2013 DOE Bioenergy Technologies Office Project Peer Review

Sorghum as an Energy Feedstock: Production, Logistics, Economics

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May 20, 2013

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Background

- Sorghum was identified as an energy crop by DOE
  - high biomass yield
    - Structural carbohydrates
    - Non-structural carbohydrates
  - drought tolerance
  - established production systems
  - annual life cycle
  - genetic resources and potential for further improvement
  - available hybrids

Background and Goal

TEXAS A&M AGRILIFE RESEARCH

- Limited Production Data for Bioenergy Sorghum
- Assess the productivity and composition of sorghum as a bioenergy crop using a diverse set of sorghum genotypes
  - Five years
  - Eight locations
- Establish optimum production environments and identify limitations to production.

Sorghum Research Overview

Timeline

- Project start date: 1-15-2007
- Project end date: 9-30-2013
- Percent complete: 90%

Barriers

- Differences in Genotype productivity
- Yield Documentation
- Composition Variation
- Assess the interaction of Genotype and Environment

Budget

Funding for FY11

DOE-$386,370 / Cost share- $96,593)

Years the project has been funded

6 years

Average annual funding.

DOE - $214,558 per year

Cost Share – 53,500 per year

Partners

Texas A&M Agrilife (project mgmt)
Kansas State University
USDA-ARS, Lincoln NE
Iowa State University
University of Kentucky
Mississippi State University
North Carolina State University
Advanta US
Ceres, Inc.

Sorghum is Diverse in Uses

Summary

- Production
  - Sorghum Yield
    - Varies: Gen, Env.
    - Water is the limiting factor.
    - Moisture content is high.
  - Composition
    - Highly variable.
    - Sugar is valuable.
- Logistics
  - Crop Complementation.
- Economics
  - Everything costs more.

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Production and Composition Objectives

- assess the biomass yield potential and composition of existing sorghum genotypes across different production sites in the U.S.
- Six sorghum genotypes:
  - Graze All, photoperiod insensitive (PI) forage hybrid
  - Graze-N-Bale, PS forage hybrid
  - TX08001, PS bioenergy hybrid
  - 22053, PS brown midrib silage hybrid
  - M81-E, PI sweet sorghum variety
  - Sugar T, PI sweet sorghum silage hybrid

