Fundamental Science of Crop Production Technologies

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Growing the Bioeconomy
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For today:

- Possible cellulosic crops
- Some history
- What are the basic research areas
- What are some possible answers
Switchgrass
(Panicum spp.)

- Native cool- and warm-season prairie grass
- Widely adapted
- Drought tolerant
- Tissue cultured already
Poplar
(Populus spp.)

- Extensive selection and varietal trials ongoing (DOE and USFS)
- Widely adapted
- Drought / water tolerant once established
- We have mapped the poplar genome
Operational RD & D support and project evaluation timeline
(DOE Bioenergy Feedstock Development Program at ORNL)

- Feasibility Study RFP issued (1993)
- MNVAP COOP formed (1995)
- Prairie Lands Bio-products COOP formation (1996)
- Completion of planting 5000 acres Populus in Minnesota (1997)
- 7000 ac switchgrass harvested - Iowa (1999)
- Co-firing test results public (2000)
- 500+ acres Salix planted in NY (2001)
Setting the stage (sources: IEA, Perlack, et al.)

Current US Energy

- **Biomass**: 3%
- **Hydro**: <3%
- **Nuclear**: 8%
- **Coal**: 23%
- **Natural gas**: 24%
- **Petroleum**: 39%
- **Wind & solar**: <1%

Potential US bioenergy feedstocks
(1.3 billion dry tons/yr)

Total annual resource potential exceeds 1.3 billion dry tons

- **Forest resources**: 403 million dry tons per year
- **Agricultural resources**: 953 million dry tons per year
- **Total resource potential**: 1356 million dry tons per year

Current use of bioenergy feedstocks
(0.19 billion dry tons/yr)
Office if the Biomass Program Biorefinery Energy “Platforms”

Each platform is comprised of components:

**Hydrolysis**
- Sugars and Lignin

**Gasification**
- Biogas

**High heat, low oxygen**
- Syngas

**Digestion**
- Bacteria

**Pyrolysis**
- Biocrude

**Catalysis, heat, pressure**
- Carbon Rich Chains

**Extraction**
- Plant Products

**Mechanical, chemical**
- Mechanical, chemical

**Separation**

**Collection, processing & storage for each platform**
- Biobased chemicals
- Biobased materials
- Liquid biofuels
- Electricity
- Heat

**Biomass**
- Grains
- Ag residues
- Energy crops
- Pulp & paper
Microbial, Plant, and Ecosystem Science to Solve Energy Challenges

- Complex Systems
- Multiple Scales
  - Space and Time
  - Biological Levels (systems biology)

Subsurface Stewardship
Ecosystem Response
Complex Traits
Molecular Machines
BioEnergy

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Bioenergy and Plant Genomics: Expanding the nation’s renewable energy resources

Yesterday

Conventional Forestry

Today

Short rotation hardwoods

Metabolic Profiling

Whole Genome Microarrays

Tomorrow

Accelerated Domestication

High yield wood crops

Putting Genomes to work For Energy Security

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Woody plant genomics – designing crops for energy & carbon sequestration

High-throughput Phenotyping

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U. S. DEPARTMENT OF ENERGY
Biomass analysis capabilities

- Biomass Supply Forecasting analysis
  - 1.3 Billion Ton study
- Biofeedstock supply logistics
- Agricultural residue sustainability

Collectible Corn Residue at Erosion Tolerance Levels

Dry Tons/Year

- w/HE
- w/o HE

Available Corn stover <$35/ton
(assuming all no tble)
106 million dry tons total

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Biomass Supply Forecasts

- **Goal** – Develop high quality information on the location, price, quantity, and quality of biomass resources
- **Recent Accomplishments**
  - Web site with up-to-date supply curves for most biomass types at county level developed; sustainable corn stover supply analysis completed
- **Plan**
  - Vision document for DOE for achieving U.S. feedstock supply of 1 billion dry tons/yr
- **Collaborators**
  - USDA, University of Tennessee, NREL, INEEL, Richard Nelson, private industry
Ag Residue Sustainability Research

- **Goal** – To provide credible data and information on the environmental aspects of producing large quantities of biomass for energy and other new uses.

