ENERGY USE IN AGRICULTURE

Production Agriculture uses 1.2% of all US Energy
ENERGY USE IN US PRODUCTION AGRICULTURE, 1974

Energy in Trillions of BTU

- Field Machinery
- Transportation
- Irrigation
- Livestock
- Crop Drying
- Pesticides
- Fertilizers
## ENERGY USE BY ENTERPRISE

<table>
<thead>
<tr>
<th>Enterprise</th>
<th>Field Operations (Gal/A)</th>
<th>Fertilizers and Pesticides (Gal/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Grain</td>
<td>26.5</td>
<td>28.0</td>
</tr>
<tr>
<td>Soybeans</td>
<td>13.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Winter Wheat</td>
<td>11.7</td>
<td>9.9</td>
</tr>
<tr>
<td>Alfalfa (Hay)</td>
<td>30.0</td>
<td>10.6</td>
</tr>
<tr>
<td>Vegetables (Fresh)</td>
<td>62.4</td>
<td>43.8</td>
</tr>
<tr>
<td>Potatoes</td>
<td>59.7</td>
<td>94.4</td>
</tr>
<tr>
<td>Sugar Beets</td>
<td>48.8</td>
<td>39.7</td>
</tr>
<tr>
<td>Oats</td>
<td>7.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Grapes</td>
<td>58.0</td>
<td>30.4</td>
</tr>
<tr>
<td>Dry edible beans</td>
<td>33.1</td>
<td>14.8</td>
</tr>
</tbody>
</table>

## ENERGY FOR FIELD OPERATIONS, MI

<table>
<thead>
<tr>
<th>OPERATION</th>
<th>Diesel Fuel (Gal/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tillage</strong></td>
<td></td>
</tr>
<tr>
<td>Moldboard plow</td>
<td>1.80</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>1.35</td>
</tr>
<tr>
<td>Roller or packer</td>
<td>0.85</td>
</tr>
<tr>
<td>Field cultivator</td>
<td>0.77</td>
</tr>
<tr>
<td>Disk</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>Cultivation</strong></td>
<td></td>
</tr>
<tr>
<td>Cultivator</td>
<td>0.39</td>
</tr>
<tr>
<td>Rotary hoe</td>
<td>0.22</td>
</tr>
<tr>
<td><strong>Fertilizer and chemical application</strong></td>
<td></td>
</tr>
<tr>
<td>Fertilizer spreader</td>
<td>0.29</td>
</tr>
<tr>
<td>Knife in anhydrous</td>
<td>0.57</td>
</tr>
<tr>
<td>Sprayer</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Planting</strong></td>
<td></td>
</tr>
<tr>
<td>Row crop planter</td>
<td>0.51</td>
</tr>
<tr>
<td>Drill</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>Harvest</strong></td>
<td></td>
</tr>
<tr>
<td>Mower/conditioner</td>
<td>0.67</td>
</tr>
<tr>
<td>Bale Hay</td>
<td>0.65</td>
</tr>
<tr>
<td>Combine or picker</td>
<td>1.49</td>
</tr>
<tr>
<td>Green Chopping</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply

April 2005
Figure 2: Summary of biomass resource consumption

- Forestlands and agricultural lands contribute 190 million dry tons of biomass - 3% of America's current energy consumption.

Source: EIA, 2004a & b

<table>
<thead>
<tr>
<th>Biomass Consumption</th>
<th>Million dry tons/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest products industry</td>
<td></td>
</tr>
<tr>
<td>Wood residues</td>
<td>44</td>
</tr>
<tr>
<td>Pulping liquors</td>
<td>52</td>
</tr>
<tr>
<td>Urban wood and food &amp; other process residues</td>
<td>35</td>
</tr>
<tr>
<td>Fuelwood (residential/commercial &amp; electric utilities)</td>
<td>35</td>
</tr>
<tr>
<td>Biofuels</td>
<td>18</td>
</tr>
<tr>
<td>Bioproducts</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>190</strong></td>
</tr>
</tbody>
</table>
Figure 17: Current availability of biomass from agricultural lands