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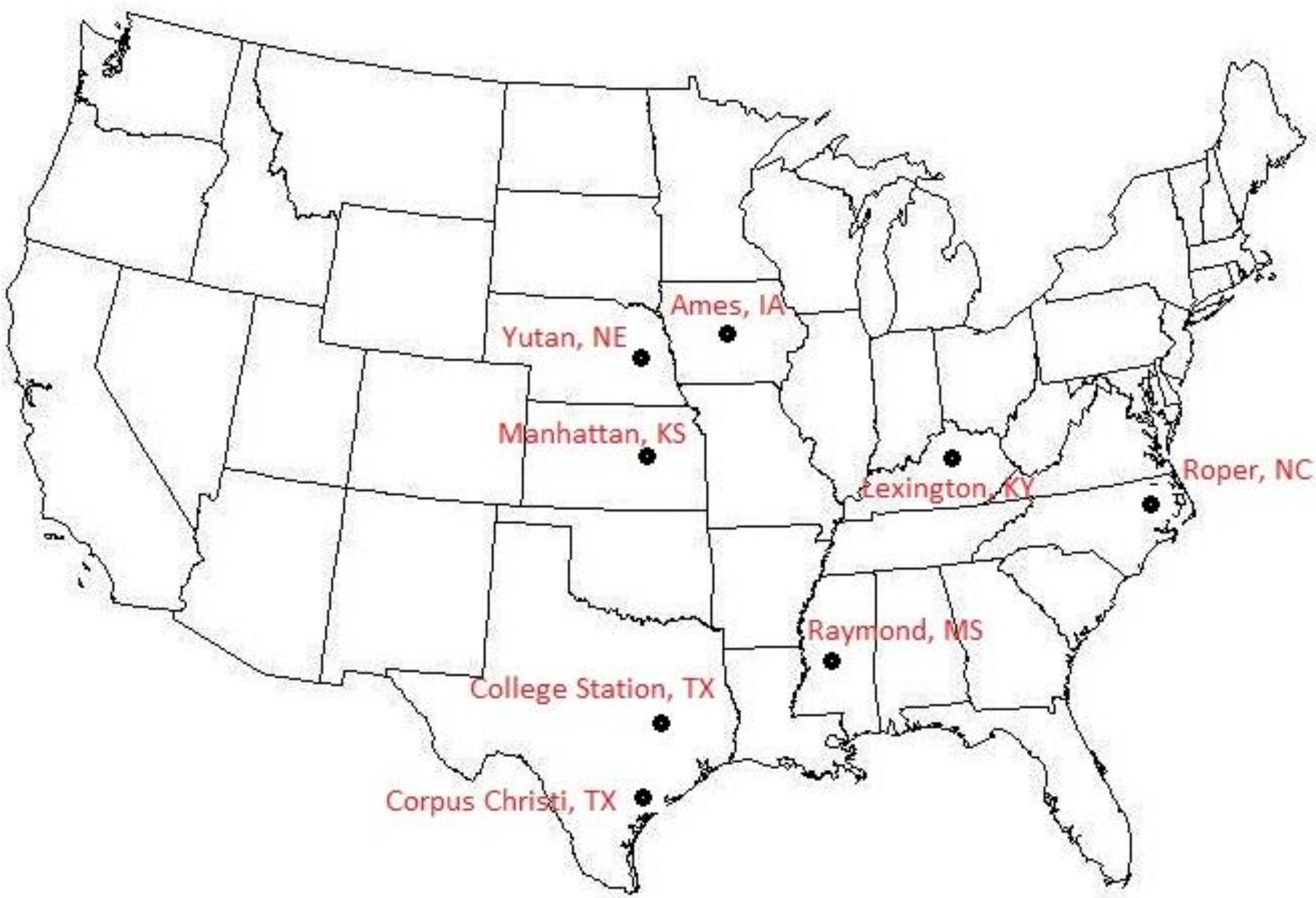
Eight locations in seven different states:



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- Planted in 2008-2011
- Variable plot sizes and number of replications
  - Small plots – hand harvested
  - ¼ acre trials – machine harvested
- All trials were rain fed (exception – Nebraska)
- Standard production practices
  - Pre-plant fertilization
  - Pre-emerge herbicide
- Harvested at optimum for each hybrid (varies)

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- Agronomic traits evaluated:
  - Fresh weight
  - Moisture content
  - Dry weight
  - Brix - soluble solids in the extracted juice
  - Grain Yield
  - Plant height
  - Days to flowering
  - Lodging
  - Disease damage
  - Insect damage
- Compositional traits evaluated using NIR:
  - Ash – mineral content
  - Protein – N removed in harvest
  - Lignin
  - Glucan - cellulose
  - Xylan - hemicellulose

Combined ANOVA, 2008 - 2012

Source	Fresh Weight	Var %†	Moisture	Var %	Dry Weight	Var %	Brix	Var %
Year	ns‡	3.5	**	22.4	ns	0	ns	0
Location	ns	5.4	ns	9.1	ns	0	*	13.3
Loc x Year	**	52.0	**	21.9	**	43.3	*	9.9
Rep (L x Y)	**	1.9	**	3.9	**	3.6	ns	0.2
Gen	**	8.7	*	5.1	**	7.7	ns	3.3
Gen x Year	ns	0.3	ns	1.9	ns	0	ns	0.8
Gen x Loc	ns	0	ns	1.5	ns	0.6	**	14.1
Gen x Loc x Year	**	14.0	**	23.8	**	27.3	**	17.5
Error		14.1		10.4		17.4		40.8

† Variation in phenotype attributable to each effect
‡ *Significant effect at α=0.05 level
**Significant at α=0.01 level
ns Not significant

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Means (ranges) per Location: 2008-12

