SWITCHGRASS AND
MISCANTHUS BIOMASS ON
RECLAIMED MINED LANDS

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12 Billion Gallons now (8%)
36 Billion Gallons in 2022 (26%)
Food vs. Fuel Debate

Solutions:
1) Grow **Cellulosic Crops** instead of food crops
2) Use **Marginal Lands** instead of farmland.

LET GO OF MY FUEL !!!

LET GO OF MY FOOD !!!
Cellulose – It’s Everywhere!
Biomass Feedstocks

Starch/Sugar Feedstocks
- Corn
- Sugarcane

Cellulosic Feedstocks
Ag Plant Wastes:
- Corn/Grain Stover
- Forest Residues
- Sawdust
- Paper Pulp

Energy Crops
- Switchgrass
- Miscanthus
Coal Mining disturbs landscapes and forests
These lands can be reclaimed to productive uses
Why not reclaim land for biofuel production?

- Large uninterrupted tracts
- Good road networks
- Access to transportation hubs
- Land not previously in ag production
BioEnergy Crops – 2nd Yr
Switchgrass on Reclaimed Mine
Switchgrass, Miscanthus
Pellets, Biomass, Ethanol
## Switchgrass Yields

<table>
<thead>
<tr>
<th>Study</th>
<th>Yield Mt ha(^{-1})</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fike et al. (2017)</td>
<td>14 – 19</td>
<td>4 cultivars, 8 sites, 5 states</td>
</tr>
<tr>
<td>Vogel &amp; Masters (1998)</td>
<td>15 – 17</td>
<td>3 states in Midwestern USA</td>
</tr>
<tr>
<td>Fike et al. (2006b)</td>
<td>14 – 18</td>
<td>Years 6 - 9 of production</td>
</tr>
<tr>
<td>McLaughlin (2005)</td>
<td>11 – 19</td>
<td>CIR; 10 years, 13 states</td>
</tr>
<tr>
<td>Schmer et al. (2014)</td>
<td>5 – 12</td>
<td>Marginal cropland</td>
</tr>
<tr>
<td>Brown et al. (2015)</td>
<td>5 – 10</td>
<td>Reclaimed land in WV</td>
</tr>
</tbody>
</table>

Goal would be 5.0 Mt ha\(^{-1}\)
What yields of switchgrass can grow on reclaimed mine lands?
Summary of Sites
Bioenergy Crops

- The Wilds, OH
- Hampshire
- Alton
- MeadWestvaco
- Black Castle
- Hobet
- Coal Mac
First 2 Sites – planted 2008

Hampshire

Hobet
Varieties

• Three varieties of switchgrass
  – Carthage
  – Cave-in-Rock
  – Shawnee
Hand seeding at Hobet
Results
Soil Properties

Hampshire (Good Site)
- 74% Fines
- pH = 7.4
- EC = 421 $\mu$s/cm
- P = 8.0 mg kg$^{-1}$ soil
- Ca = 50 cmol$_c$ kg$^{-1}$

Hobet (Poor Site)
- 55% Fines
- pH = 8.0
- EC = 109 $\mu$s/cm
- P = 50 mg kg$^{-1}$ soil
- Ca = 2.0 cmol$_c$ kg$^{-1}$
<table>
<thead>
<tr>
<th>Variety</th>
<th>Hampshire</th>
<th>Hobet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cave in Rock</td>
<td>15.1</td>
<td>1.5</td>
</tr>
<tr>
<td>Carthage</td>
<td>8.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Shawnee</td>
<td>13.2</td>
<td>1.5</td>
</tr>
</tbody>
</table>
Hampshire – 8th Year – 2015

Steady Increase!
Hampshire – 8th Year – 25 Mt ha⁻¹
Hobet – 8th Year – 2015

Poor Site Conditions

Biomass (Mg ha⁻¹)

CIR Carth Shaw CIR Carth Shaw CIR Carth Shaw CIR Carth Shaw CIR Carth Shaw CIR Carth Shaw CIR Carth Shaw

Hobet – 8th Year – 1.5 Mt ha⁻¹
Where do our numbers stand?

