Task 1. Estimating Biomass Feedstock Production Potential

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Objectives

- Estimate future biomass production potential based on an aggressive yield improvement program
  - **Economic Issues**
    - Feedstock cost/Mg for biorefinery economics
    - Producer profit and level of participation
  - **Resource Issues**
    - Land area for feedstock supply per plant
    - Carbon savings/sequestration
    - Fossil energy displacement/savings
    - Soil and ground water quality
    - Wildlife habitat
Research Strategy

• Evaluate 7 decades of breeding gains in corn to establish yield gain potential

• Project switchgrass yield gain trajectory
  - 10 y of yield baseline evaluation in the field
  - Comparative genetics and physiology
  - 10 y of switchgrass breeding research
Some Advantages of Dedicated Energy Crops

• Feedstock quality/consistency/dependability
• Regional diversity of sites and participants
• Significant benefits to the agricultural industry
• Strong societal benefits
  – Net fossil energy displacement
  – Greenhouse gas reduction rate
  – Farm economy/government subsidy gains
Attributes of Switchgrass
- Native perennial grass - Farm-compatible - High yield and energy efficiency - Ecological and economic gains for agriculture
Switchgrass can significantly improve soil quality, stability, while storing soil carbon.
Analytical Resources

- **Field Research** - >10 Years of switchgrass productivity, breeding, and ecological research and development

- **ALMANAC** - A physiologically-based crop production model parameterized for switchgrass

- **POLYSYS** - A regional econometric model to project feedstock supply, economics, and impacts on conventional crop production
ARS-NRDC Plant Materials Testing Centers - Variety Evaluation
Modeling Crop Production Levels and Impacts

• ALMANAC
  – Crop production and resource use
  – Canopy light interception
  – Soil depth, water, and nutrient supply
  – Site specific radiation, rainfall, and temperature

• POLYSYS
  – Econometric model for agricultural policy
  – Competitive profit/land among crops
  – 305 regional supply districts
  – Includes production levels costs and govt. subsidy impacts.
## ALMANAC Yield Comparisons with Field Data

<table>
<thead>
<tr>
<th>SITE</th>
<th>Conditions</th>
<th>Field Yield (Mg/ha)</th>
<th>ALMANAC Yield (Mg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blacksburg, VA</td>
<td>6 yr avg.</td>
<td>12.3</td>
<td>12.0</td>
</tr>
<tr>
<td>Meade, NE</td>
<td>2 yr avg.</td>
<td>13.4</td>
<td>13.8</td>
</tr>
<tr>
<td>Beeville, TX</td>
<td>1993 2 cut</td>
<td>11.8</td>
<td>11.7</td>
</tr>
<tr>
<td></td>
<td>1994 2 cut</td>
<td>16.7</td>
<td>15.7</td>
</tr>
<tr>
<td></td>
<td>1993 1 cut</td>
<td>13.6</td>
<td>13.6</td>
</tr>
<tr>
<td></td>
<td>1994 2 cut</td>
<td>18.0</td>
<td>10.2</td>
</tr>
<tr>
<td>Tallasee, AL</td>
<td>9 yr avg. 2 cut</td>
<td>10.5</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td>9 yr avg. 1 cut</td>
<td>10.1</td>
<td>10.2</td>
</tr>
</tbody>
</table>
Simulated Annual Yield of Corn and Switchgrass Using ALMANAC
6 States, 27 Soil Types, 13 Years

![Graph showing simulated corn yields compared to actual corn yields. The x-axis represents actual corn yields (Mg/ha/y), and the y-axis represents simulated corn yields (Mg/ha/y) and switchgrass to corn yield ratio. The graph includes points for CornSim and SWG/CORN YIELD.](image-url)
ALMANAC - Changes in N Loss and Erosion In Conversion of Corn to Switchgrass

- Runoff
- Groundwater
- Subsurface Flow
- Total N Loss
- Erosion

Annual N and Soil Loss

Corn
Switchgrass
POLYSYS Projections - Potential switchgrass production density within the U.S. by agricultural supply cells. Distribution and density based on conversion to switchgrass production at a farmgate price of $44 Mg⁻¹ ($55 Mg⁻¹ delivered).
Projected gains to agriculture from POLYSYS simulations of switchgrass farmgate prices