- The total current availability of biomass from cropland is approximately 191 million dry tons/year.
- Slightly more than one-fifth of this biomass is currently used.
- Corn stover is a major untapped source of agriculture-derived biomass.
- Small grain residues include sorghum, barley, oats, and rice. Other crop residues include cotton, other oil seeds (e.g., sunflower, peanuts, canola), tobacco, sugar crops, potatoes, beans, miscellaneous root crops, and double crops. Other residues include secondary agricultural processing residues, MSW, and fats and greases.
Total availability of biomass from cropland, idle cropland, and cropland pasture ranges from 581 to 998 million dry tons per year at crop yield increases of 25% (moderate) and 50% (high) for corn and various rates for other crops. Changes in tillage practices, residue to grain and seed ratios, and residue collection technology and equipment are also assumed. (Quantities shown do not add to 581 million dry tons due to rounding.)

The allocation of some active cropland, idle cropland, and cropland pasture to perennial crops is required to attain this level of annual biomass production.

Small grain residues include sorghum, barley, oats, and rice. Other crop residues include cotton, other oil seeds (e.g., sunflower, peanuts, canola), tobacco, sugar crops, potatoes, beans, miscellaneous root crops, and double crops. Other residues include secondary agricultural processing residues, MSW, and fats and greases.

©2005 Billion-Ton Annual Supply
Energy Content/Conversion
Figure 1. Comparison of as-fired energy densities of fuels evaluated at Penn State.
## Feedstock Survey: Sugar Released by Acid Pretreatment followed by Enzymatic Hydrolysis

### Recovered Sugars (measured by HPLC after acid + enzyme treatment)

<table>
<thead>
<tr>
<th>Feed Stock</th>
<th>Glucose (g/Kg)</th>
<th>Xylose (g/Kg)</th>
<th>Galactose (g/Kg)</th>
<th>Arabinose (g/Kg)</th>
<th>Fructose + Mannose [1] (g/Kg)</th>
<th>Total Sugars (g/Kg)</th>
<th>Ash (g/Kg)</th>
<th>Sugars [3] kg/mt DW</th>
<th>Ethanol [4] gal/T DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arundo donax</td>
<td>316</td>
<td>171</td>
<td>45</td>
<td>36</td>
<td>8</td>
<td>576</td>
<td>61</td>
<td>576</td>
<td>82.8</td>
</tr>
<tr>
<td>Elephant Grass</td>
<td>336</td>
<td>164</td>
<td>40</td>
<td>39</td>
<td>7</td>
<td>585</td>
<td>86</td>
<td>585</td>
<td>83.7</td>
</tr>
<tr>
<td>Energy Canees</td>
<td>362</td>
<td>183</td>
<td>44</td>
<td>40</td>
<td>11</td>
<td>641</td>
<td>65</td>
<td>641</td>
<td>91.9</td>
</tr>
<tr>
<td>Erianthus</td>
<td>344</td>
<td>189</td>
<td>47</td>
<td>42</td>
<td>8</td>
<td>631</td>
<td>63</td>
<td>631</td>
<td>90.0</td>
</tr>
<tr>
<td>Miscanthus giganteus</td>
<td>365</td>
<td>201</td>
<td>42</td>
<td>42</td>
<td>5</td>
<td>655</td>
<td>61</td>
<td>655</td>
<td>93.7</td>
</tr>
<tr>
<td>Switch Grass</td>
<td>324</td>
<td>183</td>
<td>40</td>
<td>50</td>
<td>32</td>
<td>629</td>
<td>50</td>
<td>629</td>
<td>90.0</td>
</tr>
<tr>
<td>Cane Bagasse</td>
<td>425</td>
<td>233</td>
<td>31</td>
<td>33</td>
<td>2</td>
<td>724</td>
<td>30</td>
<td>724</td>
<td>103.7</td>
</tr>
<tr>
<td>Sw Sorghum Bagasse</td>
<td>420</td>
<td>186</td>
<td>35</td>
<td>48</td>
<td>18</td>
<td>706</td>
<td>52</td>
<td>706</td>
<td>101.0</td>
</tr>
<tr>
<td>Tropical Corn Bagasse</td>
<td>409</td>
<td>172</td>
<td>45</td>
<td>43</td>
<td>11</td>
<td>681</td>
<td>52</td>
<td>681</td>
<td>97.3</td>
</tr>
<tr>
<td>Avg All Feed Stocks</td>
<td>367</td>
<td>187</td>
<td>41</td>
<td>41</td>
<td>11</td>
<td>648</td>
<td>58</td>
<td>648</td>
<td>91.0</td>
</tr>
</tbody>
</table>

[1] Mannose co-elutes with arabinose. A small amount of mannose may be present.