Site	Fresh Weight (MT/ha)		Moisture (%)		Dry Weight (MT/ha)		Brix (%)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
CC, TX.	37.2e†	8.2-84.4	75.2b	45.8-90.7	8.0e	2.8-25.8	10.1cd	7.9-13.7
CS, TX.	37.3e	5.7-89.0	72.7c	33.0-83.8	9.8d	1.8-29.1	11.5b	6.2-18.2
IA	56.6c	29.3-101.8	72.3cd	66.4-75.8	15.5a	8.9-28.5	13.7a	7.5-19.3
KS	41.5d	13.9-79.8	64.8f	25.8-79.9	12.0c	4.4-24.6	13.2a	8.4-16.3
KY	30.7f	5.0-68.4	71.4d	50.1-89.6	9.8d	2.2-21.6	11.1bc	0.4-17.2
MS	59.7c	17.5-109.2	73.1c	53.3-85.0	15.8a	4.1-34.1	9.1d	4.6-15.4
NE	73.6a	41.7-106.2	81.0a	73.0-86.5	13.9b	5.6-19.8	.	.
NC	64.4b	15.4-127.8	70.1e	54.4-80.8	16.0a	1.9-41.1	10.9bc	4.0-20.0

†Means within a trait followed by the same letter were not significantly different at the 0.05 probability level based on Duncan's multiple range test (Duncan, 1955).

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Means (ranges) per Genotype, 2008 -2012

Genotype	Fresh Weight (MT/ha)		Moisture (%)		Dry Weight (MT/ha)		Brix (%)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Graze All	36.7e†	5.7-113.3	67.8c	51.0-86.1	10.0e	1.8-19.9	9.9b	5.0-16.8
Graze-N-Bale	57.1b	13.5-116.0	74.5a	33.0-89.6	13.4c	3.8-29.1	9.8b	4.6-18.7
TX08001	59.9a	9.2-127.8	71.7b	55.0-86.8	16.8a	2.8-41.1	10.1b	6.4-16.0
22053	43.3d	5.0-86.4	71.0b	36.0-88.2	11.6d	2.1-20.5	10.4b	5.0-17.7
M81-E	59.2ab	9.9-118.7	73.8a	34.0-87.8	14.7b	1.9-34.1	12.3a	1.4-20.0
Sugar T	52.1c	5.4-108.5	74.1a	49.0-90.7	12.2d	2.2-26.8	11.9a	4.0-19.3

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Combined ANOVA, Composition, 2008-2012

Source	Ash	Var %†	Protein	Var %	Lignin	Var %	Glucan	Var %	Xylan	Var %
Year	ns‡	0	ns	3.4	*	10.0	ns	3.6	*	8.3
Location	ns	19.1	ns	0	*	16.7	ns	13.0	**	27.4
Loc x Year	**	42.2	**	47.4	**	26.8	**	38.7	**	19.0
Rep (Loc x Year)	ns	1.2	*	1.7	**	5.7	**	7.7	**	1.8
Gen	*	4.0	*	2.6	**	3.8	*	1.9	**	7.8
Gen x Year	*	2.3	ns	0.9	ns	0.5	ns	0	ns	0.6
Gen x Loc	ns	0.6	ns	0.9	*	3.8	ns	2.5	*	3.6
Gen x Loc x Year	**	13.3	**	17.2	**	13.4	**	9.6	**	13.7
Error		17.3		25.9		19.1		23.0		17.9

† Variation in phenotype attributable to each effect
‡ *Significant effect at α=0.05 level
**Significant at α=0.01 level
ns Not significant

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Composition Means per Location, 2008-2012

Site	Ash (%)	Protein (%)	Lignin (%)	Glucan (%)	Xylan (%)
	Mean	Mean	Mean	Mean	Mean
CC, TX.	8.5b†	4.0b	14.1a	30.9b	17.1b
CS, TX.	8.4b	4.3a	13.4bc	28.9c	16.4c
IA	6.4f	3.3d	11.3f	27.7e	14.6f
KS	7.1d	3.1de	11.6f	28.2d	15.2e
KY	6.8e	3.2de	11.9e	27.4e	15.0e
MS	7.4c	4.0b	12.7d	27.5e	15.2e
NE	9.5a	3.5c	13.5b	31.5a	17.6a
NC	7.3c	3.1e	13.2c	28.4d	16.0d

†Means within a trait followed by the same letter were not significantly different at the 0.05 probability level based on Duncan's multiple range test (Duncan, 1955).