<table>
<thead>
<tr>
<th>Farmgate Price ($/Mg)</th>
<th>30.3</th>
<th>44.0</th>
<th>52.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>M of hectares Planted to switchgrass</td>
<td>3.1</td>
<td>16.8</td>
<td>21.3</td>
</tr>
<tr>
<td>Increased farm revenue ($ M)</td>
<td>1311</td>
<td>5925</td>
<td>7745</td>
</tr>
<tr>
<td>Reduced govt. Subsidies ($ M)</td>
<td>1253</td>
<td>4035</td>
<td>5770</td>
</tr>
<tr>
<td>Sum of Benefits ($ B)</td>
<td>2.5</td>
<td>9.9</td>
<td>13.4</td>
</tr>
</tbody>
</table>
What have we learned from 70 years of corn breeding?

- Breeding gains have been approximately linear over time. 5-6X gain in 60 y
- Relative gains have decreased over time
- Improved management contributed ca. 45%
- Physiological efficiency has improved with yield
Comparative Traits of Corn and Switchgrass

**Corn**
- C4 annual grass
- Yield potential (grain)
  - 25 Mg/ha - theoretical
  - 15-20 Mg/ha - actual field
  - 5-6 Mg/ha – US commercial
- Yield Gains
  - 3-6%/y 1930’s
  - 1.3-1.8%/y 1990’s

**Switchgrass**
- C4 perennial grass
- Yield Potential (plant)
  - 47 Mg/ha(max plant), 51.6 Mg/ha (Model)
  - 16-22 Mg/ha actual field
- Commercial?
- Yield Gains (recent)
  - 5-7%/y Southeast
  - 1-2%/y Midwest
Aggressive R&D

Current

~11 Mg/ha

(@ given site)

Site Variability

Further R&D

20 to 30 yrs

~22 Mg/ha

Economic factors

Economic factors

Site Variability

Continued Increases
Implications for a 5000Mg/d Biorefinery of 22 Mg/ha vs 11 Mg/ha yield

- Feedstock supply area per facility decreases by 50%
- Maximum feedstock transport distance for 10% land area use decreases from 44mi to 31.2 mi
- With subsidy recycle, feedstock cost could decrease by more than $25 /Mg
Additional Analytical Tasks

- Distribution of potential switchgrass production acreage at increased yields
- Sensitivity of price and profit to yield
- Sensitivity of yield/supply area to climate
- Changes in farm income and government price supports at higher yields/profitability
- Ecological issues - N and water use, C storage, wildlife edge increases
## Estimating Future Switchgrass Yields (Mg/ha)

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.6</td>
<td>ALMANAC theoretical</td>
</tr>
<tr>
<td>47</td>
<td>Maximum single plant – unwatered nursery</td>
</tr>
<tr>
<td>34</td>
<td>Best small plot – single year</td>
</tr>
<tr>
<td>15-22</td>
<td>**Projected field-scale yield in 20y ***</td>
</tr>
<tr>
<td>22</td>
<td>Typical best small plot each year for each of 3 regions in SE/SC</td>
</tr>
<tr>
<td>15</td>
<td>Current regional small plot average</td>
</tr>
<tr>
<td>9.4</td>
<td>POLYSYS average US at $44/Mg  ($53.8 delivered)</td>
</tr>
<tr>
<td>11.1</td>
<td>““ at $30.3/Mg ($37.3 delivered)</td>
</tr>
<tr>
<td>9-22</td>
<td>Current range - - - field-scale</td>
</tr>
</tbody>
</table>
Simulating Corn and Switchgrass Yields with ALMANAC

Simulated Annual Yield of Corn and Switchgrass Using ALMANAC
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Actual Corn Yields (Mg/ha/y)

Simulated Corn and Switchgrass Yields (Mg/ha/y)

- CornSim
- SWGSim
Economic Implications of Yield Improvement
- 10 Y POLYSYS run - Feedstock price $40/Mg-

- Yield Gain - 11.1 > 14.8 Mg/ha  + 34%
- Hectares planted - 9.3 > 12.3Mha  + 21%
- Net gain in farm income - $1.2B
- Reduced Govt support needs - $2.23B
- Potential price credit - $24.7/Mg
- Total gain (income + govt support savings) Vs. conventional crops $8.22B/Y