The sweet sorghum opportunity: A complementary source of low-cost fermentable sugars for biofuel

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abstract

As a complementary feedstock to sugarcane, sweet sorghum offers the existing sugar-based biofuels industry a flexible, low-cost crop that can be utilized in existing harvest and processing infrastructure. In recent field tests of new "sweet x sweet" hybrids, yields of both extractable fermentable sugars and biomass have been comparable to sugarcane, with attractive production costs on a per-unit basis. Moreover, sweet sorghum may be grown on land less suited to sugarcane production, and in many regions, harvested prior to the start or following the end of the traditional sugarcane production season. Forward-thinking biofuel companies interested in sweet sorghum are working directly with seed companies to better understand and identify potential project applications, specifically with respect to selection of optimal hybrids, and to develop optimal processing, cultivation and supply chain parameters. By working together, energy crop developers and industry participants can capitalize on a near-term opportunity to expand production, more fully utilize existing sugarcane assets and lower production costs.

Keywords: **biofuel, sorghum, feedstock cost, production costs, season extension, supply chain**

Introduction

As a complementary feedstock to sugarcane, sweet sorghum offers the existing sugar-based biofuels industry a flexible, low-cost crop that can be utilized in existing harvest and processing infrastructure. In recent field tests of new "sweet x sweet" hybrids," (Figure 1) yields of both extractable fermentable sugars and biomass have been comparable to sugarcane, with attractive production costs on a per-unit basis. Moreover, sweet sorghum may be grown on land less suited to sugarcane production, and in many regions, harvested prior to the start or following the end of the traditional sugarcane production season. Such characteristics will be valuable as the sugar-based biofuels industry migrates toward the most efficient use of their land resources and infrastructure to capture low-cost fermentable sugars. In other words, as the industry matures and reaches greater scale, the most efficient cropping system with the lowest cost source of fermentable sugars will ultimately be the winner. At present, major participants in the biofuels industry are trialing sweet sorghum hybrids to better understand cultivation practices and processing specifications. At the same time, energy crop developers are developing hybrids through advanced breeding and biotechnology, while optimizing crop management practices for various processing specifications. These parallel activities require close interaction between feedstock users and feedstock developers. By working together, energy crop developers and industry participants can capitalize on a near-term opportunity to expand production, more fully utilize existing sugarcane assets and lower production costs.

Figure 1. Ceres "sweet x sweet" sorghum hybrid

Inherent advantages

Sweet sorghum, like sugarcane, produces fermentable sugars that can be extracted and converted directly to ethanol[1,2] in existing sugarcane infrastructure, or with new conversion technologies, to other liquid transportation fuels or bioproducts. Similarly, its lignocellulosic biomass - up to 100 tons per hectare at harvest in research trials - can be utilized for either cellulosic biofuel or renewable electricity production.

While it is not well suited to the production of refined sugar, sweet sorghum has multiple inherent advantages (see Figure 2). Most importantly, sweet sorghum is a seed-propagated annual. That is, a crop established through sowing seed, and which matures and is harvested in a single season. This key characteristic impacts both its fit within current production cycles as well as the pace of scale-up and ongoing improvements to the varieties themselves.

The current belief among sugarcane producers is that sweet sorghum can be harvested, collected and transported with the existing sugarcane equipment fleet and will not require additional capital investments in new farm equipment. For this reason, many industry participants believe sweet sorghum will be adopted more rapidly than other sugar-producing crops.

In addition, as an annual, sweet sorghum can be utilized in rotation with other annual crops, and potentially, with sugarcane itself, where sweet sorghum could be sown on fallow sugarcane land, hectares destined for rotation and land where sugarcane yields are limited due to marginal soils. This flexibility is due, in part, to the sorghum plant's natural hardiness and rapid growth. Plants often reach maturity in 90 to 120 days, with potential for additional ratoon cuttings following the first harvest.