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Composition Means per Genotype, 2008-2011

Genotype	Ash (%)	Protein (%)	Lignin (%)	Glucan (%)	Xylan (%)
	Mean	Mean	Mean	Mean	Mean
Graze All	8.2a†	4.1a	13.0b	29.2a	15.8c
Graze-N-Bale	7.9b	3.7b	13.0b	28.7b	16.4a
TX08001	7.6c	3.8b	13.4a	29.3a	16.5a
22053	8.2a	3.5cd	12.6c	29.2a	16.1b
M81-E	7.3d	3.4d	12.3d	28.3c	15.4d
Sugar T	7.4cd	3.7bc	12.5cd	28.4bc	15.4d

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Conclusions from Production

- Environment is Important!
- Good Environments:
  - Average Yield 12-16 MT/ha
  - High Yield, 35-40 MT/ha
- High Moisture Conten
  - Significant source of Sugar
  - Co-extracted with Sugar
- Seasonal Crop
  - Biomass from July – November
- Hybrids now available
  - Biomass
  - Sweet Sorghum

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Logistics, Just-in-Time Harvest

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Harvest Time in Energy Sorghum

- Sorghum (biomass or sweet) will not be dry……
- Significant sugar in extracted moisture….
- Sugars are not shelf stable ….
- Processors requires long harvest windows
- Maturity influences harvest time, yield and composition
- Photoperiod sensitivity influences maturity
  - Planting Dates and Maturities extend season
  - Complementary crop needed to extend season

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Complementary Crops: U.S. Gulf Coast

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sweet Sorghum			p	p	p			h	h	h		
Sugarcane	h	h						p	p		h	h

- Combined harvest results in a 7 month harvest window.
- Different maturity sorghums (and sugarcane) are critical.

- Burks et al., 2013 Agronomy Journal 105:263-7

Sweet Sorghum Hybrids

- Maturity Groups
  - Early: photoperiod insensitive (PI)
    - **85-105 days regardless of planting date**
  - Medium: Mod. photoperiod sensitive (MPS)
    - **85 (short days) - 140 (long days)**
  - Late: Photoperiod Sensitive (VPS)
    - **85 (short days) - 160 (long days)**
- Longer maturity: Higher yields
- Evaluated
  - 4 hybrids per maturity group
  - 3 planting dates (April, May, June)
  - 2 years (2010, 2011)

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Harvest Season Duration

May Planting | April Planting

Burks et al., 2013 Agro. Journal

Maturity group	Sugar yield	Fresh yield	Dry yield	Sugar conc.	Plant height	Days to anthesis
	—— Mg ha^{-1} ——			°Bx†	cm	d
Late	4.4 a‡	63.5 a	22.6 a	13.2 b	361.9 a	122.0 a
Medium	4.1 a	57.2 b	19.0 b	13.3 b	357.5 a	111.0 b
Early	2.7 b	33.0 c	9.5 c	14.0 a	267.5 b	67.0 c

† 1 degree brix (°Bx) is 1 g sucrose in 100 g solution.

‡ Letters within a column indicate that means are statistically different.

Month planted	Sugar yield	Fresh yield	Dry yield	Sugar conc.	Plant height	Days to anthesis
	—— Mg ha^{-1} ——			°Bx†	cm	d
April	4.2 a‡	57.6 a	19.8 a	14.0 a	359.5 a	101.0 a
May	4.0 a	54.3 a	18.0 b	13.7 b	344.9 b	101.0 a
June	2.9 b	41.8 b	13.3 c	12.8 b	282.4 c	97.0b

† 1 degree brix (°Bx) is 1 g sucrose in 100 g solution.

‡ Letters within a column indicate that means are statistically different.

Burks et al., 2013 Agro. Journal

Planting date	Maturity group	Sugar yield	Fresh yield	Dry yield	Sugar conc.	Harvest date
		Mg ha^{-1}			°Bx†	
April	late	5.1 a‡	75.2 a	27.2 a	13.6 a	Sept. 14
	medium	4.7 a	63.3 b	22.1 b	14.4 a	Aug. 31
	early	2.6 b	32.8 c	9.2 c	14.0 a	July 25
May	late	4.2 a	61.6 a	22.1 a	13.0 b	Oct. 11
	medium	4.1 a	60.0 a	19.9 a	12.3 b	Sept. 29
	early	3.7 a	41.3 b	12.2 b	15.8 a	Aug. 18
June	late	3.6 a	52.6 a	17.8 a	13.0 a	Nov. 16
	medium	3.5 a	48.0 a	14.9 b	13.1 a	Nov. 08
	early	1.6 b	25.3 b	7.1 c	12.2 a	Sept. 16

† 1 degree brix (°Bx) is 1 g sucrose in 100 g solution.

