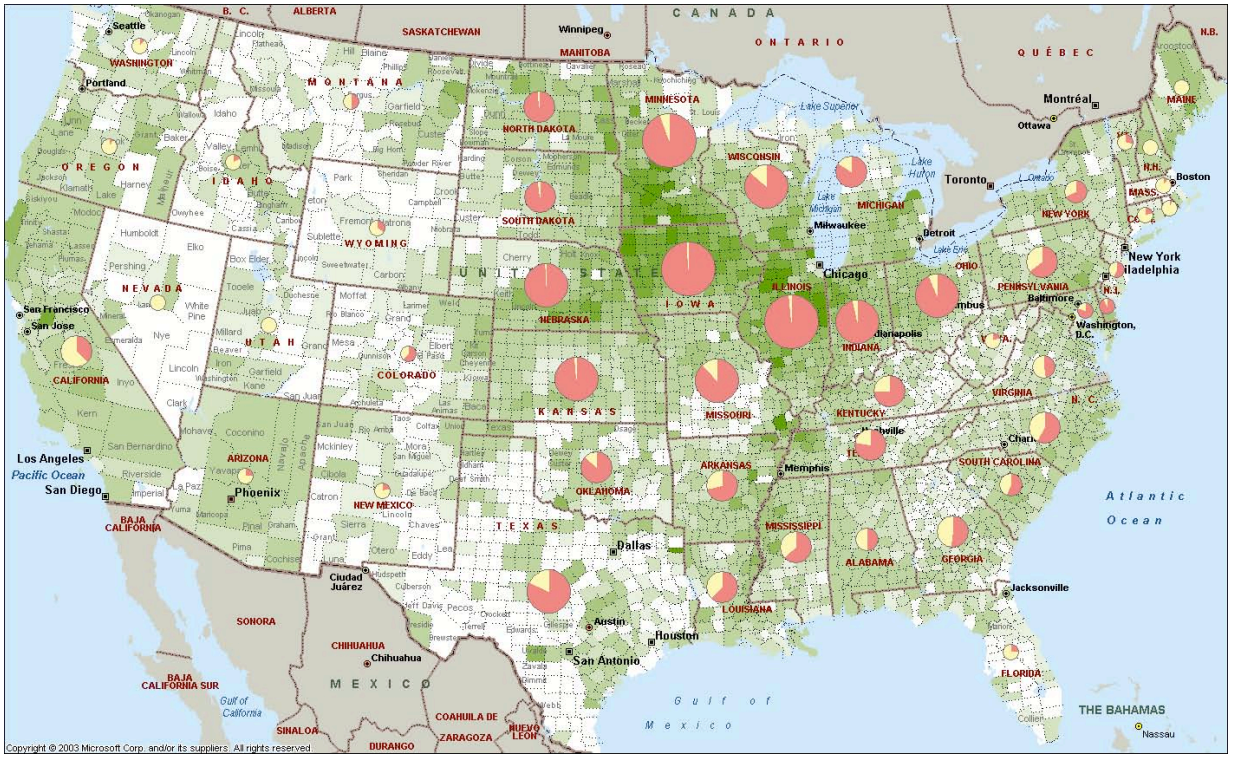
- Sustainable annual supply of **1.3 billion dry tons**
- 932 M dry tons from agriculture
  - Crop residues (446)
  - Perennial crops (377)
  - Grains to biofuels (87)
  - Process residues (87)
- 368 M dry tons from forests (forest residue only)
  - Manufacturing residue (145)
  - Logging debris (64)
  - Fuel reduction treatments (60)
  - Fuelwood (54)
  - Urban wood waste (47)