Figure 3 demonstrates a reduction of feedstock cost for sweet sorghum as compared to sugarcane due to a second ratoon cut following the first cut of the season. This analysis assumes that

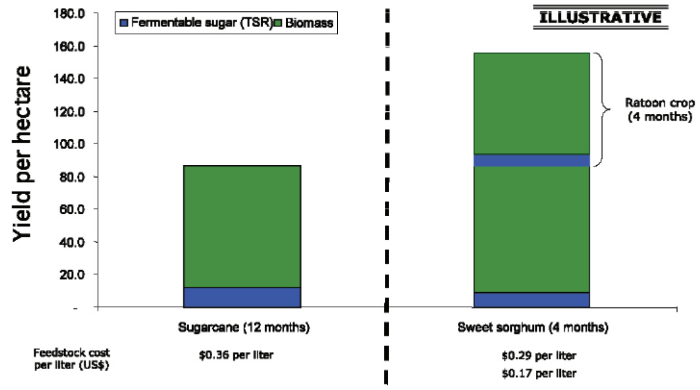
Figure 2. Inherent advantages of sweet sorghum

	Sugarcane	Sweet Sorghum
Sugar quality	↑ Sucrose	↓ Mixed sugars
Establishment cost	↓ Vegetative propagation	↑ Seed propagation
Sugar yield (% fw)	↑ 13 – 15%	↓ 8 – 13%
Input requirements	↓ Limited by water, nitrogen	↑ 50% water, 60% nitrogen
Scale-up time	↓ Vegetative propagation	↑ Seed propagation
Biomass yield/co-generation (tons/ha)	↓ 70 – 90 tons/ha	↑ 60 – 100 tons/ha*
Marginal Land	↓ Limited yields on marginal land	↑ Yield potential on marginal land
Ratoon/flexibility	↑ 12 – 18 months	? 2 – 3 cuts per year is possible
Season extension	↓ 12 – 18 months	↑ Rapid growth cycle, 70 – 120 days
Product development	↓ Perennial, 10 – 16 years	↑ Annual, 3 – 5 years

*Note: Single cut. Does not account for ratoon yield.

Sources: ICRISAT, Wu *et al.* 2008 and Ceres internal data and analysis

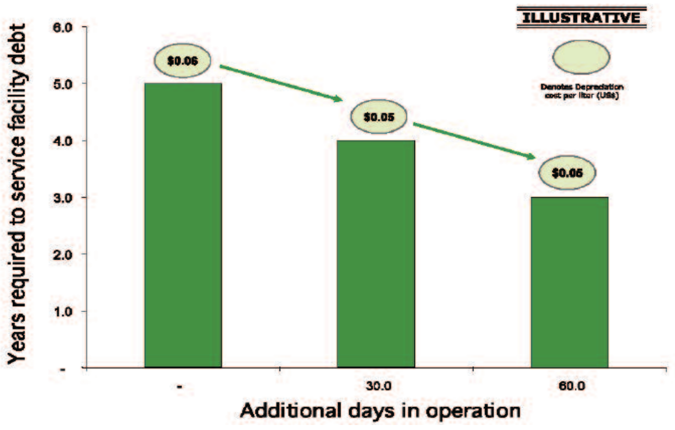
Figure 3. Ratoon crop yield potential



Note: Feedstock cost based on US production cost. No credit for cogeneration

Sources: Ceres internal trials and FAO. LSU Ag. Center

Figure 4. Impact of season extension on debt service



Note: Assumes 2.0M per year crushing capacity facility with increased capacity through extended season. $65 per ton crushing capacity. Maximum cash sweep.

there are minimal incremental inputs, with the exception of a second harvest and fertility applications following the first cut, and does not include any co-generation value for the remaining bagasse. Early results suggest that there is significant room to further increase ratoon harvest yields through improved genetics and crop management practices.

Greater asset utilization

In addition to reducing feedstock costs on a per-liter basis by increasing productivity (see Box 1), extending the production season has a significant impact on returns. Figure 4, for example, illustrates that extending the harvest season by 60 days could reduce the time to service debt by nearly two years, while reducing depreciation cost per unit of output.