‡ Letters within a column indicate that means are statistically different.

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Burks et al., 2013 Agro. Journal

Table 5. The planting date and hybrid maturity group that produced the highest yield in each of eight consecutive harvest windows in College Station, TX, in 2010 and 2011. In some harvest windows, only one maturity group was available for harvest, while others had multiple options.

Harvest date	Planting date	Maturity group	Fresh yield	Sugar yield
			Mg ha^{-1}	
16–31 July	15 Apr.	early	32.9	2.6
1–15 Aug.	15 May	early	41.3	3.7
16–31 Aug.	15 Apr.	medium	63.5	4.7
1–15 Sept.	15 Apr.	late	76.4	5.3
16–30 Sept.	15 May	medium	60.0	4.1
1–15 Oct.	15 May	late	61.6	4.2
16–31 Oct.	15 June	medium	48.0	3.5
1–15 Nov.	15 June	late	52.5	3.6

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Burks et al., 2013 Agro. Journal

Table 6. Projected planting dates, maturity groups of hybrids, and the harvesting schedule required to provide 1000 Mg of sweet sorghum biomass to a mill facility on a daily basis.

Month planted	Maturity group	Fresh yield	Area planted	Harvest date
		Mg ha^{-1}	ha	
April	early	32.9	486	16–31 July
	medium	63.5	252	16–31 Aug.
	late	76.4	209	1–15 Sept.
May	early	41.3	387	1–15 Aug.
	medium	60.0	266	16–30 Sept.
	late	61.6	260	1–15 Oct.
June	medium	48.0	333	16–31 Oct.
	late	52.5	305	1–15 Nov.
Total			2498	

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Production Logistics

- Burks et al., 2013 demonstrated use of genetic resources for just-in-time harvest
- Complementation of sorghum with other energy crops essential
- Economics define when to start and stop processing and supply logistics…..

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Costs of Production

Objectives

- Assess financial and economic costs of supplying a 30-million gallon conversion facility with locally-produced biofuels feedstocks
- Develop a modeling approach that is transferable to other regions and a variety of feedstocks is envisioned.
- How do you minimize costs of producting harvesting and transporting feedstock to an ethanol production facility?

  $/dry ton…..

