An ideal biomass crop has........

- C4 photosynthesis
- Wide Adaptation
- High Yield Potential with regrowth potential
- Water Use Efficiency
- Drought Tolerance
- Pest Resistance
- Good Crop Rotation
- Non competitive with food, feed systems

- Existing Agricultural Infrastructure
- Non-invasive
- Winter Standing
- Excellent Genetic Platform
- Composition
  - Starch, sugar, cellulose available
- Perennial Crop
# C4 Bioenergy Grasses for the Southern U.S.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Growth</th>
<th>Propagation</th>
<th>History</th>
<th>Biomass</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switchgrass</td>
<td>Perennial</td>
<td>Seed</td>
<td>None</td>
<td>Lignocellulose</td>
<td>Problems w/ seed prod. &amp; stand est.</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>Perennial</td>
<td>Cutting</td>
<td>Sugar</td>
<td>Sugar, Lignocellulose</td>
<td>cold sus. limits range</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>Perennial</td>
<td>Rhizomes</td>
<td>None</td>
<td>Lignocellulose</td>
<td>Propagation limited</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Annual</td>
<td>Seed</td>
<td>Grain, Forage</td>
<td>Sugar, Starch Lignocellulose</td>
<td>Drought tolerance</td>
</tr>
</tbody>
</table>

Source: UIUC  
Source: USDA NRCS  
Source: USDA NROS
Big Country, Many Environments, Multiple Bioenergy Crops (Source: Department of Energy)
Sorghum as a Bioenergy Feedstock

- Wide Adaptation
- High Yield Potential
- Water Use Efficiency and Drought Tolerance
- Existing Agricultural Infrastructure
- Multiple Types for Different Production
  - Sorghum is the only crop to produce sugar, starch and ligno-cellulosic biomass
- Genetic Platform is available
- Annual Crop
Bioenergy Sorghum

- Biomass Sorghum
- Grain Sorghum
- Sweet Sorghum
Sweet Sorghum

- Some Grain Yield
- Juicy Stalk
- Highest concentrations of soluble sugar
- Highly variable for
  - Maturities (photoperiod sensitivity)
  - Types of Sugar
  - Biomass and Sugar Yield
Biomass Sorghums

- Strongly PS
  - Do not flower
  - Long Canopy Duration
  - Enhanced Drought Tolerance
  - Higher Yields
- Structural Carbohydrates
  - Minimal Starch
  - Lower Sugar
Sorghum Improvement

- Grown as a Hybrid Crop
  - Seed Parent
  - Pollinator Parent
- Established methodologies applicable to all types of sorghum
- Genetic Diversity is the key
- Effective Phenotyping Critical
Sorghum Diversity
Texas A&M Agrilife Research Breeding

Exotic Sorghum

A/B – Lines (Seed Parents)  
R – Lines (Pollinator Parents)

Improvement

Good Energy Hybrids have 120 % High-Parent Heterosis

- Pedigree, Backcrossing, Population
- Winter nurseries – RGV, MX, PR
- Private Comp. Cooperative Testing
- Products: Germplasm and Parental Lines
Seed Parent Development for Energy Hybrids

First Cross Sterilization And Testcross Production

College Station Summer Year 0 Breeders Cross

P1 x P2

F1

Winter Year 0 Puerto Rico Self-pollinated

F2

Summer Year 1 College Station Self PI plants

F3

Fall Year 1 Weslaco

F3:4

Whole Genome MAB

College Station Summer Year 2

F4:5

Fall Year 2 Weslaco

Bulk Testcrosses
Seed Parent Development for Energy Hybrids

TC Hybrids
- Summer Year 5: Visual Hybrid Evaluation
  - Selection based on A3 Hybrid Evaluation

BC0 F1
- Summer Year 5: Sterilization Back to B-line
  - Score Sterility
  - Advance Best Pairs
  - Use same approach in all

BC1 F1
- Winter Year 5

BC2 F1
- Summer Year 6

BC3 F1
- Winter Year 6: Sterilization Back to B-line
  - Score Sterility
  - Advance Best Pairs
  - TC to R-line testers

BC4 F1
- Summer Year 7

BCx F1
- Advance Best Pairs
  - TC to R-line testers

Release

Advanced Hybrids
- Summer Year 7: Comprehensive Hybrid and Line Evaluation

Advanced Hybrids
- Summer Year 8: Comprehensive Hybrid and Line Evaluation

Selection on Hybrid and Inbred Performance
Pollinator Line Development for PS Hybrids

