Plant Biotechnology and Cellulosic Ethanol Production

Neal Gutterson
It’s tough to make predictions…

…..especially about the future!
We’re in the early stage of a major change in the global economy.

1800 1900 2000 2100

Carbohydrate Economy

Fossil Fuel Economy

Renewable Economy

Cellophane developed; cellulose-derived, owned by…..DuPont
One of their 5 divisions in 1927 was…..Cellulose
Transportation energy use grows...

http://www.eia.doe.gov/emeu/aer/eh/frame.html

Need: Replace petroleum with other, renewable liquid transportation fuels.
...particularly in developing world
The Challenge:

- Produce large amounts of readily convertible biomass at high-enough yields to minimize any adverse impact on the global environment.

- Don’t replace one problem (CO₂ levels) with another problem (degradation of land; loss of biodiversity; etc.).
Inappropriate changes in land use patterns can exacerbate climate change


http://www.eia.doe.gov/oiaf/1605/ggccebro/chapter1.html
Humans appropriate large amounts of global net primary production

The solution: optimized feedstocks, & use of entire plant biomass

Optimal feedstock properties:

~ High Yield (>15 tons/acre/year)
  ~ 20% of 25 mi radius = 300M gal/year
~ Low Input (fertilizer, water, tillage, pesticides)
~ High conversion efficiency
~ Sustainable
~ Stable quality from year to year

Perennial crops are ideal feedstock crops
Benefits of perennials

For efficient use of land (see later), useful biomass production from received light energy must be maximized.

Minimizing environmental impact and maximizing environmental benefit suggests perennial crops, particularly rapid cycling trees and fast-growing grasses, as dominant crops for the cellulosic biofuel economy.

Includes:

- Leading candidate grasses include switchgrass and Miscanthus
- Leading candidate trees include eucalyptus, poplar and willow
Perennials maximize light and heat capture

![Graph showing PAR interception (%) for different plants over Julian day 1993. The graph includes lines for *Miscanthus x giganteus*, *Zea mays*, and *Spartina cynosuroides*. The x-axis represents Julian day 1993, and the y-axis represents PAR interception (%).]
### US 2nd generation grass alternatives

<table>
<thead>
<tr>
<th>Crop</th>
<th>Product Attributes</th>
<th>Yield (t/acre)</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage Sorghum</td>
<td>Photoperiod sensitive tall, thick stem and/or short, small stem, BMR</td>
<td>10 -- SE</td>
<td>MW marginal/ SP/ SE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 -- SP/MW</td>
<td></td>
</tr>
<tr>
<td>Sweet sorghum</td>
<td>Non-cellulosic, combine with grain process</td>
<td>25 wet</td>
<td>Upper gulf coast</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>Seed propagated high biomass</td>
<td>10-15 (SE)</td>
<td>MW/ SE</td>
</tr>
<tr>
<td>Miscane</td>
<td>Mis/sugar cane cross, cold tolerant, 4-6 m height</td>
<td>10-15, seed propagated</td>
<td>Upper SE</td>
</tr>
<tr>
<td>Energy Cane</td>
<td>Biomass, low sugar</td>
<td>Same, costly propagation</td>
<td>SE/ S. TX</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>Perennial, seed propagated,</td>
<td>5 - 8</td>
<td>MW/ SE</td>
</tr>
</tbody>
</table>
Leading crop candidates largely “undeveloped”

Key lessons of first decade:
~ Biotechnology/genomics provides a platform for:
  ~ improved core genetics through use of dense marker maps;
  ~ biotech traits for enhanced value
~ Best demonstrated for com yield improvement

Improvement of perennial crops for cellulosic biofuel economy requires rapid adoption and application of these same tools:
~ Efficient development of dense genetic maps
~ Efficient, cost-effective development of informative markers for key traits
~ Deployment of biotech traits used in today’s crops in tomorrow’s biofuel crops
Tools to impact rapid domestication of new energy crops

- **High efficiency sequencing**
  - Lumina, 454, ABI
  - Marker ID
  - Dramatically reduces time to develop dense marker maps to accelerate marker-assisted breeding

- **Efficient transfer of developed traits**
  - Inherent yield (e.g., photosynthetic capacity)
  - Water use efficiency
  - Nutrient use efficiency
  - Drought tolerance
  - Disease resistance

Yield Stability
Mendel is pioneering rapid adoption of Miscanthus

Assembling the world’s leading germplasm collection
  ~ Establishing a world-class, advanced breeding program

Deploying biotech traits created through an extensive R&D program during our first decade
  ~ Corn is a good “model crop” for the energy grasses
  ~ Soybean is more closely related to the tree species
Mendel Miscanthus initial germplasm collection
Trials of wild Miscanthus accessions at Mendel China
Miscanthus embryogenic regeneration
Miscanthus transformed e-callus
High value biotech traits from corn

- Intrinsic yield (enhanced photosynthetic efficiency)
- Drought tolerance and water use efficiency
Yields of 2nd generation cellulosic crops can be improved substantially

Mass selection for large ears did not increase yield

Heterosis & replicated testing
Enhancing cell wall breakdown
Federal mandates for biofuels were increased late 2007.

Renewable Fuel Standard

Note: Cellulosic is a sub-category of advanced biofuel.
### Perennial grass production, bioenergy: long-term projection

<table>
<thead>
<tr>
<th>Crop</th>
<th>Acres</th>
<th>Region</th>
<th>Gal/Ac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>10 mm</td>
<td>Heartland</td>
<td>~415</td>
</tr>
<tr>
<td><strong>Corn (projected)</strong></td>
<td>30-35 mm</td>
<td>Heartland + NGP</td>
<td>~760</td>
</tr>
<tr>
<td>Grasses</td>
<td>50 mm</td>
<td>MP + EU + parts of SS</td>
<td>1,500</td>
</tr>
<tr>
<td><strong>Eucalyptus</strong></td>
<td>10-20 mm</td>
<td>Parts of SS</td>
<td>1,200</td>
</tr>
</tbody>
</table>
By the end of the third decade we will see....

- dedicated energy crops grown on over 50 mm acres in the U.S. alone (nearly 15% of arable land)
- over 250 mm acres globally (more than 10% of arable land)
- providing greater than 50% of liquid transportation fuels, and adequate food to feed 8 billion people
seeding a sustainable future

Genomics tools for advanced breeding and biotech traits will enable the rapid improvement of undeveloped grasses as feedstocks for future cellulosic industry