Agricultural Land: 15 - 20 Mt ha\(^{-1}\)

Cave-in-Rock at Hampshire: 15 Mt ha\(^{-1}\)

Shawnee at Hobet: 1.5 Mt ha\(^{-1}\)

Goal of 5.0 Mt ha\(^{-1}\)
What about other crops?
Switchgrass
Kanlow and BoMaster
Planted in 2010

Miscanthus
Illinois and MBX-002

Alton
Each 0.4 ha or 1 acre

5 plots Kanlow
5 plots BoMaster
5 plots Miscanthus – MBX
5 plots Miscanthus – Illinois
5 plots Arundo
Must Herbicide!
Switchgrass drilled into killed sod
Planted sprigs like tree seedlings
70% Fines
pH = 7.5
EC = 368 µs/cm
P = 40 mg kg\(^{-1}\) soil
K = 0.2 cmol\(_c\) kg\(^{-1}\)
Ca = 3.2 cmol\(_c\) kg\(^{-1}\)
<table>
<thead>
<tr>
<th>Variety</th>
<th>3rd Yr</th>
<th>6th Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgrass</td>
<td>4.9</td>
<td>6.9</td>
</tr>
<tr>
<td>Kanlow</td>
<td>4.5</td>
<td>8.0</td>
</tr>
<tr>
<td>BoMaster</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Goal of 5.0 Mt ha\(^{-1}\)

J9/10/2012
Switchgrass – Alton – 3\textsuperscript{rd} Yr

5 \text{ Mt ha}^{-1}
Switchgrass – Alton – 6th Yr
8 Mt ha⁻¹
<table>
<thead>
<tr>
<th>Variety</th>
<th>3rd Yr</th>
<th>6th Yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>4.9</td>
<td>11.4</td>
</tr>
<tr>
<td>Illinois</td>
<td>11.7</td>
<td>13.7</td>
</tr>
<tr>
<td>MBX-002</td>
<td>11.7</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Goal is 7.5 Mt ha\(^{-1}\)
Miscanthus – Alton – 3rd Yr
11 Mt ha⁻¹

11/02/2011
Miscanthus – Alton – 6th Yr
14 Mt ha$^{-1}$
MeadWestvaco
The Wilds, OH
Large Plots
Planted in 2010
MeadWestvaco
Switchgrass – MeadWestvaco – 2nd Yr

3 Mt ha\(^{-1}\)
The Wilds – Drilling into herbicided area
Conventional Haying Equipment
After 3\textsuperscript{rd} year on reclaimed land

**Switchgrass**: 5 to 15 Mt ha\textsuperscript{-1}

**Miscanthus**: 10 to 15 Mt ha\textsuperscript{-1}

Increasing to the 8\textsuperscript{th} year
Determine Cell Sugars in Forage to Estimate …

1. Theoretical Ethanol Production (L Mg⁻¹)
2. Theoretical Ethanol Yield (L ha⁻¹)
### Compositional traits predicted with NIRS.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbreviation</th>
<th>Reference or Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage Quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutral Detergent Fiber</td>
<td>aNDF</td>
<td>NIRSC 2011</td>
</tr>
<tr>
<td>Lignin</td>
<td>LIGNIN</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>ASH</td>
<td></td>
</tr>
<tr>
<td>Cell Wall Constituents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hexose:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mannan</td>
<td>MAN</td>
<td></td>
</tr>
<tr>
<td>Galactan</td>
<td>GAL</td>
<td></td>
</tr>
<tr>
<td>Glucan</td>
<td>GLC</td>
<td></td>
</tr>
<tr>
<td>Sucran</td>
<td>SUC</td>
<td></td>
</tr>
<tr>
<td>Soluble Glucose</td>
<td>GLCS</td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>STA</td>
<td></td>
</tr>
<tr>
<td>Pentose:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arabinan</td>
<td>ARA</td>
<td></td>
</tr>
<tr>
<td>Xylan</td>
<td>XYL</td>
<td></td>
</tr>
</tbody>
</table>

**Sugars in Biomass to estimate Theoretical Ethanol Yield**

**Cell Wall Constituents**

**Hexose:**
- Mannan
- Galactan
- Glucan
- Sucran
- Soluble Glucose
- Starch

**Pentose:**
- Arabinan
- Xylan
## Prediction of Theoretical Ethanol Yield (TEY) and Production (TEP)

### Method/Parameter

<table>
<thead>
<tr>
<th>Reference and constituents used</th>
<th>Unit</th>
</tr>
</thead>
</table>

### Method 1

Vogel et al. (2011)

- **HEX**:
  \[
  \left( ((GLC+GAL+MAN+STA) \times 0.57) + ((GLCS+FRU) \times (SUC \times 0.537)) \right) \times 1.267; \text{ assuming 100\% conversion}
  \]

- **PEN**:
  \[
  (XYL+ARA) \times 0.579 \times 1.267
  \]

- **TEY1**:
  \[
  \text{HEX+PEN}
  \]

- **TEP1**:
  \[
  \text{TEY1} \times \text{biomass yield (Mg ha}^{-1})
  \]

### Method 2

Dien et al. (2010)

- **C6**:
  \[
  ((GLC+GAL+MAN) \times 0.57) \times 1.267
  \]

- **C5**:
  \[
  (XYL+ARA) \times 0.579 \times 1.267
  \]

- **TEY2**:
  \[
  \text{C6+C5}
  \]

