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An Alfalfa Biomass System

- CO₂
- Manure
- Leaves
- Stems
- Soil
- Ash
- N₂
ETHANOL FROM CORN

Dry Milling Process

Grain

↓

Grind, Enzyme Digestion

↓

Sugars

↓

Yeast, Distillation

↓

Distillers Grains

↓

ETHANOL
ETHANOL FROM CELLULOSIC BIOMASS

Leaves (alfalfa) → Stover, Stems

Grind, Chemical Pre-Treatment, Enzyme Digestion

Sugars → Microbes, Distillation

ETHANOL → Residue
Sources of Fermentable Sugars in Biomass

- Simple sugars (sucrose)
  * Sugarcane, sweet sorghum, sugar beets

- Storage polysaccharides (starch)
  * Corn, cereal grains, potatoes

- Cell wall (dietary fiber) polysaccharides (cellulose, hemicellulose, and pectin)
  * Crop residues, switchgrass, alfalfa stems, wood
Carbohydrate Composition of Bioenergy Feedstocks

- Sugars
- Starch
- Cell Wall

Corn Grain: 80% Sugars, 70% Starch, 8% Cell Wall
Switchgrass: 60% Sugars, 60% Starch, 18% Cell Wall
Alfalfa Stems: 50% Sugars, 50% Starch, 15% Cell Wall

Concentration (% DM)
Cell Wall Composition of Cellulosic Feedstocks

- **Corn Stover**
- **Switchgrass**
- **Alfalfa Stems**

**Concentration (% DM)**

- **Hexose**
- **Pentose**
- **Other**
- **Lignin**
Theoretical Ethanol Yield*

* Based on NREL Calculator.
Cellulosic Biomass to Fermentable Sugars

- Grind
- Pretreatment to Remove Inhibitors
- Enzymatic Breakdown of Polysaccharides
- Sugar Recovery
  - Electricity & Processing Heat
  - Residual Solids
  - Fermentation
  - Product Recovery
Efficiency of Pentose Sugar Release by Dilute Acid Pre-Treatment

Efficiency of Glucose Release by Dilute Acid/Cellulase Treatment


Efficiency of Glucose Release (%)

- Immature
- Mature

Species:
- Alfalfa
- Reed canarygrass
- Switchgrass

Efficiency of Glucose Release vs. Lignin Concentration

Modified pretreatment conditions can improve alfalfa conversion efficiency.

How Does Alfalfa Compare for Ethanol Yield per Acre?

*Minnesota Example*

- Corn yield (5-year average) was 3.8 ton of grain/acre (stover yield approximately equal).
- Soybean yield was 1.1 ton/acre.
- Alfalfa hay yield was 3.4 ton/acre (leaf fraction 40 to 60%).
- All other (grass) hay yield was 1.7 ton/acre.
# Theoretical Ethanol Yield

*Minnesota Example*

<table>
<thead>
<tr>
<th>Species</th>
<th>Feedstock</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Primary</td>
<td>Byproducts</td>
<td>Protein</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gal/Acre</td>
<td>Tons/Acre</td>
<td>Tons/Acre</td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td>137</td>
<td>65</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>Corn (grain)</td>
<td>473</td>
<td>62</td>
<td>0.34</td>
<td></td>
</tr>
<tr>
<td>Corn (½ stover)</td>
<td>174</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Soybeans</td>
<td>80*</td>
<td>53</td>
<td>0.42</td>
<td></td>
</tr>
</tbody>
</table>

* Ethanol energy equivalent of biodiesel.
# Theoretical Yields

## Current Cropping Systems

<table>
<thead>
<tr>
<th>Species</th>
<th>Corn</th>
<th>Alternate</th>
<th>Total</th>
<th>Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn/Soybean (alternate years)</td>
<td>324</td>
<td>40</td>
<td>364</td>
<td>0.38</td>
</tr>
<tr>
<td>Continuous Corn (5% yield loss)</td>
<td>616</td>
<td>0</td>
<td>616</td>
<td>0.32</td>
</tr>
<tr>
<td>Corn/Alfalfa (5% yield boost)</td>
<td>340</td>
<td>69</td>
<td>409</td>
<td>0.42</td>
</tr>
</tbody>
</table>
Future Improvements of Alfalfa Biomass Production

• Develop alfalfa germplasm with greater yield, better ethanol production traits (less lignin, more cellulose), and new byproducts.