Study Area and Feedstocks

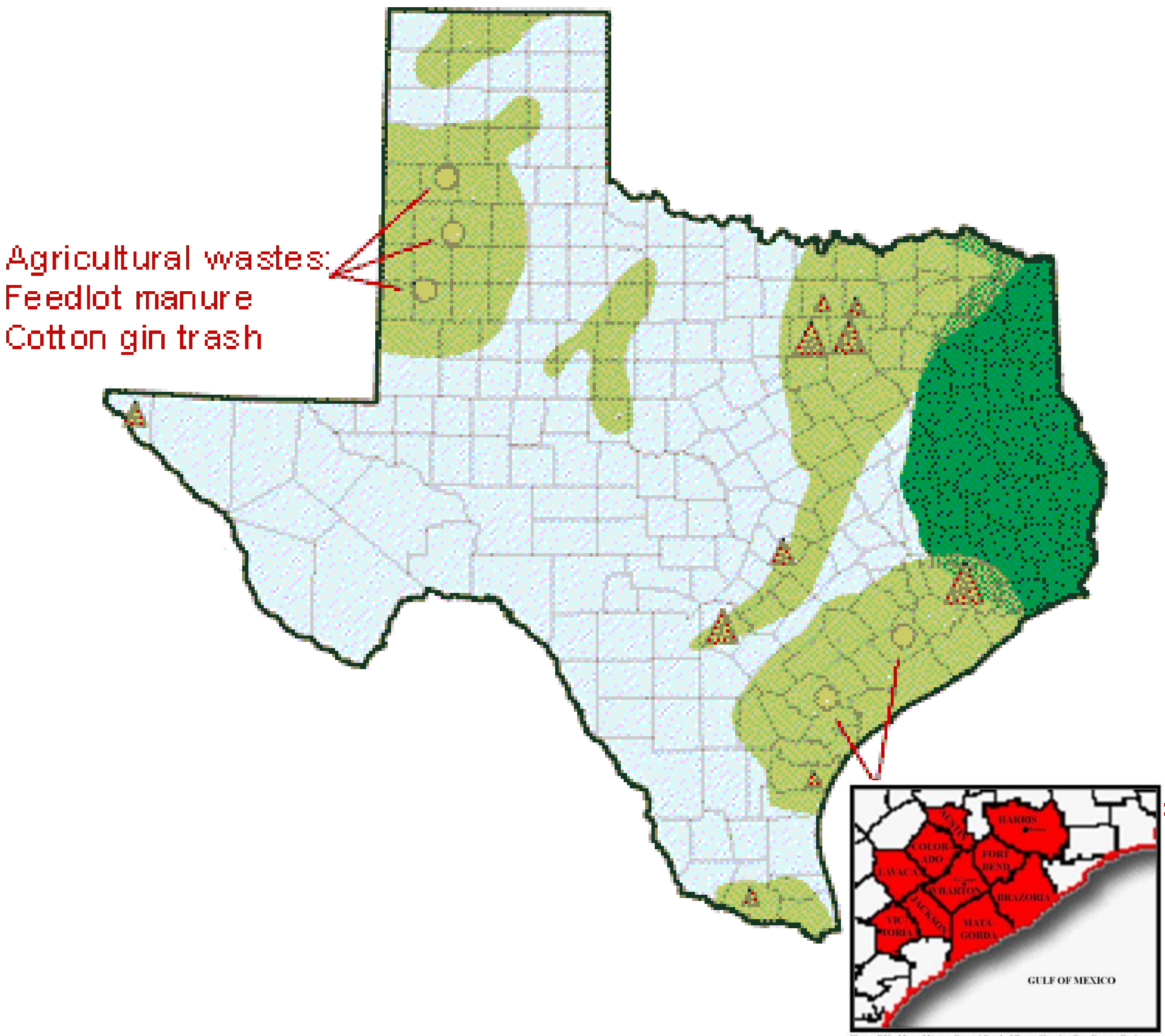

Figure B30. Map of Upper Coastal Bend of Texas Showing Ten-County Region Study Area.