The Biomass Resource & Refinery Capacity





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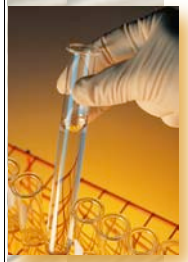
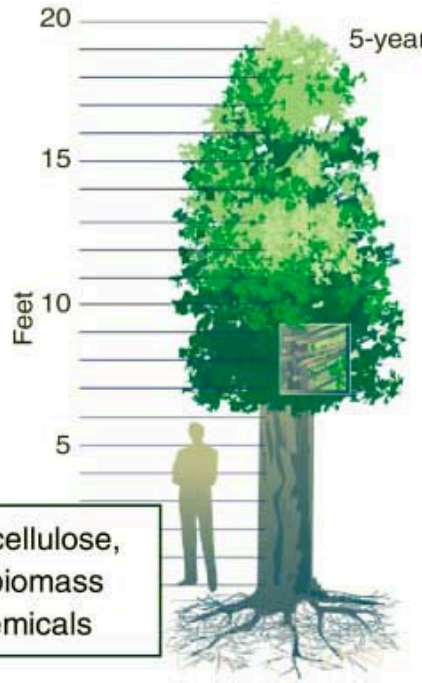



Genomes to Life - Energy

Increased photosynthesis
Optimized photoperiod response
Optimized crown/leaf architecture

Enhanced biomass production per acre by reducing perception of nearest neighbor by manipulating photomorphogenic responses of phytochrome red/far-red light perception system



Pest/disease resistance
Drought/cold tolerance
Floral sterility

Regulated dormancy
Delayed leaf senescence

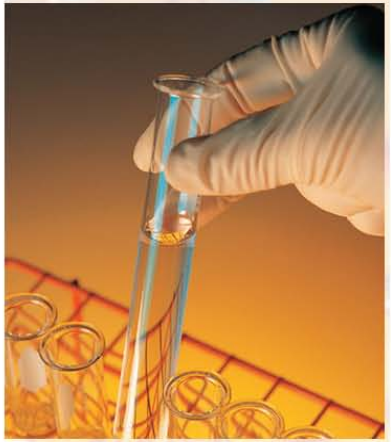
Greater carbon allocation to stem diameter vs. height growth

Less extensive root system to maximize aboveground biomass
Optimal nitrogen acquisition and use

Controlled and readily processable cellulose, hemicellulose, and lignin; tailored biomass composition with value-added chemicals

The Power of Biomass

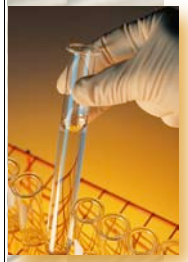


SunGrant
INITIATIVE

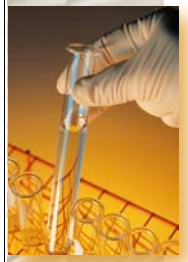
Southeastern Regional Center
Tennessee Agricultural Experiment Station

