An energy and economic analysis of energy crops processing into bioethanol as a gasoline substitute

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What is better to grow? Food commodities or energy carriers?

- Cane-like crops:
  - Energy cane
  - Sweet sorghum
- As energy carriers

- As food commodity

Farmers

Sugar cane

Processing

Electricity

Fuel (Bioethanol)

Market price

Sugar

Market price

$/Tonne=56

in 2011/2012 in Louisiana

$/Tonne=?

Farmers
General chemistry of commodity sugar and bioethanol production from cane-like crops

Stems

Cutting and pressing

Bagasse

Juice

Moisture

Fiber

Solution of **sugars** in water

Cellulose

Hemicellulose

Lignin

Lignocellulosic pretreatment and hydrolysis

Reducing sugars: glucose, fructose, etc.

Fermentation

Ethanol

Sucrose

Separation

Commodity Sugar

Fermentation

Ethanol

Reducing sugars: glucose, fructose, etc.
A conceptual model for renewable electricity and biofuel production from cane-like crops

Technology is **renewable** because the only feedstock is biomass and **self-sufficient (sustainable)** because all energy demand is met by internally generated bagasse.

The role of bagasse is twofold: (i) it provides feedstock for lignocellulosic conversion; (ii) it serves as an energy carrier to generate electricity and steam to run the process.

During the harvesting season a concentrated solution of sugars (syrup) is manufactured to allow for sugars storage and continuous biofuel (bioethanol) production in a biorefinery.

Black arrows denote material streams and orange arrows denote energy streams (power and steam).
## Energy crops composition and yield


<table>
<thead>
<tr>
<th>Component</th>
<th>Sweet Sorghum (Dale, M81-E, Theis, and Topper)</th>
<th>Energy Cane (L79-1001(L))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose, %</td>
<td>6.9</td>
<td>7.2</td>
</tr>
<tr>
<td>Glucose and fructose, %</td>
<td>4.3</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Total sugars, %</strong></td>
<td><strong>11.2</strong></td>
<td><strong>8.3</strong></td>
</tr>
<tr>
<td>Ash</td>
<td>0.96</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Fiber, %</strong></td>
<td><strong>10.6</strong></td>
<td><strong>23.9</strong></td>
</tr>
<tr>
<td>Cellulose, %</td>
<td></td>
<td>44.6</td>
</tr>
<tr>
<td>Hemicellulose, %</td>
<td></td>
<td>27.1</td>
</tr>
<tr>
<td>Lignin, %</td>
<td></td>
<td>20.7</td>
</tr>
<tr>
<td>Ash, %</td>
<td></td>
<td>0.4</td>
</tr>
<tr>
<td><strong>Moisture, %</strong></td>
<td><strong>77.2</strong></td>
<td><strong>66.5</strong></td>
</tr>
<tr>
<td>Yield, tonne/acre-year</td>
<td><strong>22.1</strong></td>
<td><strong>36.8</strong></td>
</tr>
</tbody>
</table>

**Sugars (sweet sorghum) > Sugars (energy cane)**

**Fiber (sweet sorghum) < Fiber (energy cane)**

**Yield (sweet sorghum) < Yield (energy cane)**
1G (first generation) biofuel (bioethanol) production directly from sugars in juice vs. Power generation option
Bioethanol replaces gasoline proportionally its heating value

Breakeven prices of electricity for 1G bioethanol production from sweet sorghum and energy cane. Bioethanol replaces gasoline proportionally its heating value.

Interpretation
At gasoline price 3.5$/gal, if electricity price is 40 cents/kW-h, electricity generation is more economically reasonable;
at gasoline price 3.5$/gal, if electricity price is 25 cents/kW-h, bioethanol production is more economically reasonable;
at gasoline price 3.5$/gal, if electricity price is less than 35 cents/kW-h, bioethanol production is more economically reasonable.

For comparison, in 2009-2011 the average electricity price in US stayed around 9.8-9.9 cents/kW-h and gasoline price was increased from 2.4 to 3.4 $/gallon (U.S. Energy information administration).
2G (second generation) biofuel (bioethanol) production from bagasse vs. Power generation option

Breakeven prices of electricity for 2G bioethanol production from sweet sorghum and energy cane. Bioethanol replaces gasoline proportionally its heating value.

Interpretation
At gasoline price 3$/gal, if electricity price is 13 cents/kW-h electricity generation is more economically reasonable; at gasoline price 3$/gal if electricity price is 7 cents/kW-h bioethanol production is more economically reasonable; at gasoline price 3$/gal, if electricity price is less than 10 cents/kW-h bioethanol production is more economically reasonable.

An insignificant difference between sweet sorghum and energy cane is due to slightly different composition of their fibers (only cellulose and hemicellulose are converted into sugars).

For comparison, in 2009-2011 the average electricity price in US stayed around 9.8-9.9 cents/kW-h and gasoline price was increased from 2.4 to 3.4 $/gallon (U.S. Energy information administration).
Sweet sorghum, energy cane, fiber, and reducing sugars prices* for bioethanol production technology at the price of gasoline 3.6 $/gal (average regular pump price in 2012)

<table>
<thead>
<tr>
<th>Crops</th>
<th>Crops, $/tonne</th>
<th>Fiber, $/tonne</th>
<th>Sugars, $/tonne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet sorghum</td>
<td>30.0</td>
<td>68</td>
<td>204</td>
</tr>
<tr>
<td>Energy cane</td>
<td>33.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Those prices include a profit as well as expenses for growing, harvesting transportation and preliminary handling in the front-end plant.

The total production (accounting for yields) from the area of 50000 acres and land-use efficiency indicators for two crops and two different scenarios at the price of gasoline 3.6 $/gal

<table>
<thead>
<tr>
<th>Crops</th>
<th>Technology</th>
<th>Sugars, MMtonne/year</th>
<th>Gasoline equivalent, MMgal/year</th>
<th>Electricity, MW</th>
<th>Land-use efficiency**, $/acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet sorghum</td>
<td>1G+ electricity</td>
<td>0.122</td>
<td>12.3</td>
<td>3.82</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>1G + 2G</td>
<td>0.137</td>
<td>13.8</td>
<td>0.97*</td>
<td>663</td>
</tr>
<tr>
<td>Energy cane</td>
<td>1G+ electricity</td>
<td>0.152</td>
<td>15.3</td>
<td>39.7</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>1G + 2G</td>
<td>0.301</td>
<td>30.3</td>
<td>5.78*</td>
<td>1218</td>
</tr>
</tbody>
</table>

*Generated from lignin separated from reducing sugars

**Land-use efficiency indicator includes a profit as well as expenses for growing, transportation and preliminary handling in the front-end plant
CONCLUSION

- A cultivation of sweet sorghum and energy cane to produce bioethanol as a gasoline replacement at marginal lands, unsuitable for sugar cane, sounds economically feasible at the present price range for fuels and electricity in the U.S.

- The relative selling price of one tonne of energy cane for bioethanol production is higher than the same of sweet sorghum mostly because of a greater fiber and lower moisture content.

- Sugars in crops juice have value about three times higher than fiber; therefore, taking into account this proportion, an increase in sugars content at the expense of fiber could be the way to improve quality of energy cane varieties for bioethanol production.

- A greater yield of energy cane allows for increasing land-use efficiency for bioethanol production in about two times.