Feedstock

Biomass Sorghum
Switchgrass

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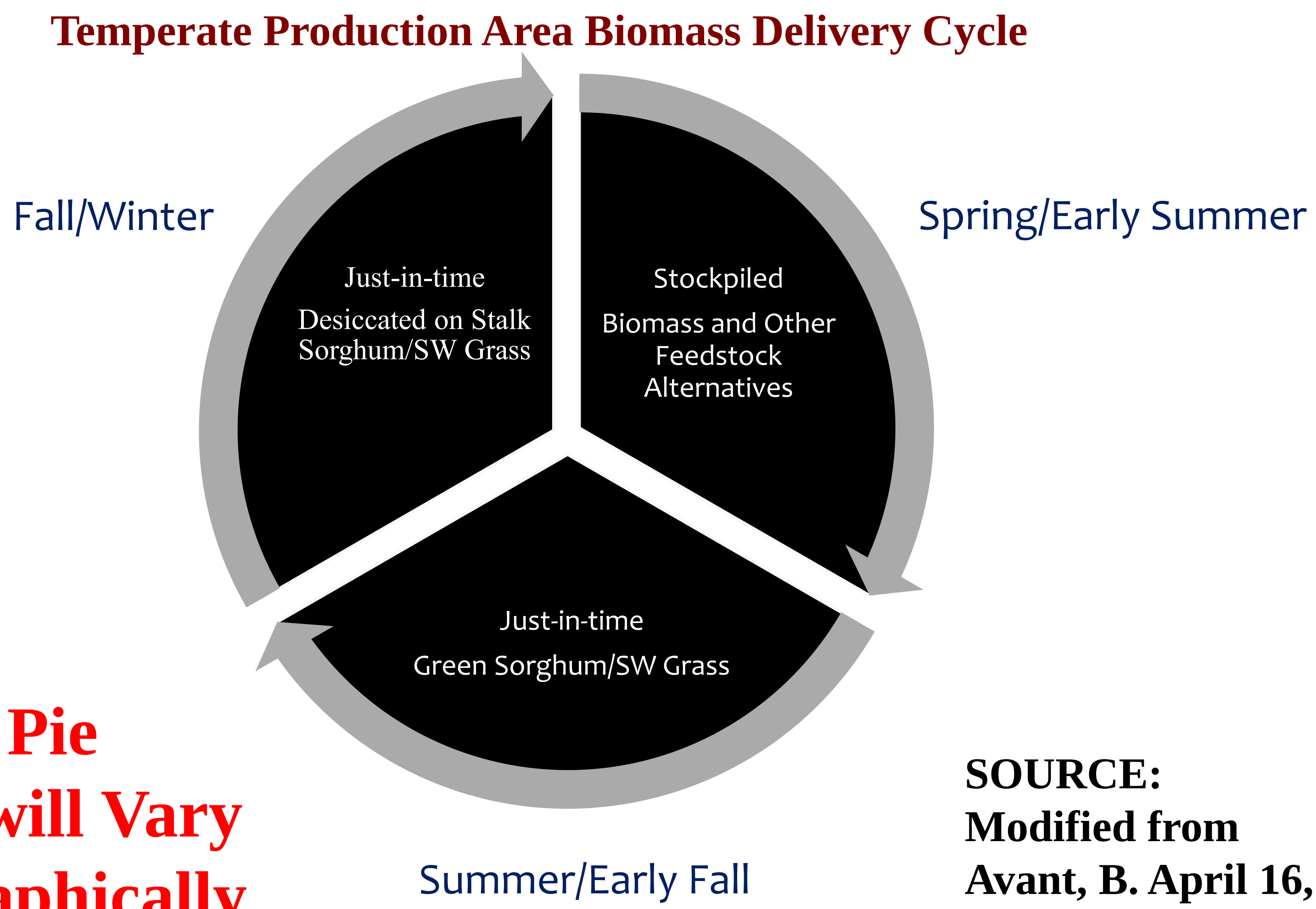
EPP Feedstock Procurement



Size of Pie Slices will Vary Geographically

SOURCE: Modified from Avant, B. April 16, 2009.

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Sorghasauras© Benchmark Results

Summary of Baseline Results for 30-Million Gallon Ethanol Facility

Total Acres Required	**36,845 * 3 HES acres 37,225 + 40,000 SG acres**
Average High-Energy Sorghum (HES) Yield	**avg of 8.50 dry tons/acre max of 12.0 dry tons/acre**
Total HES Production	**950,719 wet tons @ 60-75% 313,266 dry tons @15%**
Average SwitchGrass (SG) Yield	**avg of 2.69 dry tons/acre max of 3.0 dry tons/acre**
Total SG Production	**100,000 dry tons @15%**
Total Irrigation Water Required	**614,206 ac-in 51,183.8 ac-ft**

Production Costs ($/dry ton)