[2] Peak eluting at fructose retention time (Rt) may include unidentified sugars and/or fructose derived from polymer hydrolysis.

Most free fructose is destroyed during the hemicellulose hydrolysis procedure (145º C, 1h, 2% phosphoric acid).

3 - 90% efficiency conversion from biomass to sugars

4 - 60% efficiency conversion of sugars to ethanol

Ingram & Peterson, UF
# Energy Output/Input Ratio

<table>
<thead>
<tr>
<th>CROP</th>
<th>RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Ethanol</td>
<td>1.3:1</td>
</tr>
<tr>
<td>Soybean Biodiesel</td>
<td>3:1</td>
</tr>
<tr>
<td>Sweet Sorghum (sugar)</td>
<td>3-6:1</td>
</tr>
<tr>
<td>Sugarcane (sugar)</td>
<td>8:1</td>
</tr>
<tr>
<td>Switchgrass (heat)</td>
<td>13:1</td>
</tr>
<tr>
<td>Algae/Palm Oil (Tropics)</td>
<td>VH</td>
</tr>
</tbody>
</table>
Saving Fuel in Field Operations

- Reduce Tillage Trips
- Reduce Tillage Depth
- Optimize Wheel Slip
- Gear Up/Throttle Down
- Combine Operations
- Match Implement to Tractor Size
- Service Regularly
<table>
<thead>
<tr>
<th>Tillage Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>DIESEL FUEL GAL/Å</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>PLOW</strong></td>
</tr>
<tr>
<td><strong>DISC</strong></td>
</tr>
<tr>
<td><strong>DISC</strong></td>
</tr>
<tr>
<td><strong>DRAG</strong></td>
</tr>
<tr>
<td><strong>PLANT</strong></td>
</tr>
<tr>
<td><strong>SPRAY</strong></td>
</tr>
<tr>
<td>5.1</td>
</tr>
</tbody>
</table>
SECONDARY TILLAGE (1/2 depth)

PRIMARY TILLAGE
Optimize Wheel Slippage

10-15%
WRONG  RIGHT  WRONG
GEAR UP
THROTTLE DOWN
Properly Adjust Machinery
COMBINE OPERATIONS
Match Implement to Tractor Size
Match Implement to Tractor Size
Service Equipment Regularly
• N uses 80% of all Fertilizer Energy
• 1 gallon fuel equivalent to make 6 lbs N.
• Fertilizer Efficiency
  – Soil Test
  – N timing to crop needs
  – PSNT
  – Manures
  – Legumes
Pesticide Energy

• High Energy/Unit
• Low Energy/Acre
• Use IPM
• Herbicides = Cultivation
Conversion Systems for Biomass Energy
Direct Combustion
Energy from Combustion

• High Heating Value = heat obtained from burning all combustible contents and capturing heat
• Low Heating Value = HHV minus the latent heat of vaporization (steam expelled)
• HHV (kJ/kg) = 35160 C + 116225 H
  - 11090 O + 6280 N + 10465 S

Ash and Water decrease Heating Value !!!
Moisture Effect on Gross Energy

Moisture Effect on Gross Energy

Energy Value (Btu.lb) vs % Dry Matter

The graph shows the relationship between the energy value (Btu/lb) and the percentage of dry matter. The energy value increases significantly as the percentage of dry matter increases.
Combustion Boilers/Furnaces

- Grate firing
- Fluidized bed firing
- Pulverized fuel firing

- Fixed bed
- Bubbling bed
- Circulating bed
- Pneumatic transport

www.answers.com/topic/fluidized-bed-combustion
Traveling Grate
There are multiple pathways to create transportation fuels from biomass.