- **TEP2**:
  \[
  \text{TEY2} \times \text{biomass yield (Mg ha}^{-1})
  \]

### Method 3

Dien et al. (2010)

- **GL**:
  \[
  \text{GL} \times 0.57 \times 1.267
  \]

- **XY**:
  \[
  \text{XY} \times 0.579 \times 1.267
  \]

- **TEY3**:
  \[
  \text{GL+XY}
  \]

- **TEP3**:
  \[
  \text{TEY3} \times \text{biomass (Mg ha}^{-1})
  \]

### 6-carbon sugars

- **HEX**
- **PEN**
- **TEY1**
- **TEP1**
## Prediction of Theoretical Ethanol Yield (TEY) and Production (TEP)

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<tr>
<td><strong>Method 1</strong></td>
<td>Vogel et al. (2011)</td>
<td></td>
</tr>
<tr>
<td>HEX</td>
<td>(((GLC+GAL+MAN+STA)×0.57)+((GLCS+FRU)×(SUCx0.537)))×1.267; assuming 100% conversion</td>
<td>L Mg⁻¹</td>
</tr>
<tr>
<td>PEN</td>
<td>(XYL+ARA)×0.579×1.267</td>
<td>L Mg⁻¹</td>
</tr>
<tr>
<td>TEY1</td>
<td>HEX+PEN</td>
<td>L Mg⁻¹</td>
</tr>
<tr>
<td>TEP1</td>
<td>TEY1×biomass yield (Mg ha⁻¹)</td>
<td>L ha⁻¹</td>
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**5-carbon sugars**

<table>
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<th>Reference and Constituents Used</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td><strong>Method 2</strong></td>
<td>Dien et al. (2010)</td>
<td></td>
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<tr>
<td><strong>Method 3</strong></td>
<td>Dien et al. (2010)</td>
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## Prediction of Theoretical Ethanol Yield (TEY) and Production (TEP)

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<td>TEP1</td>
<td>TEY1×biomass yield (Mg ha⁻¹)</td>
<td>L ha⁻¹</td>
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Theoretical Ethanol Yield and Production

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>C6&lt;sup&gt;a&lt;/sup&gt;</th>
<th>C5</th>
<th>TEY2</th>
<th>TEP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIR</td>
<td>235</td>
<td>183</td>
<td>420</td>
<td>13,274</td>
</tr>
<tr>
<td>Carthage</td>
<td>224</td>
<td>180</td>
<td>405</td>
<td>5,623</td>
</tr>
<tr>
<td>Shawnee</td>
<td>230</td>
<td>181</td>
<td>412</td>
<td>17,502</td>
</tr>
<tr>
<td>SE</td>
<td>2.4</td>
<td>2.5</td>
<td>4.3</td>
<td>3,476</td>
</tr>
</tbody>
</table>

<sup>a</sup> C6 is the theoretical yield of C6 sugars (in L Mg<sup>-1</sup>) and C5 is the theoretical yield of C5 sugars (in L Mg<sup>-1</sup>), while TEY2 and TEP2 are the theoretical ethanol yield and production (in L ha<sup>-1</sup>), respectively.
Switchgrass – Hampshire in 2016

Theoretical Ethanol Yield and Production

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>C6 (^{a})</th>
<th>C5</th>
<th>TEY2</th>
<th>TEP2</th>
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## Switchgrass vs Miscanthus – 2016

<table>
<thead>
<tr>
<th>Species</th>
<th>C6&lt;sup&gt;a&lt;/sup&gt;</th>
<th>C5</th>
<th>TEY2</th>
<th>TEP2</th>
</tr>
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<tbody>
<tr>
<td>Switchgrass</td>
<td>259</td>
<td>216</td>
<td>479</td>
<td>4,261</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>266</td>
<td>209</td>
<td>467</td>
<td>5,423</td>
</tr>
<tr>
<td>SE</td>
<td>1.6</td>
<td>2.6</td>
<td>0.27</td>
<td>581</td>
</tr>
</tbody>
</table>

<sup>a</sup> Values are theoretical ethanol yield and production, with units in liters per Mg for C6 and C5, and liters per hectare for TEY and TEP.
## Theoretical Ethanol Yield and Production

<table>
<thead>
<tr>
<th>Species</th>
<th>C6(^a)</th>
<th>C5</th>
<th>TEY2</th>
<th>TEP2</th>
<th>x biomass</th>
</tr>
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<td>216</td>
<td>479</td>
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\(^a\) C6: Carbon 6, C5: Carbon 5, TEY2: Total Ethanol Yield, TEP2: Total Ethanol Production
1. Differences in TEY
CIR > Shawnee, Carthage
Switchgrass > Miscanthus

2. Differences in TEP (x biomass)
Miscanthus > Switchgrass