• Develop alfalfa management systems that enhance yield, improve ethanol conversion traits, and/or reduce input costs.

• Develop cropping systems that utilize yield potential of corn and environmental benefits of alfalfa.
Biomass-Type Alfalfa

*Developed by USDA-ARS*

Traits Incorporated:
- Large, lodging resistant stems
- Maintenance of leaf yield
- Winter hardiness
- Disease/Pest resistance
  - Root rot
  - Leaf hopper
Alfalfa Biomass Production Practices

First Production Year Stand

Modify production practices to maximize both leaf and stem yield.

**Bigger Plants:** Decrease stand density to give plants more room to grow.

**More Stem Biomass:** Delay harvest from early bud stage to late flower/green pod stage to get longer stems. Lodging increases at later maturities.

Traditional 42 plants/ft²  Biomass 17 plants/ft²

Full Bloom Maturity Stage

**Dairy Hay-Type**  **Biomass-Type**
Biomass-Type Alfalfa + Biomass Management Doubles Ethanol Yield

Production System

What is Alfalfa Leaf Meal Worth?

• Price will depend on availability of alternative protein feeds, concentration of protein in ALM, amino acid profile, and consistency of ALM product.

• Price modifiers include:
  – Non-protein nutrients
  – Handling issues
  – Carcass quality
  – Manure issues
## Prices for Protein Feeds*

<table>
<thead>
<tr>
<th>Feed</th>
<th>Protein % DM</th>
<th>Price $/Ton</th>
<th>Price ¢/Lb. Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDGS</td>
<td>30</td>
<td>110</td>
<td>18</td>
</tr>
<tr>
<td>SBM</td>
<td>50</td>
<td>222</td>
<td>22</td>
</tr>
<tr>
<td>MBM</td>
<td>54</td>
<td>270</td>
<td>25</td>
</tr>
<tr>
<td>CGM</td>
<td>65</td>
<td>398</td>
<td>31</td>
</tr>
<tr>
<td>BM</td>
<td>96</td>
<td>725</td>
<td>38</td>
</tr>
</tbody>
</table>

* Feedstuffs July 16, 2007
## Nutrient Composition of Alfalfa Leaf Meal and Other Major Ingredients

<table>
<thead>
<tr>
<th>Feed</th>
<th>Protein</th>
<th>Fiber</th>
<th>Fat</th>
<th>Calcium</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALM*</td>
<td>28</td>
<td>34</td>
<td>2.8</td>
<td>2.47</td>
<td>0.34</td>
</tr>
<tr>
<td>DDGS**</td>
<td>30</td>
<td>39</td>
<td>10.0</td>
<td>0.22</td>
<td>0.83</td>
</tr>
<tr>
<td>SBM**</td>
<td>50</td>
<td>15</td>
<td>1.6</td>
<td>0.40</td>
<td>0.71</td>
</tr>
<tr>
<td>Corn**</td>
<td>9</td>
<td>10</td>
<td>4.2</td>
<td>0.04</td>
<td>0.30</td>
</tr>
</tbody>
</table>


** NRC. 2001.
Livestock Response to Feeding Alfalfa Leaf Meal

• Successfully replaced SBM as a protein source for calves, lactating dairy cows, and feedlot steers.
• Successfully replaced up to half the alfalfa hay in lactating dairy cow diets.
• Better feed intake and weight gain of feedlot steers.
• May reduce incidence of liver abscess in feedlot steers at slaughter.

Summary

• Alfalfa stems can serve as a cellulosic ethanol or gasification feedstock.
  – Conversion processes must be optimized for alfalfa
• Alfalfa leaf meal is a useful feed for livestock.
  – Acceptance will require a large, dependable supply and demonstrated livestock performance
• Bioenergy and protein yield per acre is greater for an alfalfa/corn rotation than from a soybean/corn cropping system.
  – Alfalfa’s environmental and economic benefits must off-set the yield advantage of continuous corn
Summary

• Genetic improvement of alfalfa and modified management practices can increase alfalfa productivity in bioenergy systems.
  – *Yield will be the driving variable in the near term*
  – *Modified alfalfa cell walls can increase system efficiency in the long term*
  – *Alfalfa leaves can be used as a factory for production of industrial products (enzymes, bio-degradable plastic, pharmaceuticals, etc.)*
Tomorrow’s Alfalfa – Not Just for Cows!