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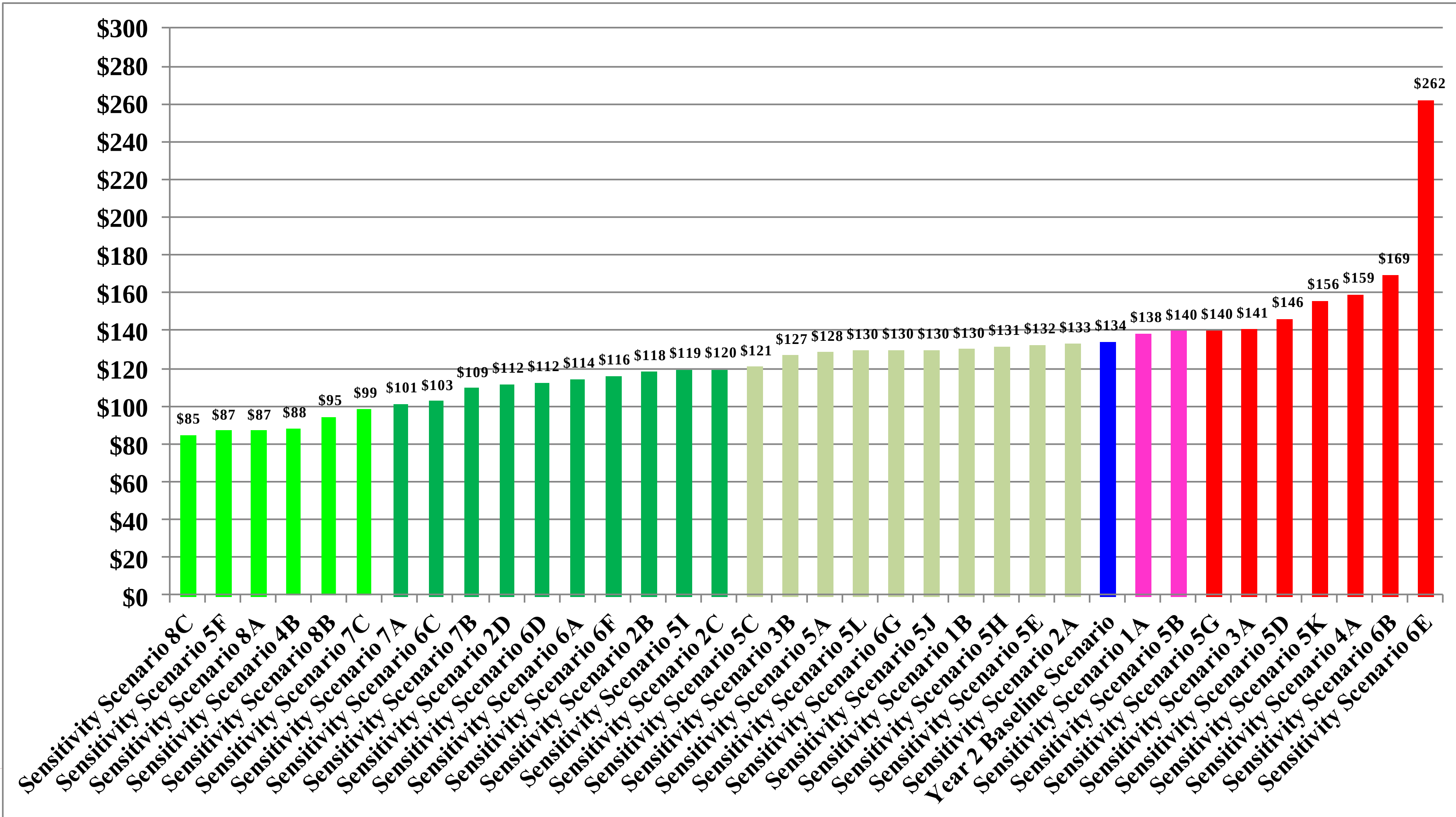

Relevance

- Sorghum can be an energy crop and component in biomass production.
- Moisture and sugar content at harvest is merging sweet and biomass sorghums
- Production logistics and economics are critical.
  - Harvesting/transportation systems are a major issue/cost
  - Consideration of the total production-harvesting-transportation-pre-refinery storage supply chain is essential

Critical Success Factors

- Hybrid Feedstock is Available
  - Yield Potential Established in Target Production Environments
  - Improved Sweet and biomass hybrids are now readily available
  - Further rapid improvement is now ongoing

- Challenges
  - Economical Production Systems Must Evolve
  - Economical Processing Systems Must Emerge

- Demonstration
  - Brazil

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Acknowledgements

- Sorghum RBFT - Production
  - G Odvody (TAMU), R Heiniger (NCSU), B Macoon (MSU), K Moore (ISU), J Pedersen (USDA), S Staggenborg (KSU), M Barrett (UKY), P. Burks (TAMU), J. Gill (TAMU)
  - Funding by US DOE Regional Biomass Feedstock Partnership (Award No. DE-FC36-05GO85041)
- Logistics of Production
  - P Burks (TAMU), T Felderhoff (TAMU), HP Viator (LSU)
  - Funding by South Central SunGrant Initiative, South Central Regional Program, Grant no. 504113
- Economics of Production
  - WA McLaughlin, ME Rister, RD Lacewell, LL Falconer, JM Blumenthal, AW Sturdivant, Dean A. McCorkle, AE Conrad, BL Harris (all TAMU)
  - Funding by Texas Water Resource Institute, Rio Grande Basin Initiative

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