**Feedstock**
- Lignocellulosic feedstocks; solid wastes
- Sugar & Starches
- Other wastes
- Bio-oils (incl. waste oils & greases)

**Conversion & Refining**
- Gasification + syngas processing
- Pyrolysis & upgrading
- Liquefaction
- Dilute acid hydrolysis
- Fermentation of sugars
- Saccharification + fermentation
- Anaerobic digestion, cleaning, separation
- Trans-esterification or hydrogenation

**Primary Energy Products**
- Fischer-Tropsch liquids
- Mixed alcohols
- DME
- Ethanol
- Methanol
- Hydrogen
- Upgraded bio-oils
- MeTHF
- Esters
- Ethanol
- Butanol
- CNG
- LNG
- Hydrogen (via reforming)
- Biodiesel
- Renewable diesel

1. Via catalytic synthesis. 2. Dimethyl ether. 3. Via syngas fermentation or catalytic synthesis. 4. Pyrolysis oils require substantial upgrading before they can be used for transportation applications, and this processing is difficult. 5. Also includes direct microbial conversion of sunlight to hydrogen.
Thermochemical Conversions

Gasification = burn in low oxygen
Pyrolysis = burn in no oxygen
Produce Syngas
Gasifier

Input

Own Gas and $O_2$

Own Gas and $O_2$

Raw Gas

$O_2$

$O_2$

Metal Slag

F.Wuchert, KBI Group, GMBH--Wikipedia
Conversion Equations

\[
\begin{align*}
C + \frac{1}{2}O_2 & \rightarrow CO \\
C + H_2O & \rightarrow H_2 + CO \\
CO + H_2O & \leftrightarrow CO_2 + H_2
\end{align*}
\]

Dry Biomass + Heat(1000C+) \rightarrow Char + CO2 + CO + H2 + H2O + Tar
**Biomass Pyrolysis** – produces a gas that burns like natural gas, liquid fuel oil and char. **Char** has recently received much attention for its crop enhancing properties and its ability to sequester carbon in the soil.
Fermentation to Ethanol

Starch/Sugar
Cellulosic
Starch and Sugar
Wet Milling Process
Ethanol Conversion Process

- Starch (Amylose and Amylopectin) → Glucose
  Amylase + Heat

Glucose → Carbon Dioxide and Ethanol (H2O)
Sacc. Yeast

NOTE: 14 lbs of Sugar = 1 gallon Ethanol
Sugarcane and Sweet Sorghum juices use second step only
Cellulosic Ethanol
**Structure of lignocellulose.** The main component of lignocellulose is cellulose, a β(1-4)-linked chain of glucose molecules. Hydrogen bonds between different layers of the polysaccharides contribute to the resistance of crystalline cellulose to degradation. Hemicellulose, the second most abundant component of lignocellulose, is composed of various 5- and 6-carbon sugars such as arabinose, galactose, glucose, mannose and xylose. Lignin is composed of three major phenolic components, namely p-coumaryl alcohol (H), coniferyl alcohol (G) and sinapyl alcohol (S). Lignin is synthesized by polymerization of these components and their ratio within the polymer varies between different plants, wood tissues and cell wall layers. Cellulose, hemicellulose and lignin form structures called microfibrils, which are organized into macrofibrils that mediate structural stability in the plant cell wall.

*From Rubin, Nature 2008*
Typical process for cellulosic ethanol production.

1. Pulverized biomass
2. Hot acid treatment (hydrolyze hemicellulose and disrupt lignin)
3. Neutralize and separate
   - hydrolysate
     - fermentation
     - Ethanol
   - insolubles
     - Cellulase and glycosidases
     - Glucose
     - Fermentation
     - Ethanol
4. Major energy costs
Sugar & Starch Crops
Sweet Sorghum
SWEET SORGHUM

*Sorghum bicolor*

- C4, Tall (8-14 ft); Annual
- Production Similar to Corn
- Drought Tolerant/Lower N
- Plant May-June, Soil@60F, 30” rows, 4-5 plt/ft
- Public Varieties Available
- Pests Common
- Harvest Sept./Oct.@ Soft Dough
Tropical Corn
TROPICAL CORN
(Zea mays)

- Tall (10 ft+), Annual, Open Pollinated;
- Same as Hybrid Corn Production
- More Drought Tolerant
- More Nitrogen Efficient?
- Good Pest Tolerance
- Small Ear-Sweet Stalk
- Varieties-Synthetic-Not Available
Sugarbeet

http://www.cals.ncsu.edu/course/pp723/Aphanomycescochlioides/sugarbeet.jpg

Potatoes

- 4.bp.blogspot.com/.../s400/Holland_Potato.jpg
Fiber Crops
Small Grains
Energycanes (Tropical and Sub Tropical)
OIL CROPS
Soybean