- **Recent Accomplishments**
  - Joint DOE/USDA workshop on agricultural residue sustainability issues
  - Manuscript on implications of corn stover removal

- **2004 Status**
  - Project stopped Jan 04 due to DOE pull back of 03 carryover

- **Collaborators**
  - USDA/ARS labs in mid-west
Mitigating energy impacts

• Carbon sequestration
  – Enhancing soil carbon sequestration
    • Increasing carbon allocation to roots
    • Altering root chemistry
    • Altering soil microbial community

• Climate change adaption/resilience
  – Drought resistant crops
  – Enhanced temperature tolerance
Carbon Sequestration and the Populus Tree

A *Populus* tree

Genome-Enabled Discovery of Carbon Sequestration Genes in *Populus*

Gene expression in above and below ground parts:
- **Above Ground**:
  - Leaves
  - Branches
  - Stem
  - Lignin
  - Hemicellulose
  - Cellulose
  - Genes important to tissue chemistry
- **Below Ground**:
  - Tap Root
  - Structural Roots
  - Fine Roots
  - Lignin
  - Hemicellulose
  - Cellulose
  - Genes important to carbon allocation

Greenhouse testing
Enhancing Carbon sequestration through microbial and plant genomic studies

### Microarrays to interrogate microbial function

<table>
<thead>
<tr>
<th>Carbon polymer degradation</th>
<th># of input genes</th>
<th># with Unq probes</th>
<th># with Grp probes</th>
<th>% inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laccase</td>
<td>190</td>
<td>97</td>
<td>79</td>
<td>92.6</td>
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<tr>
<td>Chitinase</td>
<td>413</td>
<td>248</td>
<td>100</td>
<td>84.3</td>
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<tr>
<td>Cellulase/endoglucanase</td>
<td>567</td>
<td>417</td>
<td>80</td>
<td>87.7</td>
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<tr>
<td>Beta-mannosidase</td>
<td>73</td>
<td>66</td>
<td>4</td>
<td>95.9</td>
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<tr>
<td>Polygalacturonase</td>
<td>112</td>
<td>86</td>
<td>25</td>
<td>99.1</td>
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<tr>
<td>Glutamate dehydrogenase</td>
<td>112</td>
<td>88</td>
<td>10</td>
<td>87.5</td>
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<tr>
<td><strong>subtotal</strong></td>
<td><strong>1467</strong></td>
<td><strong>1002</strong></td>
<td><strong>298</strong></td>
<td><strong>88.6</strong></td>
</tr>
</tbody>
</table>

### Carbon Fixation

<table>
<thead>
<tr>
<th>Carbon Fixation</th>
<th># of input genes</th>
<th># with Unq probes</th>
<th># with Grp probes</th>
<th>% inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide dehydrogenase</td>
<td>10</td>
<td>10</td>
<td>0</td>
<td>100.0</td>
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<tr>
<td>Formyltetrahydrofolate synthetase</td>
<td>155</td>
<td>52</td>
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<tr>
<td>Rubisco large subunit</td>
<td>470</td>
<td>158</td>
<td>87</td>
<td>52.1</td>
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<tr>
<td>Rubisco small subunit</td>
<td>299</td>
<td>16</td>
<td>85</td>
<td>33.8</td>
</tr>
<tr>
<td><strong>subtotal</strong></td>
<td><strong>934</strong></td>
<td><strong>236</strong></td>
<td><strong>259</strong></td>
<td><strong>53.0</strong></td>
</tr>
</tbody>
</table>

### Relating microbial communities to soil processes

![Graph showing relative changes compared to the ridge soil sample](image)

- **P min**: ~ 9.0 for both
- **P immobilization**
- **denitrification**
- **N fixation**
- **S reduction**
- **CH₃ degradation**
- **oxidation**

DOE terrestrial carbon sequestration research

![Image of DOE terrestrial carbon sequestration research](image)

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There is no single answer, but here’s what we need:

• Multiple and complex integrated system of benefits and costs that are qualified and quantified
• Rural and other development (GDP, and market and non-market based, with defined terms of trade and clear advantages)
• Perennial emphasis – a perennial corn plant, or the very efficient and robust Populus sp.
• Some acknowledgement of environmental increments and decrements
• There are several productive crops that will produce food, feed, fiber, and chemicals, as well as energy in some form for which we will extract a stream of value-added benefits