sungrant.tennessee.edu

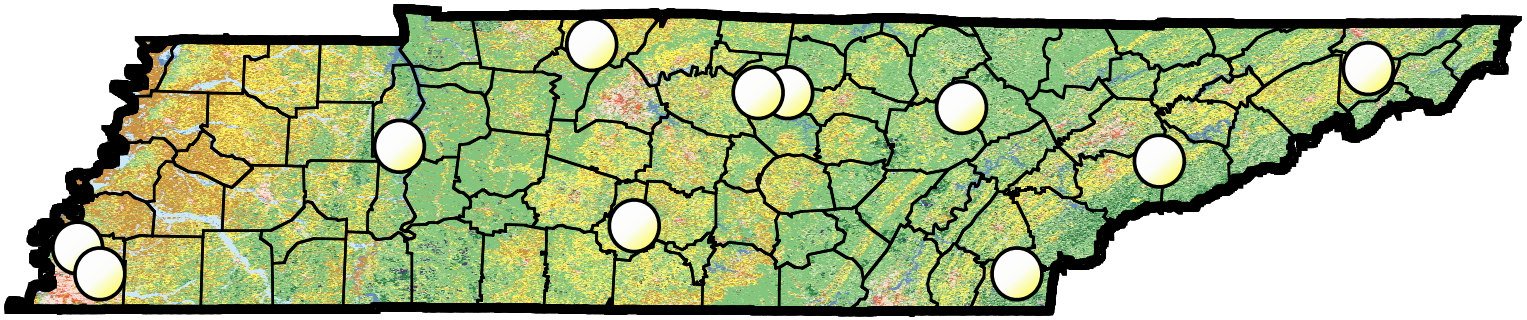


Tennessee Activities

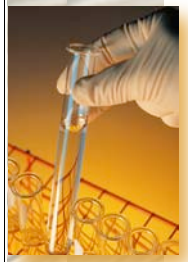
- Submitted BioEnergy Center Proposal ($125M), ORNL/UT/GaTech/Dartmouth/others
- Home to the Southeastern Regional Sun Grant Center (Tennessee Agricultural Experiment Station)
- Developing the Biomass Conversion Laboratory (UT-FPC)
- The Tennessee Biofuels Initiative



A Tennessee BioEconomy



- Produce & consume at least 1 billion gallons of cellulosic ethanol, at $1.20 per gallon wholesale
- 10-15 new biorefineries operating in Tennessee, supporting 4,000 rural jobs
  - At least 4 of the biorefineries owned and operated by local farmer cooperatives, retaining an additional $40 million in local communities
- Satellite co-product plants creating an additional 3,000 jobs and $2 billion in revenue
- More than 20 thousand farmers growing dedicated energy crops, adding $100 million in new farm revenue



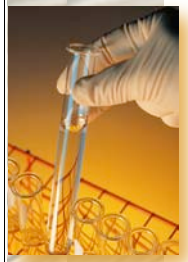
Parallel Developments

A Sustainable System

Sufficient, economical, sustainable supply of cellulosic biomass

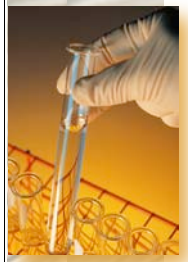
Efficient, profitable, low-risk, fuel production capacity