The potential to expand asset utilization by extending the production and harvest season with sweet sorghum will depend heavily on climatic conditions for a given geography. In Brazil, sweet sorghum may be an appropriate choice to extend the harvest season due to its productivity potential under dry conditions. In the state of Minas Gerais, for example, canes are harvested May to November. Here, sorghum may be able to extend the season into January, as many as 60 days of additional production, with potential for ratoon harvests following the initial cut and during the next sugarcane season. In any case, it will be important to work closely with seed companies, such as Ceres, to understand the market fit of new hybrids across different environments.

Minimizing feedstock cost

As competition increases and the demand for biofuel and biopower continues to grow it can be assumed that a greater emphasis will be placed on maximizing fermentable sugar and bagasse yields (rather than purely sucrose yield) while reducing production costs.

In this case, a biorefinery operator looking to maximize profitability may utilize sweet sorghum as either a complement or substitute to sugarcane due to a lower delivered cost of fermentable sugars and incremental excess bagasse. This will particularly be the case in a situation where the facility has invested in co-generation capacity or has interest in pursuing cellulosic or other advanced biofuel technologies.

As shown in Figure 5, sweet sorghum offers a potentially lower cost solution for biofuel production, especially when considering co-generation of remaining bagasse. This assessment assumes that refined sugar is not the primary product being produced, rather that the facility operators' interest is in maximizing fuel production.

Hybrid development and commercialization

Sweet sorghum has received relatively little attention and application of technology, such as advanced breeding, compared to maize, soy and cotton, for instance. Commercial sweet sorghum seed varieties consist mostly of old, open-pollinated lines, or sweet varieties that were crossed with sudangrass for use as forage. Such varieties do not provide economic yields of fermentable sugars under many circumstances.

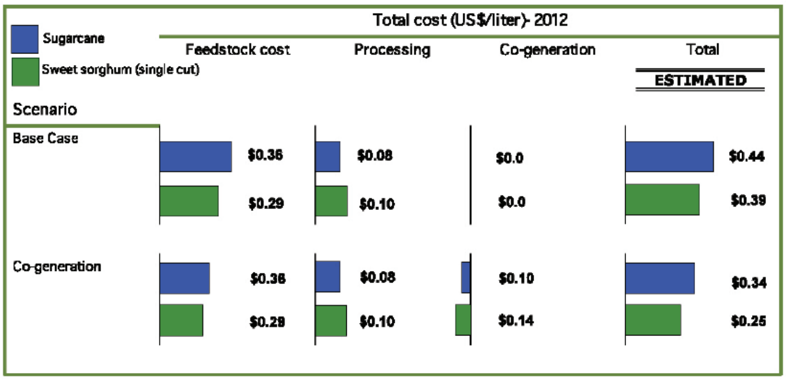
Box 1. Economic considerations of feedstock production

In mature, fuel and bulk chemical industries, feedstock costs often represent 50% or greater of the cost of the finished product. This holds true for gasoline and for ethanol derived from sugar in Brazil and elsewhere, and it will very likely hold true for cellulosic and advanced biofuels conversion systems as technology matures.

For any given biofuel conversion process, geography or business model, the best way to minimize feedstock cost is through selecting the crop that will result in the lowest feedstock cost per unit of output. In agricultural-based systems, the critical driver to the lowest feedstock cost is yield per unit area of land. A key point to be addressed is that the identification of a feedstock that maximizes returns for the facility will naturally take into consideration the required inputs costs to achieve the yield. Given a set number of agronomic and operational inputs, increased fuel yields will allow for lower production, harvest, collection and transportation costs on a per-unit basis, while also providing the opportunity to increase the value to the feedstock producer and/or cover the land rent or opportunity cost.

Increased yield can be achieved through maximizing biomass and sugar yield while concurrently optimizing biomass and sugar composition and conversion characteristics specifically for a given conversion process. The optimization of composition and conversion characteristics of both sugar and biomass will become increasingly more important as new conversion technologies emerge to take the fermentable sugar and/or biomass into more advanced molecules.