1.4 Gal/Bu
Canola
Canola

- *Brassica campestris* – Rapeseed with low Erucic acid (also lower in glucosinalates);
- Mustard family - grown in cool climates mostly in Canada and N. Europe;
- Very small seed
- Seeded Fall or Spring w/Grain Drill
- Contains 40% Oil and 23% Protein;
- **100+ gallons biofuel/A**
Hazelnuts: *Corylus avellana*

100+ gallons/A
<table>
<thead>
<tr>
<th>Crop</th>
<th>%Oil Content</th>
<th>Gal/A</th>
<th>Years to Prod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>18-20</td>
<td>48</td>
<td>.33</td>
</tr>
<tr>
<td>Sunflower</td>
<td>25-45</td>
<td>102</td>
<td>.33</td>
</tr>
<tr>
<td>Jatropha</td>
<td>40-59</td>
<td>300</td>
<td>2-3</td>
</tr>
<tr>
<td>Oil Palm</td>
<td>40-70</td>
<td>760</td>
<td>3-8</td>
</tr>
<tr>
<td>Algae</td>
<td>10-85</td>
<td>10,000?</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

Adapted from Poteet, 2006
• Southern Energycanes
• Jatropha
• Algae
• Duckweed
• Sugarcane
• Sugarbeet?
The primary mission of the REI is to foster both fundamental (basic) and applied scientific research and policy components to develop sustainable energy production compatible with economic growth and environmental vitality.

www.rei.rutgers.edu
www.njaes.rutgers.edu/bioenergy
# Fuel Value @ $3/million Btu

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Net Heating Value</th>
<th>Cost/Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premium wood pellets</td>
<td>13.6 million Btu/ton</td>
<td>$40/ton</td>
</tr>
<tr>
<td>Propane</td>
<td>71,000 Btu/gal</td>
<td>$0.22/gal</td>
</tr>
<tr>
<td>Fuel oil #2</td>
<td>115,000 Btu/gal</td>
<td>$0.34/gal</td>
</tr>
<tr>
<td>Fuel oil #6</td>
<td>124,000 Btu/gal</td>
<td>$0.37/gal</td>
</tr>
<tr>
<td>Seasoned firewood</td>
<td>15.3 million Btu/cord</td>
<td>$46/cord</td>
</tr>
<tr>
<td>Ovendried switchgrass</td>
<td>14.4 million Btu/ton</td>
<td>$37/ton</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>26 million Btu/ton</td>
<td>$78/ton</td>
</tr>
<tr>
<td>Shelled corn @ 15% MC</td>
<td>314,000 Btu/bushel</td>
<td>$0.94/bushel</td>
</tr>
</tbody>
</table>
### Renewable Energy Source Comparisons

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Miles Driven/Acre/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Photovoltaics</td>
<td>2,250,000</td>
</tr>
<tr>
<td>Wind</td>
<td>180,000</td>
</tr>
<tr>
<td>Biodiesel (Algae)</td>
<td>370,000</td>
</tr>
<tr>
<td>Biodiesel (Palm Oil)</td>
<td>31,000</td>
</tr>
<tr>
<td>Biodiesel (Canola/Rape)</td>
<td>6,100</td>
</tr>
<tr>
<td>Biodiesel (Soybean)</td>
<td>2,400</td>
</tr>
<tr>
<td>Ethanol (Switchgrass)</td>
<td>32,500</td>
</tr>
<tr>
<td>Ethanol (Corn)</td>
<td>18,000</td>
</tr>
</tbody>
</table>

Theoretical Alcohol Yields of Selected Raw Materials

Yield at 200 Proof (Gal/T)

Material

- Corn
- Grain sorghum
- Mandioc, cassava
- Molasses, beet
- Molasses, cane
- Potatoes
- Potatoes, dried
- Rice
- Sugar beet
- Sugarcane
- Wheat
THE END
Gasifier

(a) The earlier design (World War II class)

(b) The recent design