Adequate, stable, local demand and distribution capacity for alternative fuels

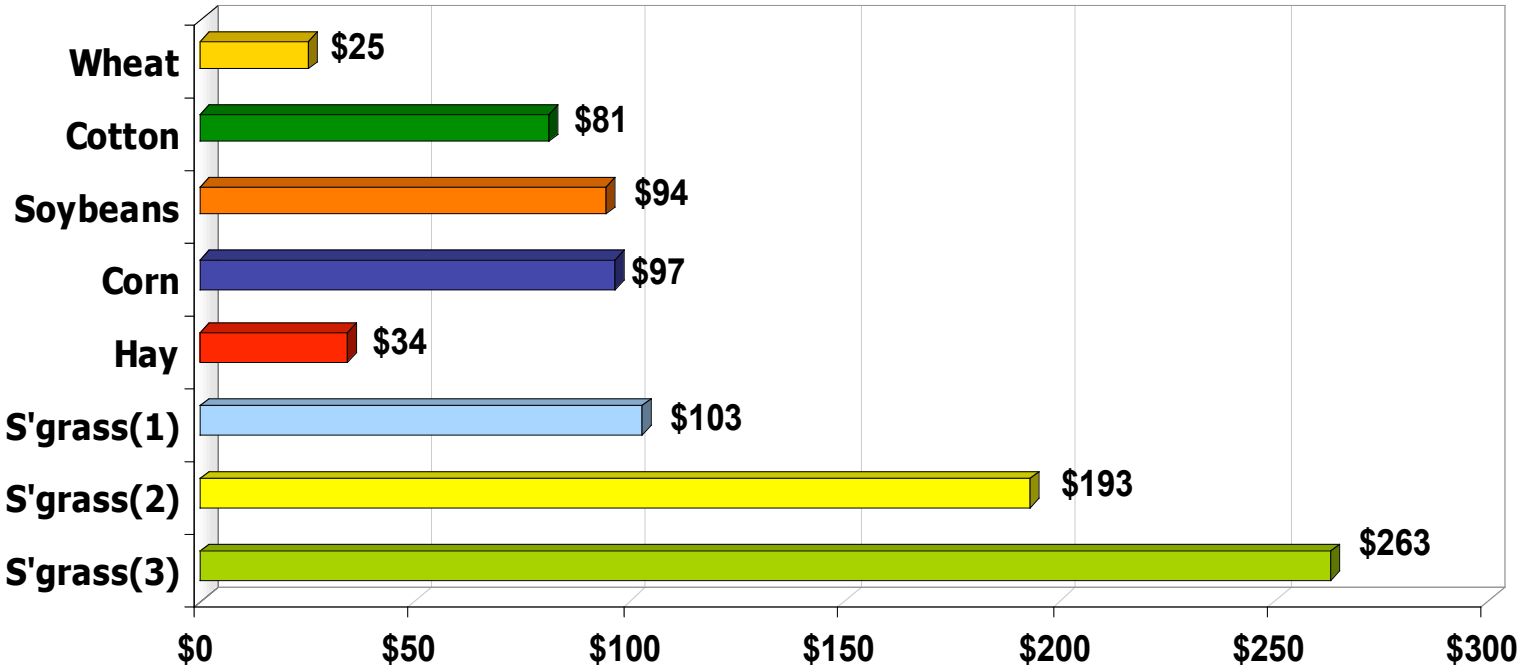



Gateway to the South

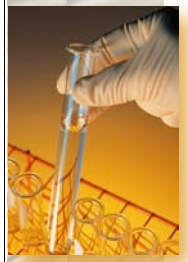
- **Construct a pilot-scale cellulosic ethanol facility in Tennessee**
  - Utilize 170 tons per day of locally produced switchgrass and wood
  - Work with partner industries to generate 5 million gallons of ethanol annually for local distribution
  - Refine the process for local resource to reduce costs, improve process, scale up to commercial
  - Deploy the model throughout the state



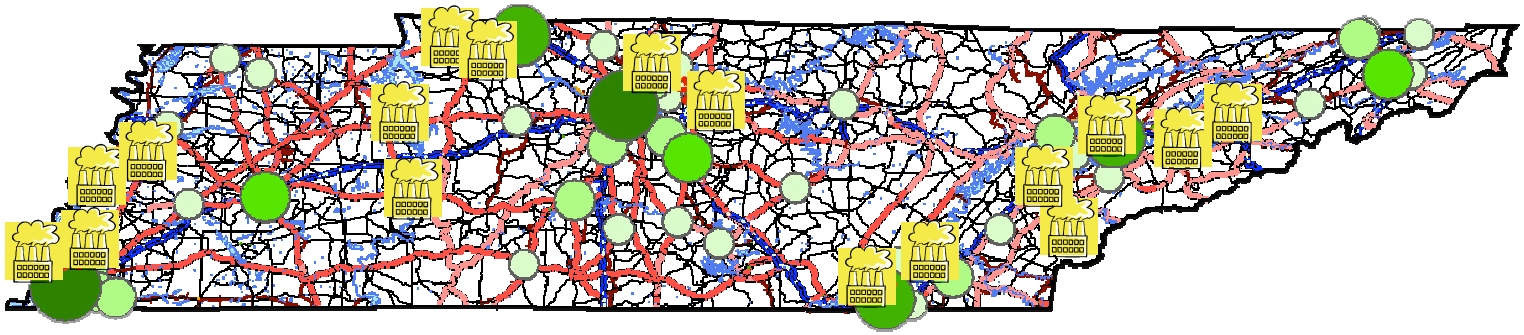
Rural Economic Development



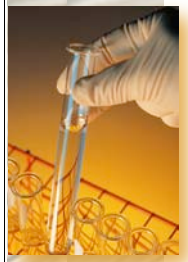
- At current yields (6 tons/ac) and $40/ton, competes with corn, cotton, soybeans for acreage
- Significantly higher returns than hay, on similar acreage
- With yield improvements, returns potentially more than double traditional row crops
- Specialty crops can return $1,000+ per acre, but with significantly higher risk, very limited opportunities