P1 x P2

F1

Winter Year 0
Puerto Rico
Self-pollinated

F2

Summer Year 1
College Station
Self PI plants

F3

Fall Year 1
Weslaco
Paired Testcrosses

MAB for
Ma1 ma5 Ma6

F3:4

Whole Genome MAB

F4:5

Summer Year 2
College Station

F4:6

Fall Year 2
Weslaco
Bulk Testcrosses

Multi-location Yield Trials

Confirmed PS Hybrids

Confirm PS Hybrids
Eliminate Poor Hybrids

ATx645 x

ATx645 x

Multiple Locations
Photoperiod Sensitive Hybrid Seed Production
Energy Sorghum Breeding

- Seed Parents
  - Short Stature
  - Acceptable seed yield
  - High Sugar
- Pollinator Parent
  - Complementary Height
  - Complementary Maturity
  - Juicy, Sugar
  - Combining Ability

- Either (or both)
  - Disease Resistance
  - Drought Tolerance
  - Lodging resistance
  - Composition
  - Heterosis
Traits

- Biomass Yield
  - Growth and Development
  - Economic Portion of Crop

- Composition
  - Non-structural Carbohydrates
  - Structural Carbohydrates
  - Protein
  - Ash
  - Lipids

- Input Use Efficiency
  - Water
  - Nutrient

- Abiotic Stress Tolerance
  - Drought
  - Nutrient
  - Lodging

- Biotic Stress Tolerance
  - Disease resistance
  - Pest Resistance
  - Lodging

- Evaluation
  - How
  - When
Olson et al., BioFPR, 2012
Traits

- Biomass Yield
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- Evaluation
  - How
  - When
Phenotyping – old fashioned ways......
QTL Analysis of PS Sorghum

Puerto Rico

R07020
R07018

College Station

R07020
R07018
Sugar and Ethanol Production

Sugar Yield = Juice (lbs/acre) * Sugar Concentration (g/100ml)

$\text{Sugar Yield} = J \times C$

$r^2 = 0.01$

$r^2 = 0.96$

Sweet Varieties

Commercial Forage Hybrids

$r^2 = 0.66$
## Composition Range (NIR estimates)

<table>
<thead>
<tr>
<th></th>
<th>Dietary Lignin</th>
<th>Dietary Cellulose</th>
<th>Dietary Hemicellulose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>9.5 - 20.6</td>
<td>14.7 - 43.4</td>
<td>13.8 – 25</td>
</tr>
<tr>
<td>Breeding</td>
<td>13.7 - 20.6</td>
<td>26.1 - 37.1</td>
<td>18.7 - 24.6</td>
</tr>
<tr>
<td>Forage PI</td>
<td>9.5 - 17.4</td>
<td>18.8 - 43.4</td>
<td>15.8 – 25</td>
</tr>
<tr>
<td>Forage PS</td>
<td>13.9 - 15.9</td>
<td>31 - 32.7</td>
<td>19.9 - 20.9</td>
</tr>
<tr>
<td>Grain</td>
<td>14.4 - 17.8</td>
<td>31.9 - 33.2</td>
<td>18.2 - 18.7</td>
</tr>
<tr>
<td>Sweet Sorghum</td>
<td>10.8 - 11.6</td>
<td>24.4 - 32.8</td>
<td>15.6 - 21.3</td>
</tr>
</tbody>
</table>

- **Significant variation for composition**
  - 2X range lignin composition
  - 2.5X range in cellulose
  - 1.5X range in hemicellulose
- Most Variation in breeding germplasm
Growth and Development
Harvest Season Duration

<table>
<thead>
<tr>
<th></th>
<th>April Planting</th>
<th>May Planting</th>
</tr>
</thead>
<tbody>
<tr>
<td>late</td>
<td></td>
<td>late</td>
</tr>
<tr>
<td>medium</td>
<td></td>
<td>medium</td>
</tr>
<tr>
<td>early</td>
<td></td>
<td>early</td>
</tr>
<tr>
<td>late</td>
<td></td>
<td>late</td>
</tr>
<tr>
<td>medium</td>
<td></td>
<td>medium</td>
</tr>
</tbody>
</table>
Complementary Crops: U.S. Gulf Coast

- Combined harvest results in a seven month harvest window.
- Different maturity sorghums and sugarcane are critical