Figure 5. Feedstock cost economics



Note: Does not assume a ratoon crop. 10% TSR for sweet sorghum.
Feedstock production costs based on US locations.
Source: USDA ARS, LSU Ag. Center, Cosan Quarterly Financial Letter, Ceres Analysis

However, new sweet-by-sweet hybrids, which are the result of crossing two high-sugar lines, have been shown to produce significantly higher volumes of fermentable sugars and biomass. Plant researchers are focusing on further improving biomass and sugar yields, enlarging the areas where economic yields can be achieved, reducing inputs such as nitrogen, and introducing a portfolio of hybrids with different maturities. As in other crops, access to well-proven genetic technologies, such as molecular markers and biotechnology, will prove critical to the success of these endeavors.

Crop management practices are also being optimized in tandem with improved genetics. Ceres, for instance is establishing a global trialing network to better define cultivation practices, biomass supply chain considerations and specifications for processing. Together, optimized genetics and crop management practices, such as optimal harvest time, provide an opportunity to optimize feedstock parameters and reduce variability.

Fortunately, ethanol refineries do not need to wait decades for improvement. Again, due to sorghum's rapid lifecycle, plant breeders and agronomists are able to complete two to three planting cycles in a single year using both hemispheres, whereas with sugarcane, the breeding cycle can be 10 years or more. And, once a new sweet sorghum hybrid is identified, it is also faster to produce commercial quantities of seed. One hectare of seed production can support up to a thousand hectares of commercial production. In contrast, vegetative propagation (the method of production used for sugarcane scale-up) can take several years to scale up, with multiplication factors as low as 5X.

Remaining hurdles

Sweet sorghum remains in the beginning stages of commercial deployment. While a significant opportunity exists, the majority of the sweet sorghum biofuel projects have been pursued for purposes of proof of principle at a pilot or demonstration scale. This underscores a relatively high degree of inexperience and emphasizes the need for additional research to aid in the development and commercialization of improved hybrids, well-defined cultivation practices and processing specifications. Clearly, there is plenty of headroom for improvement.

While significant capital investment will not be required to incorporate sweet sorghum into existing infrastructure, operationally there is still a learning curve. First, it will be important to develop feedstock specifications based on the value of feedstock quality, such as the mix of fermentable sugars, and their downstream impact on a process. Just as important will be the development of process performance guarantees on equipment, technologies and facilities that cover the processing of sweet sorghum in these facilities. The latter will allow for facility operators to adopt sweet sorghum with full confidence that the feedstock will integrate smoothly into their capital asset. The former will create a feedstock target to aid in value decisions for the facility management with respect to the appropriate price for delivered feedstock, and to understand what operational changes may be needed based on incoming feedstock. These technologies can also contribute to process improvements driven by continuous monitoring of sugar quality.

Second, and concurrently with the above actions, high yielding hybrids need to be selected and their use in the existing biomass supply chain must be demonstrated and shown to have no additional constraints in order to "de-risk" feedstock supply. These activities will likely be required to demonstrate performance at a commercially relevant scale in order for sweet sorghum to gain traction with highly efficient processors.

Summary

Utilization of sweet sorghum as a complement to sugarcane through season extension as well as for production on underutilized land may offer a substantial opportunity to improve the overall cost competitiveness of biofuels. Relative to other cost components, feedstock cost will continue to remain a significant fraction of the overall cost of the end product, and biofuel operators are actively investigating new options to improve overall costs to remain competitive. Integration of new sweet sorghum hybrids into the existing sugar ethanol asset base may not require significant changes to the current infrastructure, but processing guarantees and feedstock specifications will need to be developed to reach commercial-scale production. Forward-thinking biofuel companies interested in sweet sorghum are working directly with seed companies to better understand and identify potential project applications, specifically with respect to selection of optimal hybrids, and to develop optimal processing, cultivation and supply chain parameters.

Endnotes

[1] Nan, Lu, *et al.* (1994) Ethanol production from sweet sorghum, (chapter 4). In *Integrated Energy Systems in China*. Published online by the Food and Agricultural Organization of the United Nations.

[2] Wu, X., Staggenborg, S., Propheter, J., Rooney, W.L., Yu, J. and Wang, D. (2008) Features and fermentation performance of sweet sorghum juice after harvest.written for presentation at the *American Society of Agricultural and Biological Engineers* (ASABE) Annual International Meeting, Providence, RI, June 29-July 2, 2008. Paper number 080037: 8-10.