Economic Impacts

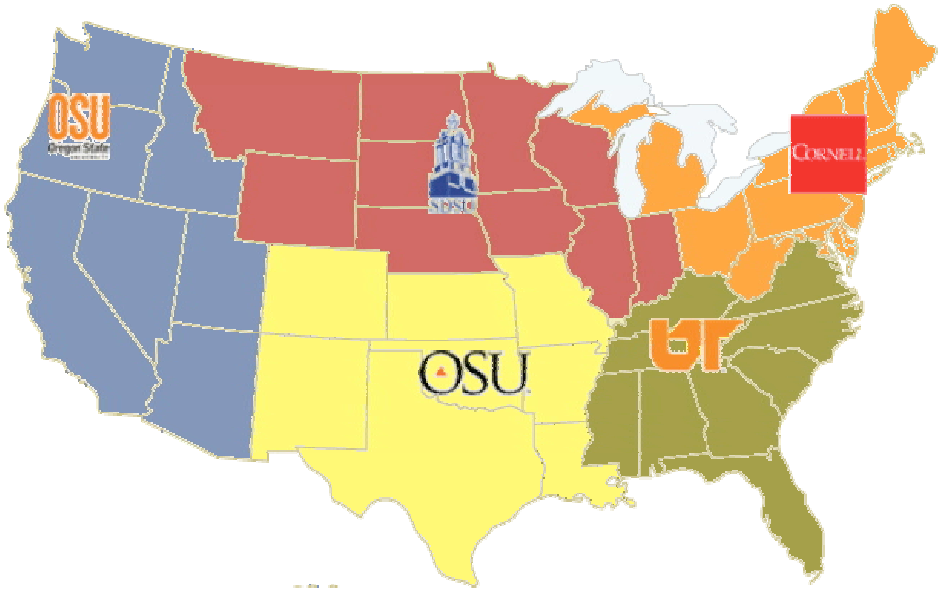


- Tennessee's ROI
  - For a billion gallons of ethanol production[1]:
    - 10,000 to 20,000 jobs created
    - $400 million dollars will be added in state & local taxes
  - Each 100 MGY ethanol plant will[2]:
    - Increase Gross State Product by $223 million
    - Support the creation of 1,600 new jobs
- Each commercial facility:
  - Directly employs 200
  - Supports 1,400 jobs indirectly
  - Contributes $200+ million in total economic activity
  - Generates $40 million in new tax revenue
- Ownership of a facility by a local cooperative retains an additional $10 million per year in the local economy



The Sun Grant Initiative

A concept to solve America's energy needs and revitalize rural communities with Land Grant University Research, Education, and Extension programs on renewable energy and biobased, non-food industries



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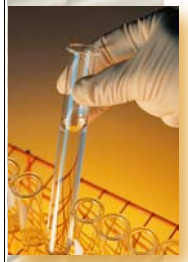
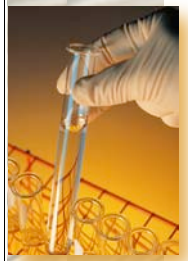
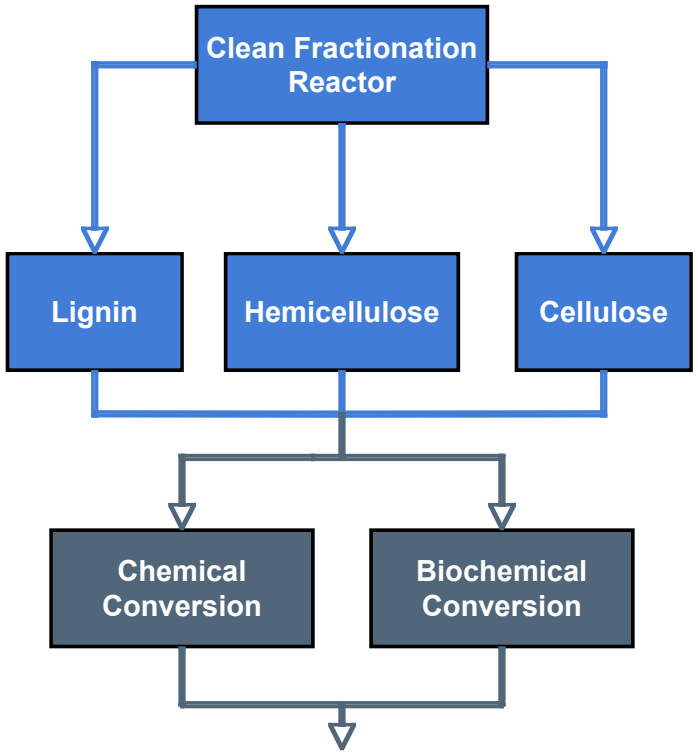


The Southeastern Sun Grant Center

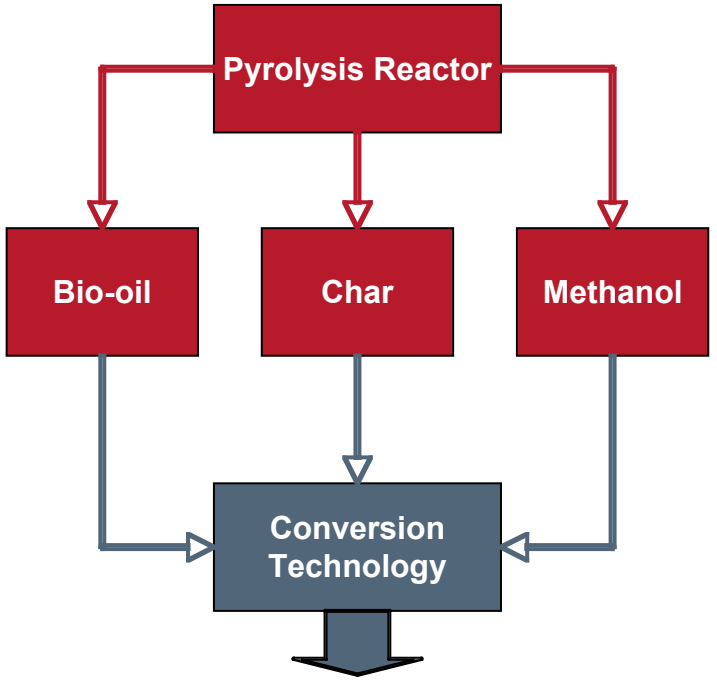
- Manage a competitive grants program available to the land grant universities in the region (RFP in February 2007 and 2009)
- Offer research fellowships to enhance collaboration between land grants and DOE national laboratories
- Expand research and development in biomass conversion at the TAES Sun Grant Center (internal competitive grant)
- Compile and manage electronic database of information on bioenergy, biofuels, and bio-based materials (BioWeb available in March 2007)



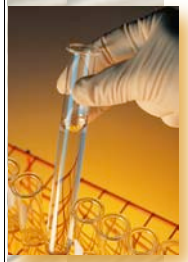

The Biomass Conversion Laboratory



Carbon fiber
High value chemicals
Composites
Polymers
Nanomaterials
Coatings



Fuels
Soil amendments
Adhesives
Polymers




Concluding Remarks

- The biorefinery offers a unique opportunity to revitalize and rejuvenate the rural Tennessee economy
- Questions and challenges abound at the logistical and technical level to the science and technology level
- Tennessee has emerged as an important source of information on conversion of lignocellulosic biomass
- Capabilities continue to evolve and expand with new resources - Sun Grant, BioConversion Lab, Biofuels Initiative